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Developments in Weed Management

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Environmental weed management

Benefits and principles for planning environmental weed control in conservation reserves

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Summary This paper will review some basic issues around planning for environmental weed control in native vegetation. The benefits of good planning are reviewed as well the costs and some of the processes for planning that can be used. Principles for applying weed management regimes in different situations, assessing weed threats and developing site-specific and/or species-specific approaches are then discussed.

Keywords Environmental weed control, weed management planning.

Introduction

It is widely acknowledged, 'exotic plants and animals invading Australian ecosystems are now recognised as the second most important threat to Australia's ecology. Only the continuing clearing of native vegetation constitutes a greater threat…' (CRC for Australian Weed Management 2003). The threats to indigenous biodiversity are primarily from environmental weeds, rather than agriculture, and a response to this issue is important for all managers of conservation reserves and native vegetation on private land.

This paper will provide a brief overview of the benefits and costs of environmental weed management planning and general principles for planning weed control in native vegetation in conservation reserves and public open space. Environmental weeds, including many exotic pasture grasses and garden ornamentals with the lack of laws concerning their control, are quite often the dominant weed group in native vegetation. The context of this paper is primarily a view of planning weed management and control in indigenous vegetation, which is often reduced to scattered remnants in urban and/or rural environments with lots of edges vulnerable to weed invasion.

Planning is essential because of the ongoing, significant and even massive impact of environmental weeds, which are constantly invading urban bush land reserves, roadsides and national parks. Planning should emphasise the control of high impact weeds in areas of significant ecological values as the first priority.

Issues of scale

My experience is with a wide range of native vegetation reserves, from small Council bushland reserves to large national parks, and the principles discovered apply at any scale. Examples will be provided throughout this paper.

For example, every site has invasion points or fronts that must be addressed. Small urban sites will have concentrated storm water structures causing weed plumes at discharge points across large areas of a site. A large national park may have limited invasion points such as roads and picnic grounds and birds bringing seed of weeds such as blackberry into the riparian zones from a long distance.

Scale is also relevant in the sense of the areas that any individual person or authority might manage. Land management and responsibility is by necessity in bits and pieces; a Council might manage a sprinkle of sites across a region and might only prepare a weed management plan for one site at a time. However, weeds do not respect boundaries and many species must be controlled across a region for there to be any hope of success in containing them, cooperating across property boundaries across a region or landscape is the hardest planning task. Most land managers will be familiar with the small or medium scales as the scale of their responsibility and have probably often looked over a fence wanting control efforts to continue across the line.

Benefits of planning environmental weed control

Morale: building hope in the war against weeds…

Most of this audience will understand the enormous impact of weed invasions but many people in our community are not very conscious about environmental weeds but the ever increasing Landcare and Bushcare movements bring new people into a level of awareness. However, as I have often observed, once people become aware of how significant the problem is, they often feel overwhelmed by the diversity and abundance of weeds in their local bushland reserve. The complexity and intensiveness of weed invasion can be quite intimidating to novices making it difficult for them to assess and determine where to begin their weed control efforts.

For example, a bushland reserve might have 150–200 flora species and over half might be exotic 'weeds'. However, in my experience there might only be 5–10 truly high priority weeds that need control in all or some areas of a reserve. Planning weed management helps land managers assess the species present and develop the best response possible, so achievable tasks with good outcomes are achieved. Controlling major weeds in a reserve one by one, like checking off a list, is also a popular approach. These approaches have points along the way to help remind participants in the process that they can achieve success through targeted and strategic incremental efforts.

Ensuring that limited budgets are spent effectively

Often insufficient resources are available for the optimum maintenance regime and weed control programs in bushland. The ongoing works that are required should aim to maintain a 'status quo' at minimum. With proper planning and analysis of the weed threats, the limited funds that are available can be put to the best use so that incremental improvement is possible. Even the most minimal of maintenance budgets can be designed to 'improve' the condition of native vegetation over time by addressing the highest priorities.

Addressing the highest priorities for a reserve, municipality and/or region…

Too often the highest profile weeds are the focus of weed control in native vegetation and they are not necessarily the weeds with the greatest existing or potential impacts. For example, the highest priority weed in a reserve, shire or region might be an uncommon weed of minimal current cover but of major bioclimatic potential, such as *Nassella* species in parts of the Melbourne region. A small infestation of Chilean needle grass (*Nassella neesiana*) in a grassland has enormous potential for greater invasion but may go unnoticed by some land managers or the community with an interest in the reserve if they are not aware of the priority this weed has in the wider region. Another contrasting example might include a weed such as kikuyu (*Pennisetum clandestinum*) that is a high priority in good quality groundstorey in grasslands and grassy woodlands but would not be a priority in slashed areas.

Costs, resources and management planning processes required

The cost to develop a management plan for a conservation reserve or a region can be substantial. This would usually be the case because much assessment of the condition of the site and its ecological values must occur before management directions, including weed control priorities, can be determined. Management directions for different zones of a reserve and different parks in a municipality would then have appropriate management responses developed.

Often on public land a great deal of the cost of developing management plans is spent on documentation so that internal and external communication about land management decision-making is done to a high standard. However, in smaller reserves or on private land management can be a simpler task without as much documentation. In fact, many if not most private land managers and some public land managers may have nothing in a written form but could still easily implement good planning over time if they understand the important process of prioritizing weeds for control.

The following table illustrates the process that one Council in eastern Melbourne has devised for regionally significant bushland reserves. The Master Planning step requires much community consultation and detailed documentation but the other steps simply fit into the framework established early for the reserves, so are much simpler and less expensive to develop (Table 1).

However, too often management plans get unnecessarily complicated. Preparing management plans in simple formats (easily reproduced for different sites) is the priority so that they get read and used as the guiding resource for management. I would suggest that a management plan for a bushland reserve or small property should aim to be as simple as a map of management blocks or zones with a table illustrating short-term actions and long-term objectives along the following lines. A simple management plan based on the structure in Table 2 can easily be translated to regular work programs as required into the future.

The costs of management plans with strategic responses to environmental weeds as one of the primary threatening processes can vary a great deal depending on the context of the site and the other requirements that are associated with that land. Assessment of an entire reserve or subject areas is critical background to determining weed control priorities and this tends to be the major cost of planning.

Some level of assessment of conditions is an important process however expensive because the weed management and control priorities are only reasonably based on existing conditions. Nonetheless, it should be possible for a skilled botanist or weed specialist to develop a brief but clear management plan across a reserve or property for a relatively small cost if the format is kept simple.

General management regimes affect weed control priorities

Each reserve or property will have a unique set of land management objectives and site conditions that should drive weed management into the future. The determination of general management requirements for blocks or zones within a park is based on a whole range of objectives. The general management requirements of any particular block will potentially change the way weeds are prioritized and controlled; this is important, as the site-specific or species-specific approach for different weeds will change in different management regimes.

Analysis of weed invasion threats

There are certainly formal processes, developed for application across the country, of assessing the threats of different weeds and their impacts that would be useful in many circumstances. However, much of the knowledge used to determine weed control priorities in a reserve or local area is very site-specific. For example, across the Melbourne area there are dramatically different soil-types and rainfall patterns; environmental weeds of wetter places such as the Dandenongs are not much of a problem out on the hot dry plains to the north and west of the city.

The priority of weed invasion threats can be as much about the site being invaded as the inherent ecological characteristics and

Table 1. Documents used for managing major reserves and native vegetation in Whitehorse City Council

Planning document and size	Role	Timing
Master Plan Greater than 100 pages with lots of plans	Set general directions for reserve management across all zones and identify major projects and objectives (City of Whitehorse 1998).	Every 10 years or so
Vegetation Action Plans Up to 50 pages	This document considers the areas of native vegetation in the reserve and defines more specific objectives for particular zones over the following three years.	Every three years
Quarterly Native Vegetation Management Programs Up to 5 pages at most	This document is the operational program for works on the ground in native vegetation. It takes the bushland zones and the general management guidelines and translates it to appropriate detailed actions, most prominently weed control tasks..	Every three months

Table 2. Simple structure for bushland reserve management plan

Block or Zone	Current conditions and issues	Short-term Actions	Long-term Management Regime
A	This would review the conditions that need to be responded to…	High priority weeds	On-going weed monitoring etc.
B			
C			
	And so on		

potential invasiveness of the weed species. Sites of indigenous vegetation with high conservation value that are at risk of weed invasion often have a wide array of weeds that may have an impact on its integrity. In contrast relatively few weeds will require control over a larger area because weed invasion to areas other than bushland or natural areas is relatively minimal in an urban setting but would be partially true of farming regions as well. The other circumstance that is typical in conservation reserves is the fact that weeds in slashed firebreaks require a very different response than those in indigenous vegetation.

The control techniques used for a weed species may also vary between different situations. Cutting and painting might be the safest method for woody weeds in natural areas but spot spraying will be appropriate in less significant areas where other indigenous herbs are not present and at risk from drift.

These contrasts demonstrate the division between two major weed control strategies, either site-specific with a focus on sites being managed for certain objectives or species-specific where certain weed species are the target no matter where they grow.

Site-specific weed control priorities

When it comes to planning for the management of environmental weeds in native vegetation the site should the primary focus for control. The environmental weed problem does often come from nurseries and/or gardens (and must be dealt with in some way on the regional level with a species-specific focus) but planning weed control will be primarily about defending sites of conservation significance from the sea of weeds and their propagules lapping at the gates. This is also true because of the nature of land ownership frameworks and the clear and delegated responsibilities for different landowners or managers under the Victorian *Catchment and Land Protection Act*.

A site-specific weed focus makes many weed species a high priority for control in native vegetation but there would be little reason to control these plants in areas of other land uses. The best examples of these species are invasive rhizomatous grasses such as couch (*Cynodon dactylon*) or kikuyu (*Pennisetum clandestinum*) or pasture grasses such as phalaris (*Phalaris aquatica*). These species have an enormous impact on the important groundstorey species in grasslands and grassy woodlands but are desirable elsewhere, such as pastures and cricket ovals. Pines (*Pinus radiata*) are another example of a site-specific weed focus. Although many people looking after bushland invaded by pines would probably like to remove all of the pines in the local area they usually would not be able to.

Species-specific weed control priorities

A species-specific focus has long been the main approach to weed management, particularly on a wider landscape and regional level through noxious weed legislation. However, this approach has inherent problems, particularly in native vegetation. Native vegetation is invaded by many weed species, most of which have no legal requirements for control and many are desirable in gardens and farms.

A species-specific weed control strategy is essential for some classes of weeds, particularly new invasive weeds, but has been completely ineffective on many fronts. For example, I have seen bushland being managed for a few noxious weeds while numerous environmental weeds get no attention. It is as if the older structures of noxious weed laws have produced a selective blindness when it comes to certain weeds. It's as if two insidious diseases are eating away at a human but doctors only see the one with the higher legal profile.

The species-specific approach is most important for emergent weeds of potentially high impacts on any scale. For example, a weed species of high invasive potential might be new to a state, region or reserve but may be at a level that may still allow eradication with control efforts within the relevant context. If you are the manager of a conservation reserve there might be a small clump of Chilean needle grass in a disturbed corner that is not directly threatening high value assets and that may initially seem a low priority but it has great potential and requires a species-specific approach to control.

Other weeds that certainly require a species-specific approach across a reserve and hopefully beyond are the wide range of berry producing ornamentals, from bridal creeper (*Asparagus asparagoides*) to sweet pittosporum (*Pittosporum undulatum*) trees. These weeds have the help of birds to spread their seeds across wide areas. A species-specific approach is essential for controlling these weeds because wherever they are birds can move the seeds long distances.

One last important issue

As highlighted above weed control is done in an inconsistent manner across a landscape or region because of the nature of land ownership and management. This inconsistency can often be seen on a small scale where many boundaries and responsibilities meet. The mosaic of land ownership and management responsibilities typically around riparian strips (where weeds are a particularly significant problem) produce an odd state where confused boundaries and attached responsibilities somehow produce a state of no responsibility taken. Many neglected sites such as these exist across the Melbourne area. There is an urgent need for better cooperation and planning across property boundaries to protect native vegetation and natural resources. Planning weed management within conservation reserves is most important but cooperating across boundaries is also extremely important to 'chip away' at the significant impacts of environmental weeds.

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Environmental weed management plans: options for formal surveys and assessments

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Introduction

In order to develop effective environmental weed control programs, formal surveying and assessing is required to determine the presence of invasive species and the extent of weed incursions. Some of the main weed surveying and assessing methods available to managers are described below.

Factors influencing choice of methods

Various factors influence the scope and detail of all environmental weed surveys and assessments including resources, size of the area under study, topography and accessibility.

The size of the management area inevitably influences the choice of methods adopted and the detail that is likely to surface. As a general rule, the smaller the unit under study, the greater the detail that emerges. This usually has as much to do with resource availability as any issues of scale. Topography and the density of vegetation also have major influence; it may mean only select areas can be surveyed in detail.

When surveying in larger tracts of native vegetation (>100 hectares) one approach is to focus efforts on areas likely to contain weeds or be at greatest risk of weed invasion, i.e. roadsides, tracks, trails, service easements, edges, disturbed areas, boundaries and watercourses. Zones with specific conservation values, i.e. scientific reference areas, rare fauna and fauna habitat, may also be a priority for weed surveying. This approach was adopted for weed surveying at Bunyip State Park, a reserve covering 21 000 hectares and containing large sections with difficult terrain and extremely dense native vegetation (Muyt 2002).

Numerous environmental weeds – primarily woody shrubs and trees – may establish away from disturbed areas and in essentially intact native vegetation (Carr *et al* 1992) so if surveys can not cover an entire site, there is the risk that serious weed incursions may be overlooked. While it may not be possible to survey every square metre of a large site, managers should at least survey boundary zones and along watercourse as these are usually the areas most susceptible to weed invasions.

Survey and assessment methods

Weed mapping

Formal weed surveys are generally best undertaken as mapping exercises as this makes it easier to relocate weeds and develop control/eradication programs. Basically it consists of physically surveying a site and plotting particular weed occurrences onto maps or aerial photos (Rennick 2001).

Weed mapping may cover all or part of a stand of native vegetation. Often areas of vegetation less than a few square kilometres in size can be mapped in entirety but in larger tracts, only accessible areas or sections most at risk of weed invasion, may be all that can be mapped.

Vegetation quality maps

In the 1980s the NSW National Trust developed Vegetation Quality Mapping for bushland management purposes (Buchanan 1989). The method is particularly suited to smaller, accessible tracts of native vegetation and basically involves mapping the condition (quality) of the ground-flora and/or over-storey across an area using a four-tiered scale. Separate colours are used to distinguish the four bands on maps (Table 1).

Vegetation quality maps are very useful tools for setting management priorities and targeting weed control works; they highlight weed occurrences as well as the cover of indigenous and exotic vegetation (Kern and Muyt 1995, Muyt 2003). In order to pick up any changes and trends in vegetation cover, follow-up mapping should occur every five to ten years.

Table 1. Vegetation quality maps

Map colour	% indigenous cover	Description
Green	75–100	Areas largely or completely intact and carrying little or no exotic flora.
Blue	50–75	Areas substantially intact but with a moderate cover of exotic flora.
Orange	25–50	Areas substantially degraded and predominantly carrying exotic flora but where some indigenous vegetation remains.
Red	<25	Areas severely degraded and largely or totally dominated by exotic flora.

Quadrats

Quadrats are a proven means of surveying vegetation but the size of the area and quality of the vegetation usually determines whether the focus is purely on weeds or on both weeds and indigenous species. In smaller and isolated reserves, quadrat surveys commonly cover both introduced and indigenous species and are generally <1000 m^2 in size.

Establishing weed-specific quadrats is of most use in larger tracts of bush (>100 hectares) or areas where most native vegetation is intact. As weed incursions often commence in a scattered pattern, the size of weed quadrats in large stands of bush or intact vegetation, usually needs to be 0.5–1 hectare in size to ensure weed occurrences, abundance and cover patterns are discernible. Where the density of bush prevents quadrats of this size being used, one option is to place a transect line over a set distance (i.e. between 200–500 metres) and then survey 10 or 20 metres on either side of this line.

Ideally more than one quadrat should be placed around areas subject to disturbance or weed incursions. Quadrats should be located strategically around such areas and incorporate part of the disturbed edges in order to identify weed species and cover patterns. Where a watercourse (permanent or seasonal) runs through or near one of these locations then at least one quadrat should incorporate the watercourse.

Along park boundaries the number of quadrats in an area will depend on the size of the boundary (the edge), what the weed flora consists of on adjacent properties and whether specific species or invasion fronts can be anticipated. For example, along one boundary the weed flora on neighbouring properties may be insignificant so only one or two quadrats may suffice here. On another boundary, there may be large populations of highly invasive species on adjacent properties, nearby roadsides or bushland. In this case it would be appropriate to establish several quadrats.

Depending on what species were identified in initial surveys, quadrats should be re-surveyed every 2–4 years. This time-frame acknowledges most invasive species will not reach sexual maturity in

<2 years; in many cases, species may not reach sexual maturity in <4 years.

Transects

Weed transect surveys are also useful in larger tracts of bush and in areas where most of the vegetation is intact. Transect lines can cover any length but for practical reasons (i.e. topography and vegetation density) are unlikely to extend for more than a couple of kilometres. Surveys are conducted at regular points along the line (e.g. every 100 metres) and cover a set distance on either side (e.g. 10–20 metres) of the line.

Vehicle-based weed surveys

Numerous invasive species are known to spread along and from roadsides into areas of native vegetation (Muyt 2001). Recognising this, many land managers look for weeds when driving along tracks and roads. These informal checks can be of value; they are certainly not a waste of time nor inherently wrong. The limitation with such an approach is that the method relies too heavily on an individual's powers of observation: ultimately it is a hit and miss affair and tends to be reactive rather than preventative.

A more useful approach in large parks and rural/semi-rural municipalities is to develop a formal weed survey program for all roadsides and vehicle tracks. Roadside weed surveys can plot the locations of highly invasive and potentially serious weeds and incorporate information that aids weed management such as the general condition of verges, parking areas, drains, culverts and creek crossings.

As many highly invasive ground-flora weeds can reach maturity within two years, vehicle-based weed surveys should typically be undertaken every two years (at least along major roads).

The Victorian Roadside Conservation Advisory Committee developed a model to broadly determine conservation values along roadsides. (RCAC, undated). A modified version of this system could be developed for roadside weed surveying, substituting weed occurrences, cover and abundance for conservation values.

Aerial surveys

Aerial surveys have the obvious limitation that most invasive species will not be discernible from the air. However, aerial surveying may have validity in certain situations, for example, along watercourses where deciduous invasive tree species are common. In some situations highly invasive woody weeds with very distinct form or foliage (i.e. pines and olives) may also be distinguishable from the air.

Conclusion

A number of formal environmental weed survey and assessment methods are available to land managers including mapping, quadrat and transect surveys and aerial and vehicle-based surveys. For any area of native vegetation determining which methods are suitable and how widely they are applied will be influenced by factors such as resource availability, size of the area under study, topography and accessibility.

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The basics of community weed mapping – a vision for the future

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Summary Weed mapping is discussed with particular reference to systems currently available in Australia and how new WEB browser technology could make community weed mapping a reality in the near future.

Keywords Weed mapping, interactive mapping, mapshare, web, community.

Introduction

The cost of weeds to Australia has been estimated at $3300 million on present day figures without considering losses to biodiversity (Anon. 1997). More than $452 million is spent annually on herbicides alone, more than double the amount spent on insecticides and fungicides (Anon. 1997).

Some biologists have placed the $value of environmental weeds in the same order of magnitude as that of weeds of primary production (Anon. 1997).

An integral part in planning a weed control program is being able to document the extent of infestations and to allocate resources efficiently and appropriately for their management. The extent of weed infestations needs to be recorded in order to assist in the development of management plans, for documenting control and to monitor program progress. Weed mapping is therefore a critically important component in natural resource planning.

Historically, weed mapping in Australia was undertaken by government weed officers. For example the *Victorian Integrated Pest Management System* (*IPMS*), managed by the Department of Sustainability and Environment, contains thousands of entries on weed infestations and weed management (Backholer 2000). This data is however not available to private land managers for the purpose of developing weed management plans or part of their property plans. New technologies such as use of geographic positioning systems (GPS) potentially makes mapping weeds easier and more accurate, but current resources don't make it possible for comprehensive mapping of all noxious weeds as has been done in the past (Lane *et al.* 1980).

One of the most significant gaps in Victoria is mapping of crop weeds. The last comprehensive survey was undertaken in 1977 (Wells and Lyons 1977). This survey aimed to:

- Provide reliable and current information on the distribution and density of cereal crop weeds in Victoria;
- Provide a factual basis for the estimation of cereal crop losses due to weeds in Victoria;
- Assist in the determination of research priorities;
- Provide baseline data against which measurement of containment or spread of weed species could be made.

The 1977 survey mapped the distribution and abundance of the 42 most abundant cropping weeds across 1382 individual cereal crops. Another survey of Victoria's crops was undertaken by Gardner and Flynn (1989). They looked at four different crop types over a four year period and documented substantial weed changes during the eleven year interval between their survey and the 1977 Wells and Lyons survey.

Existing weed mapping systems

Victoria and Tasmania are the only States in Australia that have statewide weed mapping databases. Western Australia is in the process of developing one. In Victoria, the Department of Sustainability and Environment uses the IPMS for mapping weeds. Catchment Management Officers across Victoria enter information into a centralised computer network which includes information on weed species, extent of infestation (ha), date of inspection, land manager details, land tenure, treatments applied to infestations and so on. At present, this information is recorded as point location information but it is planned to upgrade this to cadastral (mapping the precise geographic boundaries of an infestation) information in the near future. This will enable direct downloading of GPS data on infestation size, shape and precise location.

Mapping of Victoria's flora including weeds, is undertaken by the Department of Sustainability and Environment (DSE) using the Flora Information System (FIS). This uses a grid system where Victoria is divided into 10′ (minute) grids (approximately 15 × 18 km). Flora identified within each grid is documented and this information can be used to map particular species at larger scale to get a statewide perspective. The database covers the entire vascular flora of Victoria, both native and exotic, and includes more than 1.5 million records of about 5500 species. The FIS also has a comprehensive identification database which includes photos of over 2900 species. The FIS has produced a CD, Wild Plants of Victoria (Viridans 1999) that can be used as an interactive tool for identifying plants in a particular location in Victoria or can be interrogated on information about a specific species. Information for FIS comes from DSE surveys, plant collections and increasingly from botanists, amateur botanists, friends of groups, etc. collected over the last 25 years. These records are tagged according to the perceived accuracy/knowledge/training of the recorder.

Another weed mapping tool that has been developed is *Weed Manager* http://www.weedmanager.net by Viperware software. *Weed Manager 2002* integrates a handheld GIS (geographic information system) GPS system with an automatic link direct to the desktop software, to allow recordings of weed infestations. The desktop software allows the user to place controls (the type of treatment to be applied), check the status of a weed, and keep commercial chemical spray information as well as record the outcomes of the weed control program. *Weed Manager* enables quick summaries of weed infestations, and has an on-screen search facility for easy recall of infestation information and a status screen to remind users what assessments, controls and follow-ups have been done in a particular month. *Weed Manager* also allows users keep a tab on where money has been spent on their weed program and to link into Mapinfo and/or Arcview to view maps of infestations. Viperware is working on a freeware version of *Weed Manager* due to be launched in late 2003 early 2004.

In Tasmania, a new statewide mapping system has been set up called RETICLE. It is a standardised weed mapping system designed for use by Tasmanian Government authorities, utilities, State Departments, farmers and community groups. RETICLE uses a CD system that produces a WEB based form to be filled in by the weed recorder. Once filled in, the information is automatically uploaded via the WEB to a centralised access database. Organisations, farmers and community groups receive weed identification training prior to becoming part of the RETICLE project. This system uses point locations and to date has 22 organisations using the system.

Another community weed mapping system is being developed by the Western Australian Department of Agriculture. It consists of a field book, electronic weed identification key and an internet-based mapping program (Moore 2002). It aims to build onto a system being used by Oregon State University called *WeedMapper* (Johnson 2001).

WeedMapper is a web-based, spatially referenced database of noxious weeds that anyone may query. The database includes locations of noxious weeds throughout Oregon as collected by federal, state, and local agencies. The electronic maps are viewable at the state, county, township, or section (square mile) level.

WeedMapper is designed to facilitate identification, reporting, and verification of noxious weeds in the state of Oregon. It provides maps of known infestations of the most serious weed pests, as well as photographs and taxonomic and diagnostic characteristics to assist in identification.

WeedMapper helps farmers and land mangers to easily locate weeds that are proximate to their land. If they know of an infestation that has not been reported, they can find the coordinates on the map and file an electronic sighting report. This report is forwarded to local weed officials for verification and inclusion in the database.

New weed mapping capabilities

The Department of Sustainability and Environment (DSE) and the Department of Primary Industries (DPI) in Victoria have recently implemented a shared infrastructure that facilitates the publishing of interactive maps on the WEB, accessing and displaying authoritative mapping information maintained in corporate DSE/DPI databases. Currently, these interactive maps allow the end-user to zoom-in and zoom-out, pan around the map, identify features in the map, do queries on databases, link (hyperlink) to other sites and print out maps based on specific themes of interest as published by DPI/DSE businesses. Initially a generic interactive map interface has been developed that all DSE/DPI businesses can easily use to rapidly publish mapping information to the WEB. In addition DSE/DPI businesses are currently developing additional functionality and more sophisticated interfaces that, amongst many other things, allow the end user to interactively feed data back to the central database. These interactive mapping interfaces and the associated infrastructure are known internally to DSE/DPI as *MapShare*. The generic interactive map interface that is currently in production can be viewed at, http://www.dpi.vic.gov.au/mapshare where it is being used to deliver a number of different map themes.

A vision for Victoria is that everyone would have access to a universal weed mapping system, providing the community with the capacity of recording weed infestations to a central database. The Victorian community weed mapping project aims to use the existing MapShare infrastructure to build a WEB browser-based application that would enable land managers to directly enter weed distribution data onto a central weed database for the State.

The application would enable land managers to utilise their home computers to zoom down from a map of Victoria to the boundaries of their property and enter weed distribution data via a grid placed within the property boundaries. It is envisaged that a process of tagging and verifying data from users will be put in place to ensure that only quality data would be available for viewing across Victoria. It is also envisaged that users would have to be registered and would only be able to enter data for their particular property, unless they have an agreement as a landcare group/consortium to allow access across several properties.

Developing this community weed mapping site will entail several steps:

1. Consultation with stakeholders to develop a comprehensive, user-friendly system that enables detailed assessment of Victorian/Australian weed problems.
2. Development of a web-based mapping system to allow community groups to add weed distribution information to the existing databases under the jurisdiction of DSE/DPI.
3. Communicating and educating the community on how to use this new technology.
4. Community groups/individuals would need to become registered users. Data would need to be tagged at different levels of validation/verification.
5. The GIS system would allow the registered land manager to zoom in to the property level for data input (available in Victoria).
6. The recorder's details, date, etc. would automatically be included on the assessment sheet for verification.
7. The land manager will be able to place a grid (perhaps 10 m × 10 m) across the map and designate density (high, medium, low) for each weed infestation recorded.
8. These grids will then activate larger grids to provide an overview of the infestation's extent.
9. To attract land managers to record weed infestations onto this database, incentives would be necessary. An example of these is the inclusion of links to information sites providing weed control, management and identification options. A web site will be developed to provide users with the very latest weed control and management information.

The development of this project would address several goals and actions of the National Weed Strategy, Weeds of National Significance Strategic Plans and the Victorian Weed Strategy. These include:

- Goal 1, Objective 1.2 of the National Weed Strategy (Anon. 1997) is, 'To ensure early detection and rapid action against, new weed problems'. The linked WEB site to the community weed mapping site would supply identification and early warning information on new and emerging weeds. The mapping software would enable fast recording of such infestations.
- Each Weed of National Significance strategic plan places mapping the extent of weed infestations as an important component in planning how to deal with it. This project will enable community groups in Victoria to become directly involved in mapping these important weeds on their properties.
- Goal 3, Strategic Action 20 of the Victorian Weed Strategy (Anon. 1999) is 'Involve the community in a coordinated mapping procedure to determine the extent and severity of existing infestations of priority weeds'.

Discussion

Detailed mapping of weeds using satellite technology, particularly at sparse or medium densities is problematic (Bulman 2000). Until these technologies become a reality, weed mapping will rely on local land manager knowledge. Resources no longer make it possible to map all 90 declared noxious weeds and 21 state prohibited weeds in Victoria. DPI now selects a shortened list of priority weeds from each Catchment Management Authority (CMA) to focus its weed mapping and control programs. The people with the greatest knowledge of the weed distributions are the farmers, Park Rangers and land managers dealing day to day with weed issues on their land. Community participation in weed mapping is the way that a more comprehensive weed database can be built up.

Though the Victorian Department of Primary Industries has a statewide mapping system (IPMS) that many other states envy, it could be much more effective and comprehensive. At present it doesn't link in with weed mapping activities undertaken by Parks Victoria, DSE (though the FIS and IPMS do swap data at regular intervals), VicRoads, Shires, utilities, community groups or individual farmers. These different agencies and individuals will continue to use their own preferred mapping systems. What is required is to build a system that has a platform enabling easy data transfer between the different mapping techniques. This is another challenge that needs to be addressed.

Victoria's largest weed knowledge gap is the distribution and abundance of cropping weeds. Previous surveys have been useful but it has become clear that the survey results depend substantially on the type of year (wet/dry/average) occurring when the survey is undertaken (Moerkerk personal communication). The development of an interactive mapping tool for input by grain growers would enable continual surveys of weeds providing a clearer and more comprehensive assessment of key weed issues.

What is the communities' capacity to use this technology? Greg Smith from the Victorian Farmers Federation (VFF) suggested that approximately 50% of farmers use computers but only 10–15% use the WEB frequently (Greg Smith personal communication). Similarly, Tania Pittard from the VFF Grains team suggested that 60% of grain producers use computers and 40% of these would use the WEB regularly (Tania Pittard personal communication). A major barrier for implementation of such technology is access to high speed and cheap telecommunications to rural communities. Telecommunications is a vital aspect of this technology and this project will only become fully realised if rural communities get access to high speed internet cabling/satellite technology at comparable costs to their metropolitan cousins.

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Weed mapping in Tasmania: experiences

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Summary A weed mapping database has been developed by the Department of Primary Industries, Water and Environment (DPIWE), Tasmania. The principal aim of the database is to facilitate collection, sharing and efficient use of spatial and temporal weed information by all Tasmanian weed managers.

Named RETICLE (meaning a network of veins), the database allows different organisations and individuals to collect and exchange information about specific weed occurrences and how these are being managed.

Resources for weed management in Tasmania are likely to continue to be limited relative to the magnitude of the problem. Therefore a strategic approach to managing weeds incorporating coordination of activities, integration of control techniques and resource sharing must be employed to make the most of available resources. RETICLE is a management tool that supports this approach.

Keywords Weed mapping, RETICLE, database, community, distribution, weed control, enforcement, information.

Introduction

The development of a relatively accurate picture of the location of weeds and the size of infestations is fundamental to any weed management program. This information is essential to strategic planning and effective monitoring and evaluation of weed control initiatives over time. WeedPlan (DPIWE 1996), Tasmania's Weed Management Strategy, identifies the need for a central weed mapping database that both stores information about weed occurrences and allows it to be accessed by the community. The database is a companion tool to the successful *Tasmanian Weed Mapping Guidelines* (DPIWE 2000). These guidelines were developed to assist all weed managers to collect and record weed mapping information in a standard form that permits ready exchange. The guidelines specify a number of weed infestation characteristics that need to be described during mapping procedures. RETICLE is a repository for all the mapping information collected using the guidelines.

Database operation

Database development and capability

The development of the 'front-end database' of RETICLE was undertaken jointly by four TAFE computing students and officers from the DPIWE Weed Management Section over the period 2001–2003. The front-end database is developed in Microsoft Access and provides an easy to use format incorporating a range of drop down and text entry fields that allow efficient and standardised data capture.

The front-end database has three categories of input: general weed data, control data and information relating to enforcement activities.

Entry fields for general weed data are consistent with the *Tasmanian Weed Mapping Guidelines*. Plant growth stage, size and density of the infestation, land use, soil type, relief and aspect may be recorded along side the name of the land owner and property number. The location of the weed or the infestation is given in full Australian Map Grid coordinates using the 'thirteen figure' or '6-7' methods.

The control section allows users to enter information regarding control measures undertaken at the mapped site at any particular time. These include techniques and methods, type of chemical products and application rate. The individual or organisation that has undertaken control measures is also identified.

The enforcement section captures records of gazetted weed inspectors. For example, details of requirement notices or infringement fines can be logged. In this way, a file of regulatory activities relevant to a particular site is created. It provides an essential history and reference point for weed inspectors and helps ensure that regulation at any site proceeds in a fair and consistent manner over time, regardless of which inspector is involved.

Database administration and access.

Upon registering to input data to RETICLE, individuals or organisations are assigned a unique project code by the database manager, DPIWE. Copies of the front-end database are provided to all registered users free of charge. These can be run on desktop or laptop computers as well as handheld PCs/PDAs. All data from each project is managed discretely so that ownership is maintained. Whilst other users may view some or all of the information entered for a particular project, only the owner can add data or modify existing data. Once data has been collected in the front-end it is exported using an in-built export function to the RETICLE manager at DPIWE. The data is uploaded to the main 'back-end database' housed on DPIWE servers. Once there it is immediately available to all registered RETICLE users through any internet portal via the Tasmanian Parks and Wildlife Service's online geographic information system, GTSpoT (Geo-Temporal Species Point Observations Tasmania).

When registered users log onto GTSpoT they are able to access weed mapping data exported from all projects. The exception is enforcement information, access to which is password protected and restricted to gazetted weed inspectors. Other weed mapping information may be combined, for example, with road and topography layers to produce useful site maps. A number of search functions are also available through GTSpoT. These allow for data retrieval by species, site and other attributes. Reports may be printed directly from the GTSpoT screen or downloaded as a delimited text file into Microsoft Access or Microsoft Excel.

Non-registered users may also access RETICLE through GTSpoT but their level of access is limited to broad weed distribution maps.

Discussion

RETICLE supports a cooperative, strategic approach to weed management in Tasmania. As a repository for distribution, control and regulatory information, it is critical to establishing priorities and planning on-ground weed control.

Although the development of RETICLE has only been completed recently it is already proving important to a number of weed management programs. For example, the Tasmanian bridal creeper eradication program involves planning and coordinating on-ground action for over 130 sites around the State. RETICLE is an invaluable point of reference for program coordinators and participants because it provides for centralised data storage and retrieval. This is especially useful at the State level since it allows the logistics of annual control efforts to be determined effectively and efficiently. The results of accurate monitoring of the size and location of infestations can be used to estimate resource requirements. A suitable workforce and materials such as herbicides and spraying equipment can be procured or negotiated in advance.

One limitation of RETICLE is that it can only handle weed locations as point data. Due to limitations inherent in GTSpoT, RETICLE cannot record and display data as polygons. GTSpoT will be upgraded to provide this facility in the future. In the meantime users wishing to display and interrogate data as polygons must download the data into their own GIS software and extrapolate polygons from the attribute data associated with each record.

RETICLE allows weed distribution information to be managed and preserved over time, even if the individuals or organisations responsible for collecting the data cease to participate in weed mapping activities. This is particularly useful since the generally short term funding of many community-based weed management efforts means that the risk of data loss is high. In this sense RETICLE provides much needed continuity – spatial information about weeds at a particular site may be shared between groups with an interest in that site over time. Accordingly, all weed managers, existing or newly formed are encouraged to make use of RETICLE when contemplating weed mapping activities.

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Assessing the effectiveness of weed management programs in Victoria's parks and reserves

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Summary Parks Victoria is enhancing its environmental management programs by implementing standardised performance monitoring across pest management programs. Pest plant mapping and monitoring protocols have been developed and will be trialed in a number of parks. The protocols will then be reviewed and developed as a user-friendly instruction handbook that assists park managers to design and implement monitoring programs. This will enable the effectiveness of weed management programs to be determined.

Keywords Pest plants, weeds, monitoring, mapping.

Introduction

Parks Victoria is responsible for the development and delivery of high quality and innovative environmental management of Victoria's parks and reserves, which comprise 17% of the State. Parks Victoria employs an Environmental Management Framework (EMF), which provides a consistent approach to the development and delivery of Natural Values Management based on the systematic collection, analysis and interpretation of environmental information. The EMF uses principles of risk management and identifies natural attributes, the threatening processes that pose a risk to those attributes, and the strategies employed to ameliorate risks and thereby improve the condition of attributes.

Monitoring the performance of management strategies is a critical component of the EMF. It allows Parks Victoria to measure the effectiveness of its management strategies by measuring progress towards achieving defined ecological management objectives. Therefore, a monitoring framework is being developed to support the EMF. The framework outlines a consistent approach towards monitoring, and identifies three performance indicators:

1. *Efficiency indicators*: quantitative measures of threat management actions. For example, the number of hectares treated to manage English broom;
2. *Effectiveness indicators*: quantitative measures of the outcomes of threat management actions. For example, the density of English broom following treatment;
3. *Environmental indicators*: quantitative measures of the outcomes of threat management strategies on natural attributes. For example, improved regeneration of native species.

Standardised measures are required for all three indicators to enable collection of information that is consistent and comparable across parks. Current reporting of pest management programs is based largely on *efficiency indicators*. However, Parks Victoria has recently developed standard monitoring protocols to measure *effectiveness indicators*. A similar process has been undertaken for New Zealand (Department of Conservation 2000), but no other standards for pest plant monitoring have been developed in Australia. Ultimately, these protocols will be expanded to incorporate standardised measures for *environmental indicators*.

This paper summarises Parks Victoria's pest plant mapping and monitoring protocols, and outlines the proposed process for their implementation. Some of the limitations are discussed, and associated programs in development are also described.

Parks Victoria's pest plant monitoring protocols

Standard mapping and monitoring protocols for pest plants were developed for Parks Victoria that comprise: a review of best-practice mapping and monitoring techniques, an introduction to the proposed methods, a decision key to select the most appropriate method, and instructions for planning and implementing a mapping or monitoring program, including data collection and storage.

These protocols are intended to provide consistent, robust and repeatable methods to implement mapping and monitoring programs for two key purposes: 1) to map the extent of various pest plant species within parks and reserves, so that new pest plant incursions can be detected; and 2) to assess the effectiveness of pest plant management through on-going, quantitative monitoring programs. A clear distinction is made between mapping and monitoring:

Mapping is recording the extent of weed infestations at one point in time. The accuracy of mapping depends on the scale of the infestation, the size of the area of interest, and the manner in which the data were collected and are stored. Although mapping can assist in planning control programs, it is generally unsuitable to measure the effectiveness of control programs: resources are not available to map all infestations accurately.

Monitoring 'is the assessment of change in vegetation' (Carr *et al*. 1992, p. 27). This is achieved most efficiently through a monitoring program that has been established using rigorous scientific sampling. Monitoring the effectiveness of weed control programs involves measuring changes in the abundance and condition of weed populations (Department of Conservation 2000).

Protocols for mapping weeds

The key steps in mapping weeds within parks include:

1. Setting objectives. It is important that the purpose of weed mapping is clearly defined, as this will determine both the sensitivity and level of resources required. Objectives may include mapping the distribution of a particular species within a park, or mapping all weeds within a particular area (e.g. high conservation priority zone).

2. Defining search area. This will depend largely on the objectives (see above). A good starting point may be to obtain any existing information on weed distribution, particularly from local sources such as rangers, friends groups, or park visitors.

3. Selecting technique. Weed mapping may be either cell/unit based or transect based and weeds may be mapped as presence/absence within grids, as polygons (boundary of infestation recorded) or as point locations (centre of infestation/individuals recorded). A decision key has been developed to assist in selecting the most appropriate technique.

4. What to record. The level of information to be recorded will depend on the objectives and available resources. Essential data will include the date, name of recorder, species, location, how it has been mapped and effort expended. Additional data may include: lifecycle stage, density estimate, pattern of infestation, area of infestation and any other comments.

Protocols for ***Effectiveness*** *monitoring*

The key steps in developing and implementing a monitoring program to measure the effectiveness of control programs include:

1. Define the key question(s) to be addressed. This first step is critical to any monitoring program: it is important to understand how the information collected will improve weed management. Objectives and targets, as well as time frames for achieving them, should be clearly identified (Department of Conservation 2002). For example, questions could be: 'has the density of English broom been reduced by 60% within year 1?', and 'is the population of English broom being maintained at 5% cover or less?'

Managers should also recognise that important questions will change over time: as pest plant strategies control or eradicate certain species, other species are likely to invade and become the primary focus in a management area. This highlights the need for a robust sampling design, which should be adaptable to changing priorities.

2. Select method(s). A decision key is included to facilitate the selection of the most appropriate parameter(s) and technique to answer key questions. Recommended parameters and techniques described in the protocols are:

i. Frequency, measured from quadrats.
ii. Density, measured from quadrats.
iii. Cover, measured using either line or point intercepts.

Visual estimation of percentage cover was not included as a recommended technique, as estimates can vary widely among observers, making it difficult to draw strong conclusions from results.

Decisions on which method to use for monitoring various weeds are based on two key criteria: life-form/habit of weeds, and abundance of weeds. For a sub-canopy shrub such as karamu, the recommended methods are density counts or cover by line intercept, with an emphasis on density counts where the pest plant is moderately common or a heavy infestation. For climbers and creepers (e.g. Japanese honeysuckle, bridal creeper), frequency methods are recommended for thinly scattered or moderately common infestations, and cover by line or point intercept for heavy infestations. Instructions are also provided for infestations of grasses, herbs, small shrubs, and trees.

3. Decide sampling regime. The protocols describe several sampling strategies. Ideally, sampling would occur before and after pest plant control, both in treated and non-treatment sites (BACI design). This allows conclusions about whether the result was due to the management action, or due to factors out of the control of park managers (e.g. drought). However, rigorous sampling programs are often expensive, and will require careful budget planning within management programs. Given this, sampling before and after management (without non-treatment comparisons) is likely to be used most commonly.

4. Instructions for implementing technique and data collection. Detailed step-by-step instructions are included. These are presented as simply as possible for users with minimal scientific background. The protocols also document the data that should be recorded. The principal data storage and reporting tool for on-ground management actions is Parks Victoria's Environmental Information System (EIS). The EIS is a spatial database and includes a weed mapping module.

5. Data analysis. The protocols recommend the use of t-tests to analyse before and after data. However, more sophisticated data analyses could be undertaken provided appropriate sampling design is used. It is important that data are also presented in a format that is easy to interpret, such as bar charts with error bars to compare before and after, treatment and non-treatment sites, or line graphs to show trends.

Trial process

To ensure the successful implementation of these protocols, it is proposed that they will be trialed at five parks during 2003–04. The protocols will be followed to develop and implement a monitoring program at each park. Trialing the protocols in a limited number of parks, as opposed to a statewide roll-out, serves four purposes: i. to test how easy the protocols are to use; ii. to test how well the data collected through the protocols are able to answer management questions; iii. to gain worked examples of monitoring programs to 'showcase' the use of monitoring as a critical component of management programs; and iv. to enable review and improvement of the protocols before they are rolled out more widely. The key steps in the trialing process, which will focus on effectiveness monitoring, are outlined here.

1. Site selection. Proposed trial sites encompass a variety of park sizes, weed life forms/habits, and densities. Sites with existing weed mapping were preferred, so that effectiveness monitoring could be implemented (rather than needing to map distribution first). The sites all have existing weed management programs in place and adequate staff capacity.

2. Monitoring program development. The pest plant monitoring protocols have been provided to park staff. Key questions will be identified and monitoring plans developed with support from a Parks Victoria monitoring scientist and weed ecology consultants. Appropriate levels of monitoring will be determined through pilot sampling. Power analyses, using pilot data, will assist with determination of sample size. Activities, time schedule, staff, and the required financial and equipment resources will also be identified within a monitoring plan.

3. Finalise the design. This step is a quality check on the decisions made throughout the design process.

4. Field trials. Training will be provided to assist staff in implementing monitoring programs at each park. Initial data collection may require specialist advice on weed identification and monitoring techniques.

5. Data analysis. A Parks Victoria monitoring scientist will facilitate a workshop for staff from all trial parks, to assist with data entry, summary and analysis. Specifications developed for the storage of monitoring data within the EIS will be tested. Summaries of all trials will be prepared as case studies for further trials.

Expected outcomes By June 2004, staff at the trial parks will be in a position to report on the effectiveness of pest plant management, with data from before and after management actions. For example, staff could report that for $x and y person-days, an a% reduction (with a b% certainty) of a pest plant has occurred over z hectares. Results will serve as a benchmark for future weed control programs.

Future developments

Feedback from the trials will be used to improve the protocols. Issues that are likely to require further clarification include: the planning process; definition of sampling units; experimental design; and analysis of data. Packaging this information in a user-friendly format that can be understood by people with limited scientific background will be one of the biggest challenges. Ultimately the protocols will be presented to staff as part of a monitoring package, which will include standard protocols for monitoring vegetation condition, pest animals, over-abundant native animals, selected threatened species, and ecological management of fire.

Long-term data storage is a critical component to the success of any monitoring program. Further development of the EIS to incorporate monitoring specifications will ensure that information collected using these protocols can be entered, stored, summarised and extracted at local and statewide levels for improved program planning, decision-making and reporting.

Training programs and templates will be developed for writing monitoring plans, collecting data in the field, and analysing and reporting results. Trials of the Standard Operating Procedure for Monitoring Weed Control by Department of Conservation (Department of Conservation 2000) provide valuable lessons to assist this process. Advice has included 'spend 1/3 on development of tool, 2/3 on training and after-sales service' (Keith Briden personal communication); and 'setting appropriate objectives for weed control can be difficult – and for weed control monitoring is even harder' (Ian Popay personal communication). A formal review of the Standard Operating Procedure for Monitoring Weed Control is scheduled by Department of Conservation for 2003–04. Parks Victoria will be able to benefit from the lessons learnt in New Zealand.

Implementing monitoring programs in individual parks will assist in improving management effectiveness and efficiency at a local scale. Parks Victoria also recognises the opportunity for a coordinated, strategic approach to improving management effectiveness at larger landscape scales. The monitoring protocols will link into two other projects – Adaptive Experimental Management (AEM) of weeds and Weed Risk Assessment.

A pest plant AEM project will be established in 2003–04. AEM involves using monitoring information to model and field-test the relative effectiveness of various management options over a number of sites. The most efficient and effective management program for a site is then adopted and refined over time (Walters 1993). Outcomes from the protocol trials will assist in designing robust mapping and monitoring for Parks Victoria's AEM project.

The Weed Risk Assessment project will use information on weed distributions to assess the threat that pest plants pose to park values, and therefore identify priority species for management programs. These species are also likely to be priorities for effectiveness monitoring.

Establishment of monitoring systems in management agencies is a challenging task. Corporate commitment and funding is critical, but it is the enthusiasm and capability of on-ground staff that ultimately will determine the success of monitoring programs. Providing enthusiastic, well-resourced staff with user-friendly, scientifically-rigorous monitoring and reporting tools and systems should lead to the establishment of scientifically-defendable monitoring programs. In addition, developing database systems to facilitate the storage and accessibility of results aids knowledge building and data retention. Maintaining Parks Victoria's current commitment to monitoring will create a culture within the organisation that accepts monitoring as part of sound environmental management.

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Computer assisted information systems in weed management

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Summary The use of new information technologies can be a powerful aid in weed management. Managers and organizations need to make astute and well-informed decisions when venturing into and operating in this territory.

Keywords Computer information management system weed.

Introduction

It is easily taken for granted that any information system will be better if it is computer assisted. Such a conclusion may be very far from the truth.

Most agencies, organizations and businesses now have computer assisted business applications. In the weed management sector, the systems are as many and varied as the natures of the organizations themselves. Many computerized information systems used in weed management today are dazzlingly impressive, whilst by contrast, others may seem quite pedestrian or downright disappointing.

The challenge facing weed managers is to borrow, buy or build a system that 'delivers the goods' for them and their stakeholders.

Discussion

Whether a system is good, bad or indifferent can be judged on a range of criteria reflecting the many facets of effective performance.

These criteria include:

- close alignment to the business needs and operations of the organization;
- captures and uses relevant data;
- value-for-money relative to the resources of the organization;
- maintains an effective corporate memory;
- has validation and correction features that maximize data quality;
- has a robust backup and disaster-recovery plan;
- is well-suited to the attitudes and developing skills of the people who are expected to use it;
- has acceptable response times over a corporate wide area network or over the internet;
- is intuitive and aesthetically pleasing to use;
- has a sound development strategy to enable it to adapt to changing conditions and requirements;
- adopts technological innovation where justified by business needs and user circumstance;
- is responsive to stakeholder needs;
- is adequately resourced with training and support staff and a technical maintenance program;
- seeks opportunities for synergy with related systems;
- is able to utilize existing relevant data from other sources;
- is able to make selected elements of its database available or accessible to appropriate stakeholders by convenient means.

Particular examples will be used to illustrate these general principles.

Woody weed control guides and property plans

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Summary The *3 Cycle Planner* and *Woody Weed Control Guide* from Dow AgroSciences provide valuable tools for assisting in the development of control programs, suitable for many specific woody weeds infestations.

Record keeping and documentation during both the planning and implementation process is important in ensuring a logical programmed approach is utilised, as well as allowing for review of the success of control measures and activities.

Agricultural chemical companies involved in the woody weed market, such as Dow AgroSciences, are available as an information source for managers and practitioners undertaking weed control programs.

Keywords Woody weed control, control guides, property plans.

Introduction

When considering control of a woody weed it is important to recognise that complete control is unlikely from any single treatment and that a programmed approach will generate better results.

Dow AgroSciences (formerly Dow Elanco) developed a simple planning procedure for woody weed control, titled the *3 Cycle Planner*. This planner moves through five steps over three seasons to allow landholders to develop plans to assist with both the control of woody weeds and the rehabilitation of infested land. By utilising information contained in commercial publications, such as Dow AgroSciences' *Woody Weed Control Guide*, a successful strategy may be designed to facilitate the control of a specific weed.

Discussion

Woody weeds, by nature are difficult to control in most situations, particularly where other desirable vegetation is present. Effective control in pastures, on roadsides, in public areas and National Parks can become difficult due to competing interests. The persistent nature of woody weeds means that often total control can not be achieved in a single treatment (chemical, mechanical or cultural). Often regrowth will occur and if follow-up measures are not carried out the infestation may easily return to the original state, with the initial investment being wasted. As such, a programmed approach often needs to be utilised in order to prioritise resources so that the desired results are achieved.

Dow AgroSciences' *3 Cycle Planner* was designed as a management tool to assist with the development of programs for the control of woody weeds. It was also designed in recognition that complete control can generally not be achieved in one season, or in one treatment, and as a means of ensuring that sufficient resources are available to effectively undertake the control program being planned.

The planner works through five steps over a period of three years, or seasons. With the steps of any control program it is important to document and record all information, activities and results. This enables a logical process to be followed in the development and implementation of a plan. It also provides a means of reviewing the effectiveness of individual activities or measures for future reference in other situations.

Step 1: Define the problem

Assess the situation and identify where the problem weed(s) currently exist. Weed infestations should be recorded and their location mapped. Notable environmental hazards such as riparian zones as well as the potential for off-target damage should also be recognised at each site.

By locating the target weeds and recording this information it is possible to ensure all known infestations are being considered and monitored.

Step 2: Develop a program

Identify the weed species in each location that need to be controlled. Determine the infestation density and rate as scattered, medium or dense. Detail the size of the infestation at each location in square metres or hectares. Then determine priorities (rating 1–5) for which areas need the most attention.

The size of the problem should now have been identified and by listing the gathered information into a chart will assist in determining priorities. At this stage it may also be necessary to determine who is responsible for implementing control measures on the infested sites and to gain the support of all land owners and managers associated with these sites.

Evaluation of priorities will vary between different observers (e.g. private versus public land), often based on what they wish to achieve. Someone controlling weeds from purely a legal or regulatory perspective will most likely take a different approach to somebody who wants to increase their carrying capacity and improve land management or ascetics.

Some common factors however can be considered in determining priorities. Productive land or high profile sites should have primary consideration. It is advisable to divide large problems into smaller achievable segments, clean up small scattered infestations first, then work on treating the edges of large areas to prevent further spread.

Environmental and community issues such as whether the weed is toxic or habouring vermin, as well as the risk that infestation poses, from continued growth or as a seed source, to other parts of the property or neighbouring land, should also form part of the priority assessment.

Step 3: Develop solutions

This step involves evaluating control options, with regard to available resources and based on the size and severity of the infestation, in determining the most suitable control measures.

There may be more than one option available for control of a particular weed. Different control measures can be evaluated with regard to many criteria, such as their suitability to carry out at that site, the likely control level of that method, the cost, the ability of, or likelihood of follow-up work.

Within any program or plan it is generally recommended to integrate a variety of control measures that may include; herbicides, mechanical, fire, grazing and pasture management. The utilisation of a variety of control options in a program will assist in achieving long term control of woody weeds.

Step 4: Create a financial plan

It is important to allow for integrating all the initial control measures when planning the costs of a program as well as to make provision for follow-up treatments to occur in subsequent seasons. Determine what resources are required to implement the program and which of these need to be acquired.

Costs that may need to be considered could include; labour, herbicides, application, slashing, timber removal, pasture establishment (seed and sowing), fertilizer, fire, fencing, signage and finance.

Again, it is extremely important to allow for resources to be available for follow-up work. Do not over-extend efforts in the first season at the expense of treatments in subsequent years.

Step 5: Calendar your activities

Having determined what solution is to be applied and when it should be implemented, it is necessary to plan a timetable specifically for when each control measure needs to be carried out, when rehabilitation works need to occur and also for follow-up activities.

Labour activities need to be coordinated with other workforce demands as well as allowing for other variables, such as weather conditions. As with all planning, a degree of flexibility is required to satisfy changing conditions and requirements.

Woody Weed Control Guide

While the above planning process provides the template for a general control program, information specific to the particular weed(s) being controlled needs to be incorporated into the process. This additional information on individual weeds and control practices can be gathered from a variety of sources including government departments, local shires, agricultural chemical companies and retail outlets.

As a major player in the woody weed control market, Dow AgroSciences has accumulated a vast amount of information on the effectiveness of many control measures, covering many different weed species, in many different terrains and climates. This knowledge has been condensed into the *Woody Weed Control Guide* and is also available online at (www.dowagrosciences.com.au).

The *Woody Weed Control Guide*, while covering general topics such as how and why to control weeds goes on further to discuss control measures for specific woody weeds. It lists the herbicides that may be applied to each weed, as well as the most effective herbicide application method and timing for that individual weed.

These guides are available from many agricultural chemical retail outlets or directly from Dow AgroSciences.

References

Bruzzese, E. and Lane, M. (1996) 'The blackberry management handbook'. (Keith Turnbull Research Institute, Frankston, Victoria).

Anon (2002) 'Woody weed control guide'. (Dow AgroSciences, Sydney.)

Anon (n.d.) '3 cycle planner'. (Dow AgroSciences, Sydney).

SESSION 2
New weed incursions

Weed identification, recognition of key environmental weeds and where to find information resources

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Summary The correct identification of a new or common weed is extremely important. Knowing the correct name of the plant you are dealing with influences a whole series of decisions including the priority you put on its management, treatment techniques and legislation implications.

There are numerous ways of finding out which plant you are dealing with but in Victoria, the authoritative identification should be given by the National Herbarium of Victoria. There are many guides and information sources available from many places to help improve your weed recognition skills.

The important thing to remember is that if in doubt about a plant's identity, don't pull it out.

Keywords Weed, identification, recognition, information, resources, herbarium.

Introduction

Of the approximately 3000 weedy plants in Australia, about 1900 of these are environmental weeds invading natural ecosystems (R.P. Randall personal communication 2001). To be able to recognise and name all these plants and be able to differentiate between the weeds and indigenous species is quite a feat. There are few people, usually botanists, who have these skills.

Why is it important to know exactly what the name of the plant is? Accurate identification is important for several reasons:

- to differentiate between a weed and an indigenous plant
- for weeds, it influences the management approach and priority
- it influences the treatment methods used for weeds
- it may also influence the level of funding available.

Like a school teacher on the first day of the year in front of a class of 30 children trying to learn new names and faces, it is possible to learn many weeds. The school teacher learns the trouble-makers and the excellent students first, then the rest over time. For weeds, you remember the ones of most significance to you first. They might be the prickly ones or the one that your grandmother used to grow in her garden. Association of certain characteristics or situations is important in remembering particular weeds.

If you are just beginning to learn weeds and are intimidated or find it difficult to learn botanical names, remember that plant names like 'Chrysanthemum' are used in our everyday language despite it being quite a difficult word to say and spell if you haven't come across it before. It is possible to learn botanical names – it just takes practice.

Recognition versus identification

It is important to differentiate between recognition and identification. Recognition is the ability to recognise something, to know it again based on something you already know. You rely on your memory of a weed based on previous experience with it. Identification implies more authoritative naming of a plant based on certain characteristics usually from a botanical key or by comparison with already named weed specimens.

In the field, it is important to have recognition skills of common, new and potential weeds. To confirm a plant's identification, it is necessary to collect a specimen of the plant with information from where it is growing and submit it to the National Herbarium of Victoria. It is then possible to arrive at the correct name of the plant.

Recognition at speed

An additional valuable skill to acquire is the ability to recognise a weed from some distance including from moving vehicles. Becoming familiar with the 'GIST' of a weed is very valuable. The GIST refers to the 'General Impression of Size and Texture'. It is a variation of the term 'GISS' (general impression of size and shape) apparently used during the 2nd World War. People were taught to recognise instantly the difference between enemy and friendly overhead aircraft so that only enemy aircraft were shot at.

Bird watchers use the term 'JIZZ' to describe the essential characteristics of birds enabling 'twitchers' to instantly recognise a bird. There has been considerable debate about the origins of these terms and the debate continues today (McDonald 1996). I prefer to use the term GIST to describe the instant recognition of weeds from a momentary glance including from a moving vehicle at 100 km per hour.

To recognise a plant by its GIST, observe the following characteristics:

a. growth habit e.g. upright, spreading
b. colour of flowers and leaves
c. flower type and shape
d. leaf shape
e. unique features such as unusual seed pods, bark, smell of crushed leaves
f. height.

How to find out what the weed is

There are several options to find out what the name of the plant is you are dealing with. Firstly, remember that having a specimen with flowering and/or fruiting parts on it substantially increases the chances of making a positive identification.

Identifying it yourself

To identify a plant yourself when you are not familiar with it, there are several resources available to provide further information. There are botanical keys such as the 'Flora of Victoria' that have detailed descriptions of plants including weeds in the State. If you are not familiar with botanical terminology, it can be confusing but a glossary of the terms is provided in the back of the keys. A botanical dictionary can also be helpful.

Comparing the specimens with authoritatively named specimens in the National Herbarium of Victoria can also assist.

An easier but less reliable method is to look at pictures with descriptions in weed and plant books. There is now a range of weed field guides available including guides for environmental weeds in south eastern Australia. These include:

- Blood, K. (2001). 'Environmental weeds: A field guide for SE Australia'. (C.H. Jerram & Associates, Mt. Waverley, Victoria) ISBN 0 9579086 0 1.
- Muyt, A. (2001). 'Bush invaders of south-east Australia'. (R.G. & F.J. Richardson, Melbourne) ISBN 0 9587439 7 5.

The problem with some weed publications is that they do not always cover new or potential weeds. Gardening books and field guides from overseas also contain a wealth of information that can be helpful. If you suspect that a weed comes from South Africa, looking at plant books from that part of the world can be valuable including wildflower guides.

There are a number of interactive keys or weed guides available on compact disk.

There is also a range of brochures with photographs such as local government guides and Landcare Notes that focus on the identification of many weeds. These are available on compact disk and the internet and can be printed. Be aware that a number of guides published by local government and other groups contain incorrectly named photographs. A range of Landcare Notes for Victoria is available at www.dse.vic.gov.au

Searching on the internet for information on particular weeds puts you in touch with resources from around the world.

Many of the guides and useful publications and web sites are included in:

- Blood, K., Taylor, U., Nugent, T. and Timmins, S. (1998) 'Weed Navigator: resource guide'. (Weeds CRC, Adelaide) ISSN 1440-9534.

Many of the publications mentioned here and in the 'Weed Navigator' are available from libraries, larger book stores, stores that specialise in gardening, farming and environmental publications, and from specialist weed publishers and distributors. A number of these suppliers are listed in Blood 2001. Search the internet for publication availability in Australia and overseas.

Publications containing lists of weeds including new or potential weeds include:

- Randall, R.P. (2002). 'A global compendium of weeds'. (R.G. and F.J. Richardson, Melbourne, Victoria) ISBN 0 9587439 8 3.
- Ross, J.H. and Walsh, N.G. (2003). 'A census of the vascular plants of Victoria', 7th ed. (Royal Botanic Gardens Melbourne) ISBN 0 9587408 9 5.

Live versions of these lists are often available on the internet.

There are a number of training courses on weed and plant identification. Apart from formal training through universities and TAFE, courses are also offered through government agencies (e.g. DPI) and non-government groups such as Greening Australia Victoria (www.gavic.org.au).

Various items such as bookmarks, posters and fridge magnets are available from agencies that can help to reinforce weed recognition (see the 'Weed Navigator').

Seek advice from others

Seeking advice from others is the next option to find out what your weed is. There are many talented naturalists, botanists and enthusiasts within local community groups and government agencies. Seek their advice.

An alternative is to employ the services of botanists or consultants experienced with weed identification.

There are many generous people who subscribe to various email discussion groups or listservers who share information and have access to weed resource material from around the world. Taping into these networks can be very fruitful when trying to find out information on new and common weeds. These email discussion groups include 'Enviroweeds' managed from Australia (subscribe via www.weeds.crc.org.au) and 'Aliens' managed from the USA.

Submit specimens

The most reliable method is to collect specimens and field information and submit them to the National Herbarium of Victoria. There are a number of guides on how to do this including:

- Albrecht, D. (1993). 'Collecting and preserving herbarium specimens'. (National Herbarium of Victoria, Royal Botanic Gardens, Victoria) ISBN 0 9599758 5 3.
- Bedford, D. and James, T. (1995). 'Collection, preparation and preservation of plant specimens', 2nd ed. (Royal Botanic Gardens Sydney, NSW) ISBN 0 7305 9967.
- Blood, K. (ed.) (2001). Environmental weed workshop course notes, environmental weeds of south eastern Australia. Weeds CRC, Adelaide, SA.
- Bridson, D. and Forman, L. (eds) (1999). 'The herbarium handbook'. 3rd ed. (The Royal Botanic Gardens, Kew, UK) ISBN 1 900347 43 1.

There is usually a fee charged for identification services at the Herbarium. Check first through the identification desk before sending in specimens. The Herbarium usually welcomes specimens and field information for even common weeds, as people in the past have not typically collected weed specimens. The contact details of the Herbarium are:

Identification Desk, National Herbarium of Victoria, Royal Botanic Gardens, Birdwood Avenue, South Yarra, Victoria 3141. Phone: 03 9252 2300.

Botanists at the Herbarium often seek expertise from overseas on particular plant groups including specialist botanists from the plant's country of origin.

For potential, new and emerging weeds, the submission of specimens with field information is just as critical. Until an authoritative identification has been done by the Herbarium, new incursions (new weeds into the State) cannot be recorded as such. If the weed is new to Australia, support from the Federal Government for its eradication may be available but it relies first on correct identification.

The information submitted to the Herbarium also forms the basis of distribution maps that help to visually record the spread of an infestation. Maps are valuable in investigations to look at methods of spread and sources of new weeds. This distribution information then assists prioritisation given to the new weed and helps to formulate surveillance and management programs.

The important thing to remember is that until you are certain of the identity of a plant, don't pull it out assuming it is a weed just because you haven't seen it before. It may be a rare or threatened indigenous plant.

Practice makes perfect

To reinforce the recognition of weeds and their names, practice makes perfect. Think of novel ways of placing images of the weeds where you can look at them and practice their names. Place weed posters on the kitchen fridge, on the toilet wall, as a screen saver on your computer. Leave gardening or weed picture books on the coffee table and flick through them during the television add breaks each night. Take ten minutes one day a week to practice writing the botanical names out of the plants you have difficulty spelling. Recite the names of weeds while travelling or practice spotting them on roadsides and naming them.

Acknowledgments

I would like to thank all the people who have influenced my plant recognition skills over the years. My mother, Marian Blood, and her good friend Mary Richmond (both now deceased) taught me lots about indigenous and weed recognition from childhood. My sisters and family continue their lessons.

Denis Cox helped me learn many of the analogies that I still use today to help others learn about weeds. Many generous colleagues, such as David Cameron, Randall Robinson, Geoff Carr, John Hosking, Rod Randall, Sandy Lloyd, Barbara Waterhouse, Cindy Hanson, Ian Faithfull, David McLaren, Richard Groves and many others, continue to share their knowledge and skills. The staff at the National Herbarium of Victoria are also very generous and I appreciate all their assistance. Like a sponge, I soak up all they have to say.

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Identification of crop weeds

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Summary The correct identification of crop weeds, especially at the seedling stage of growth, has always been difficult. The early identification of crop weeds is important so that they can be controlled before reducing crop yields.

Techniques used to assist in the identification of important crop weeds, particularly at the seedling stage of growth, are shown. Some major crop weeds and the key identification features of each are discussed.

Keywords Crop weeds, identification.

Introduction

Weed control, a critical and costly part of producing crops, is becoming more and more complex with the increasing availability of new types of herbicides and new methods of application. In crop production weeds are most competitive early in the life of the crop. Therefore it is important to be able to recognise crop weeds at the seedling stage so that they can be sprayed at the most appropriate time with the most suitable herbicide and be controlled before seriously reducing crop yields.

Methods of identification

The correct identification of weed seedlings in crops and pastures has always been difficult. As the plant matures identifying features become more apparent. Identification is a lot more straightforward once the plant has produced flowers and/or seed pods. However, there are a few methods that can be used to make the identification of crop weed seedlings easier.

Local knowledge helps in building the weed spectrum that is to be found in your area. Many weed species grow together in situations where waterlogging, soil pH, soil texture and salinity are common. Use other weeds in the paddock to help in identification. Some examples of weed associations are listed below:

Acid soils prone to waterlogging over winter – capeweed, toad rush, loosestrife, phalaris, and crassula are common.

Lighter textured, acidic soils – capeweed, geraniums, sorrel, ryegrass and silvergrass.

Mallee alkaline sands – bromegrass, ryegrass, capeweed, caltrop, skeleton weed, and medics.

Wimmera grey clays – fumitory, dead nettle, rough poppy, muskweed, bedstraw and mustards.

Experience will help build on knowledge of commonly occurring weed associations. Use peers to assist in identifying weeds. Keep a record of the weeds found in each paddock and monitor them so that they do not get out of hand. Knowing what weeds are present in a paddock will allow for appropriate management strategies to be developed.

Close examination of a weed seedling will reveal a few key characteristics that can be used to help identify the plant. Once again experience and practice will help build a knowledge of the key characteristics of each species. The first step is to establish whether a plant is a narrow-leafed or a broad-leafed. Narrow leafed weeds have one cotyledon or seed leaf and the mature leaves are long, narrow and usually with parallel veins. Broad leafed weeds have two cotyledons and the leaves, unlike those of narrow leaved weeds, do not have parallel veins.

Narrow leafed weeds (monocotyledons)

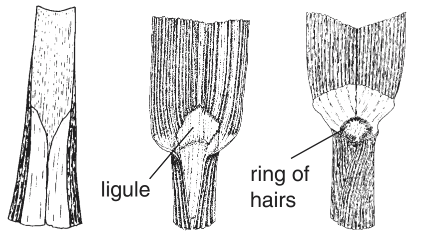
Narrow leafed weeds are very difficult to identify at the seedling stage. The majority of narrow leaved weeds in crops are grasses, parts of the grass plant are shown in Figure 1.

Identifying characteristics of narrow leafed weeds

The most useful characteristics to look for are :

Seeds Weed seeds have characteristic sizes and shapes. It is sometimes useful to pull up the seedling to inspect the remains of the seed as an aid to identification. This is particularly important with help in distinguishing between grasses.

Ligule (structure at summit of sheath) Is it present or absent? If present, is it a membrane or a ring of hairs and what is its length?



ligule absent | ligule present | ligule replaced by ring of hairs

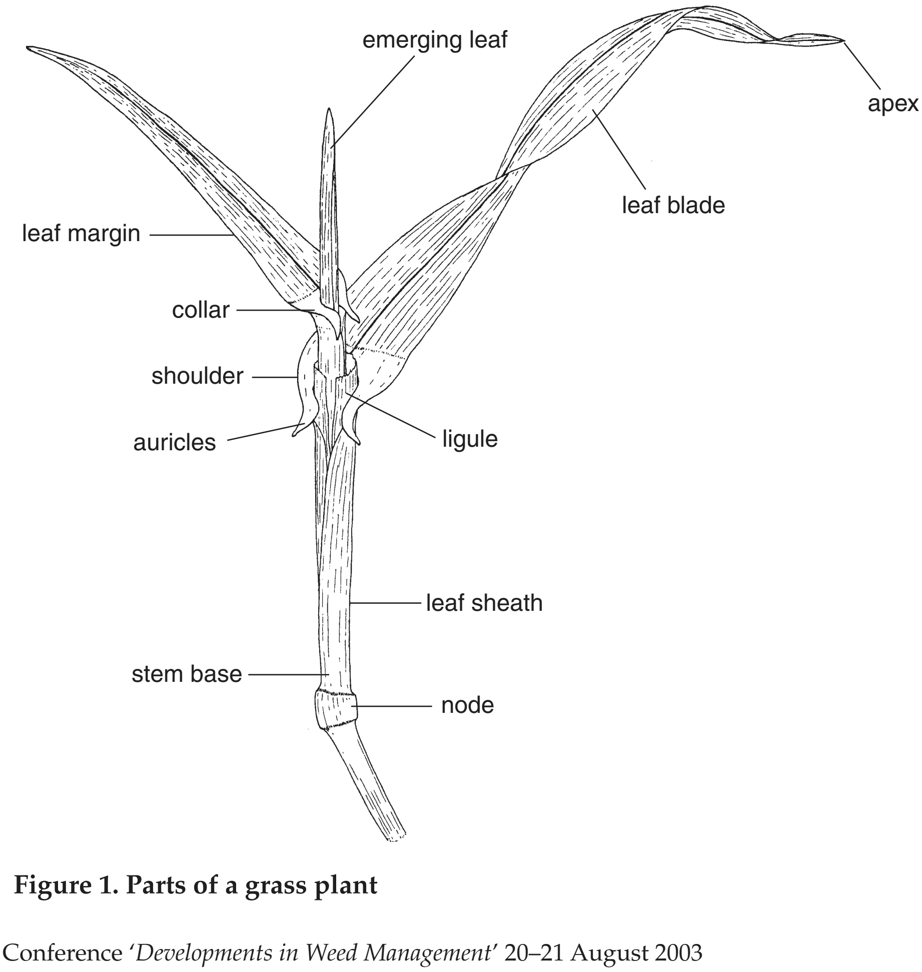
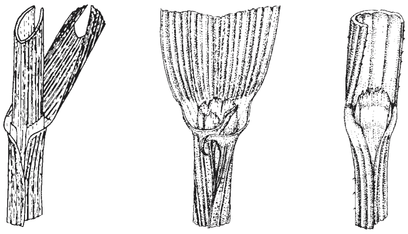
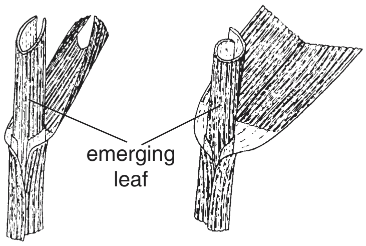


Figure 1. Parts of a grass plant

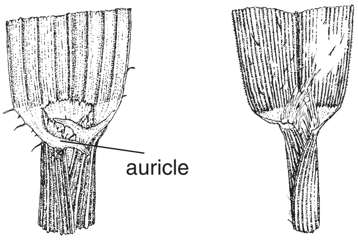
Leaf blade Is it folded, flat or the edges rolled in?



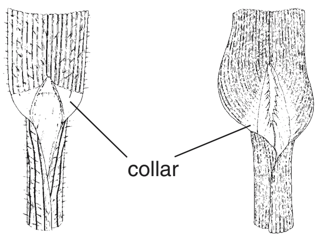
Emerging leaf (youngest leaf) Is it folded or rolled?



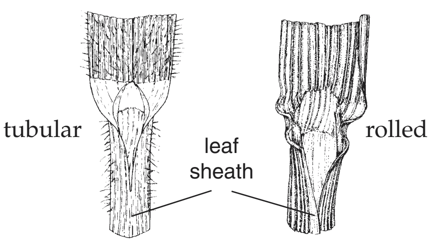
Auricles (claw-like teeth at the base of the leaf) Are they present or absent? How long are they and are they hairy?



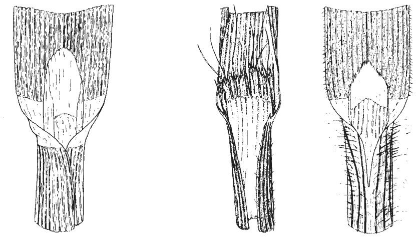
Collar (base of the leaf blade behind the ligule) Is it prominent (different in colour from the leaf blade) or not prominent (not greatly different from the colour and texture of the leaf blade)?



Leaf sheath (part of the leaf surrounding the stem) Is it tubular (no joins) or rolled for some of its length (overlaps)?

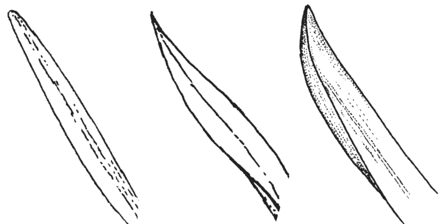


Hairs Are they present? What position, density, length and direction are they?



Stem base What is the colour of the stem? Does it bleed when squashed with a finger nail?

Leaf blade apex Is it blunt, pointed or hooded (boat shaped)?



Broad leafed weeds (dicotyledons)

Parts of a broad leafed weed are shown in Figure 2. Some plants, such as legumes, have characteristic stipules (a pair of leafy or scaly appendages at the junction of the stem and petiole (Figure 3).

The leaves may be in rosettes (when the stems are very short and the leaves emerge from the base), opposite (in equal sized pairs), alternate (growing individually one after the other and of different sizes), or in whorls (growing from a central point around the stem) (Figure 4).

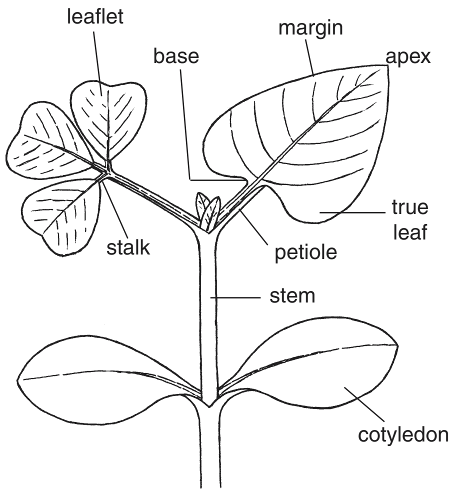


Figure 2. Parts of a broad leafed weed

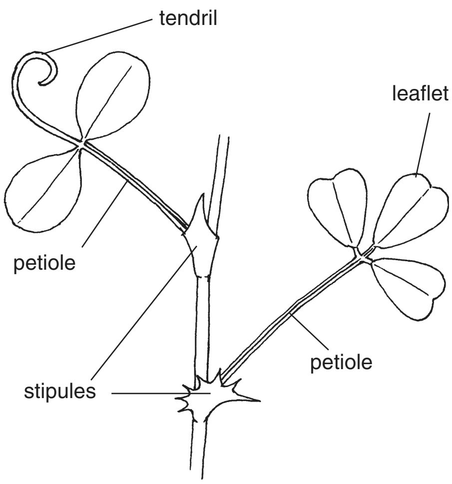


Figure 3. Parts of a legume leaf

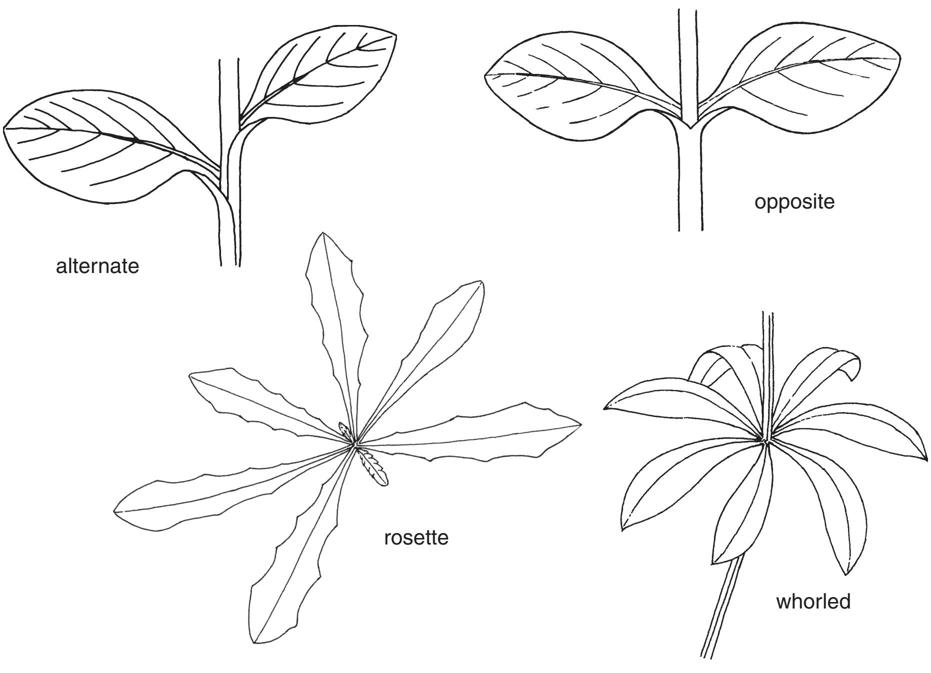


Figure 4. Leaf arrangements

The most useful identification characteristics of the cotyledons, first leaves and mature leaves are:

Shape The shape and size of the leaf including the apex, base and margin. Illustrations of differing cotyledon and leaf shapes, margins and bases are shown in Figures 5, 6, 7 and 8.

Hairs The distribution of hairs is very useful for plant identification. They may occur on the upper and/or lower surface, margin or veins of leaves and/or cotyledons, the petiole and stem of the plant. The length (short or long), density (sparse or dense) and texture (stiff or woolly) of hairs are also important distinguishing features.

Leaf surface structure and colour The texture of the leaf surface can be described as smooth, wrinkled, warty, pimply, glossy, frosted ,dull or succulent. The colour of the leaf surface and stem can aid in identification. However, the colour of plant parts may vary depending on environmental conditions.

Leaf markings The colour (white, red, purple, pinkish) and shape (irregular, spots, crescent) and position (scattered, basal, upper surface , lower surface) of leaf markings can be an important identification aid. Although, leaf markings can vary between species and across environments.

Venation Veins on the cotyledon and leaves can be prominent or not prominent. Prominent veins are clearly visible, veins which are not prominent need to be looked for closely. Veins may form an

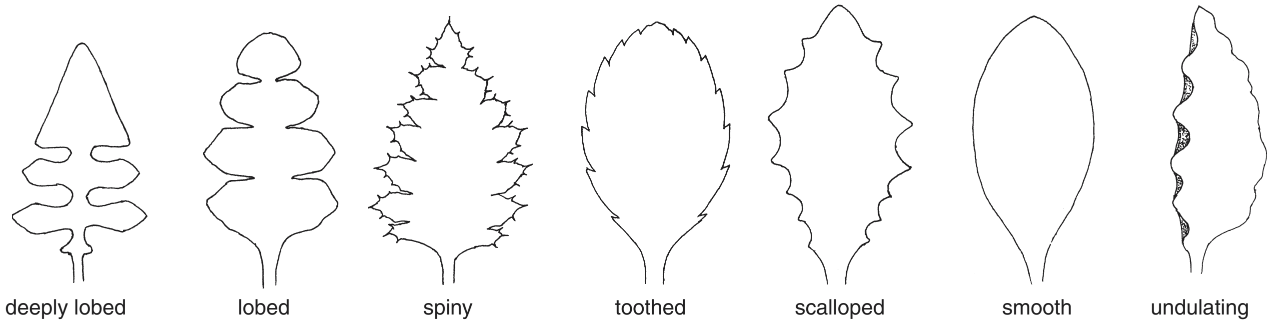


Figure 5. Margin shapes

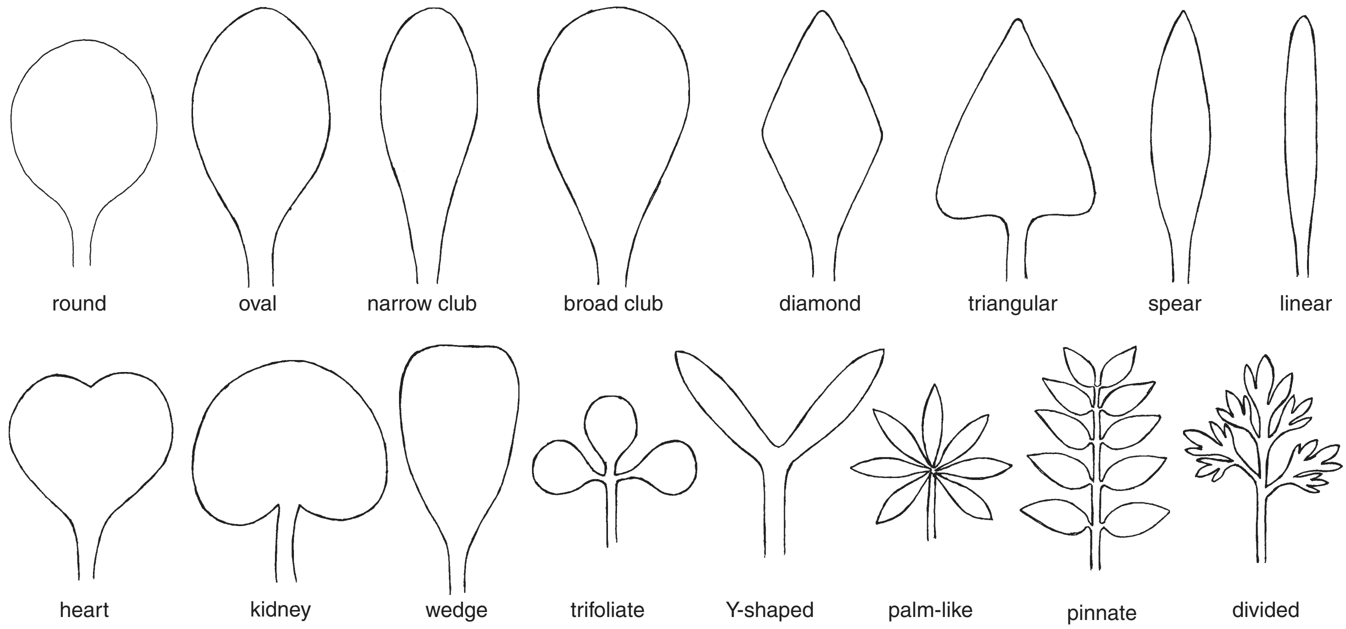


Figure 6. Leaf shapes

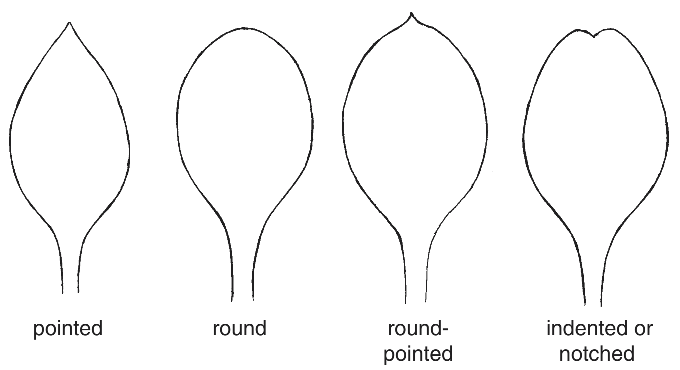


Figure 7. Apex shapes

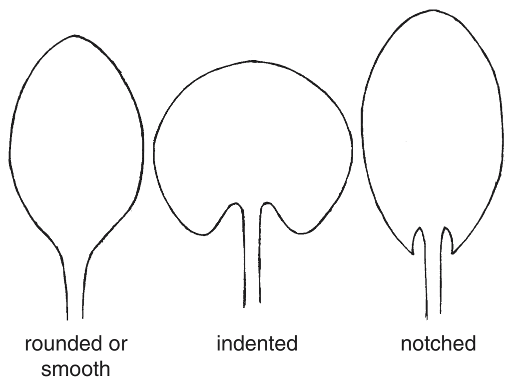


Figure 8. Base shapes

almost parallel pattern or be many branched or web-like (Figure 9).

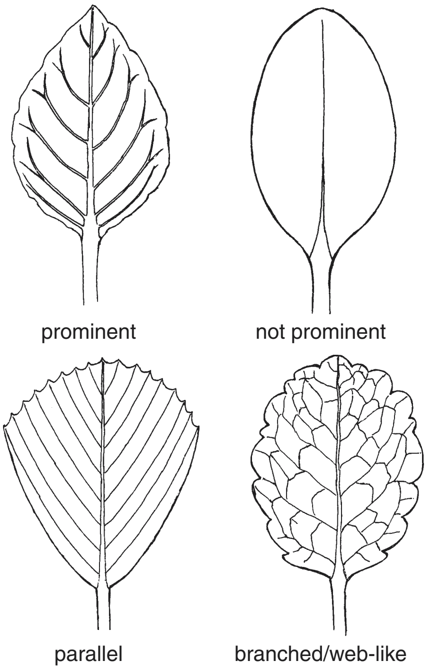


Figure 9. Venation types

Important crop weeds

Wild oat (*Avena fatua* L. POACEAE)
Autumn–winter germinating annual.

Key characteristics: Plants have few scattered hairs on leaf blade. Auricles absent. Ligule is a membrane. Leaf sheath rolled/overlaps. Dark seeds with gold/brown hairs.

Mature plant: Erect, up to 1.7 m, wild oat, oats and bearded oats are difficult to distinguish without the seed present. The spikelets of wild oat droop to both sides of stem, not to one side as in bearded oat. The seed of bearded oat have long pale hairs compared to the gold/brown of wild oat.

Great brome (*Bromus diandrus* Roth POACEAE)
Autumn–winter germinating annual.

Key characteristics: Plants hairy. Leaf sheath tubular, prominent purple stripes on leaf sheath. Long hairs on leaf blade margin.

Mature plant: Erect, up to 90 cm, hairy. Leaf sheath tubular (this is a characteristic of all *Bromus* species). Seed spikelets are sharp and can cause injury.

Barley grass (*Hordeum leporinum* Link POACEAE)
Autumn–winter germinating annual.

Key characteristics: Plants have few soft hairs. Auricles present. Leaf sheath rolled/overlaps. Seeds with multiple awns.

Mature plant: Erect, up to 45 cm, leaves have soft hairs. Seed spikelets are sharp and can cause injury.

Wimmera ryegrass (*Lolium rigidum* Gaudin POACEAE)
Autumn–winter germinating annual.

Key characteristics: Hairless. Base of plant is red. Ligule present as a membrane. Back of leaf is very shiny. Auricles present in older plants but absent at small stage. Emerging leaf rolled.

Mature plant: Erect, up to 90 cm, shiny hairless leaves. Stems hairless and reddish purple towards base. Spikelets are three to nine flowered.

Capeweed (*Arctotheca calendula* (L.) Levyns ASTERACEAE)
Autumn–winter germinating annual.

Cotyledons: Club shaped, apex round, hairless

First leaves: Spear shaped and deeply lobed, apex round. First two leaves grow as a pair, later leaves singly: white hairs on upper surface and lower surface covered with matted web of hairs that appears white.

Mature plant: Stemless, prostrate, up to 50 cm diameter. Leaves in rosette at the base, serrated and deeply lobed, apex pointed, hairy on upper surface and white mat of hairs on lower surface. Yellow flowers with black centre. Seeds covered with pink-brown woolly hairs.

Prickly lettuce (*Lactuca serriola* L. ASTERACEAE) Autumn or spring germinating annual or biennial.

Cotyledons: Club shaped, apex slightly indented, very small hairs scattered on upper surface and petiole.

First leaves: Club-shaped, apex rounded, margin toothed, very small hairs scattered on upper leaf surface, margin and petiole.

Mature plant: Erect up 1.5 m. Leaves alternate, deeply lobed, apex pointed, spines on margin and underside of midrib. Stem stiff and spiny. When broken exudes a sticky white sap. Leaves often aligned a north-south direction. Frequently found on fallows.

Paterson's curse (*Echium plantagineum* L. BORAGINACEAE)
Autumn–winter germinating annual.

Cotyledons: Oval, apex rounded, short hairs.

First leaves: Oval, apex pointed, longish hairs.

Mature plant: Erect up to 1 m. Rosette leaves oval, apex round, short petiole: stem leave narrow almost triangular, stem clasping, apex round. Leaves and stem hairy. Stems branched. Purple trumpet-shaped flowers.

Wild radish (*Raphanus raphanistrum* L. BRASSICACEAE) Autumn–winter germinating annual.

Cotyledons: Heart shaped hairless

First leaves: Oval, apex round, margin toothed and sometimes lobed, veins prominent, short stiff hairs, rough to touch.

Mature plant: Erect up to 50 cm. Basal leaves form rosette. Deeply lobed, margin toothed, short stiff hairs. Stems branched, lower parts have short stiff hairs. Pale yellow, white or lilac flowers with dark veins: fruit a long tapered pod, breaking into three to nine segments when ripe.

Indian hedge mustard (*Sisymbrium orientale* L. BRASSICACEAE)
Autumn–winter germinating annual.

Cotyledons: Oval, apex slightly indented, hairless.

First leaves: Oval, apex slightly pointed, margin toothed, few hairs.

Mature plant: Erect, up to 80 cm. Young plant forms rosette: basal leaves deeply lobed, pointed. Upper leaves alternate, spear shaped. Stem woody, many branched, few hairs on lower leaves and stem. Flowers yellow. Frequently found on fallows.

Fumitory (*Fumaria parviflora* Lam. FUMARIACEAE)
Autumn–winter germinating annual.

Cotyledons: Spear-shaped, apex pointed. Hairless.

First leaves: Divided, leaflets deeply lobed, hairless, dull blue-green leaves. Stem reddish.

Mature plant: Semi-erect up to 25 cm high. Leaves alternate, divided, deeply lobed, hairless. Stems many branched, soft, five-sided, hairless. White flowers with dark red or purple tips, fruit a nut-like capsule. Frequently found on fallows.

Hogweed (*Polygonum aviculare* L. POLYGONACEAE) Autumn–winter germinating annual or biennial.

Cotyledons: spear-shaped, apex pointed but not sharp, hairless, 7 mm long.

First leaves: Spear-shaped, apex pointed, stem is a pinkish-white colour.

Mature plant: Prostrate, stems up to 1 m long. Leaves alternate, oval, apex pointed, hairless. Stipule pointed and toothed. Stem tough and wiry with longitudinal grooves, hairless. White flowers. Frequently found on fallows.

Acknowledgments

Much of the text has been used from Michael Moerkerk's workshop notes and from *Crop Weeds* and *More Crop Weeds*.

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How to discover new weeds using *Oxalis* to trace sources of infections

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Summary The genus *Oxalis* is used as an example to test the theory that it is possible to trace the sources of known and potential weed species and that the sources of these species can provide insight into where to 'discover' new weeds.

Of the 102 species of introduced *Oxalis* recorded in Australia only five could not be traced back to a source associated with deliberate cultivation, namely commercial nurseries or private collectors. Of these five species, two are pan-tropical weeds of cultivation and two are of doubtful taxonomic status and potentially native.

Ninety-nine percent of introduced *Oxalis* taxa could be traced to a specific address within Australia and several traceable to their country of origin. Ongoing commercial and non-commercial domestic and international exchange of Oxalis species was found to be carried out despite Federal quarantine regulations, state and local laws.

A list of all known introduced Oxalis species is presented as well as a partial list of commercial growers of Oxalis in Australia.

The use of searches using literature, nursery catalogs and the internet are proposed for a range of families and genera containing known weed species as a means of 'discovering new weeds'.

Keywords Oxalis, weed, Australia, nurseries, quarantine.

Introduction

Before the development of predictive modeling, most 'discoveries' of new weeds were accidental, and in many respects this remains the case. Recent advances in information management including databases such as *A Global Compendium of Weeds* (Randall 2002), allow anyone armed with the scientific name of a plant and access to the internet to make rudimentary predictions of the weed potential of a plant. The example of *Nassella tenuissima* (Craw 2002) clearly illustrates how predictive modeling coupled with existing databases allow for the timely 'discovery', intervention and eradication to prevent a potentially serious weed from establishing in Australia.

Despite technological advances, weed 'discovery' remains largely relegated to the realm of chance. The active systematic pursuit of potential weed species has yet to be carried out. The establishment of a network of 'weed spotters' by the Victorian Department of Primary Industries (Blood 2002) represents the desire to actively pursue weeds. However, the question remains; 'Where do we look for new weeds?'

The principle of locating the point source of infection, so commonly utilized in on-ground weed control programs and tracing of diseases in the medical profession, may provide a potential model for 'discovery' of new weeds on a local, regional, state, national and international scale.

Materials and methods

To test the theory that it was possible to trace an infection back to a point source, a suitable example was needed. The genus *Oxalis* was selected as suitable.

The genus *Oxalis* contains approximately 800 species of mostly herbaceous plants (Thompson 1982). Several species of *Oxalis* are well known as difficult to control weeds of horticulture, the environment and agricultural crops, most notably *Oxalis corniculata* s.l., *O. pes-caprae,* and *O. purpurea* (Peirce 1998). The popularity of *Oxalis* as a garden plant has been limited in the past due to its perception as a weedy genus. Recent reappraisal of the genus by some avid plant collectors has resulted in Oxalis becoming more widely grown. The newfound popularity of Oxalis is evidenced by the formation, in April 2003, of an international internet society devoted to its horticultural appreciation, growth and promotion. Recent additions of introduced Oxalis species to the census of Vascular Plants in Victoria (2003) indicate a rise in naturalizations.

A literature and internet search was carried out to establish which taxa of Oxalis presently existed within Australia and where these taxa were located. Additional physical searches of several nurseries in the Melbourne area were also carried out. Naturalizations of *Oxalis* were determined using Ross and Walsh (2003), The Australian Plant Name Index (2003) and Shepherd *et al.* (2001). Suppliers, their plants and addresses were sourced from *The Aussie Plant Finder 1999/2000* (Hibbert).

The general term 'Taxa' has been used throughout the text and includes species, subspecies, varieties, forms and cultivars.

Results

A total of 102 introduced taxa of *Oxalis*, representing 72 species, are recorded as being found in Australia. Ninety-seven (99%) of these taxa are cultivated. Forty-six taxa (47%) are available commercially. The number of commercially available taxa may be as high as 70 if unconfirmed reports are true and may contain species not identified in this study. Twenty-seven percent of all introduced taxa are recorded as naturalized. An additional 14 taxa (14%) presently cultivated in Australia are listed as being naturalized worldwide.

The 97 taxa of *Oxalis* taxa identified as cultivated could be traced to a specific address within Australia. Forty species (41%) were traced to just two growers, one in Tasmania, the other in the ACT.

Discussion

Tracing the sources of *Oxalis* in Australia proved useful and provides a list of introduced species. Although time and physical constraints on the author limited the search a large number of taxa were found. More specifically, growers were located, with addresses, for nearly all of the taxa. This study allows future researchers to actively investigate and assess individual taxa but more importantly indicates specific points to begin physical searches.

A society devoted to the growing of *Oxalis* species and cultivars was located on the internet (The *Oxalis* Growers group http://groups.yahoo.com/group/Oxalis-growers). The slogan for this group is 'For those people interested in the cultivation rather than eradication of these plants, worldwide'. The moderator of the *Oxalis*-growers group has a personal web site at http://www.oxalis.50megs.com/. The *Oxalis*-growers group was formed on the 30th April 2003, but as of the 17th July 2003 had thirty members. Although some collectors and their collections of oxalis were sourced through this web site their addresses were not included in the list of growers that follows.

Messages contained on the web site of the Oxalis-growers group clearly tell of illegal transportation of *Oxalis* corms between a grower in the ACT (Australia) and Palmerston North (NZ). Travel logs showing the route taken by one grower on his travels around south-eastern Australia include visits to other collectors. This type of information clearly indicates specific points and potential stops on the way where 'new weed discoveries' could take place.

Lack of clarity and consistency in the use of names in *Oxalis* has lead to considerable confusion as to exactly what taxa are present. All names in italics in Table 1 represent presently accepted names. Plant names in brackets represent how the names of *Oxalis* appeared in growers'

Table 1. List of *Oxalis* species recorded for Australia (1 – Naturalized species, 2 – Listed in *A Global Compendium of Weeds* (Randall 2002), 3 – Commercially available species, 4 – Cultivated species)

Oxalis	1	2	3	4
acetocella L.		*		*
adenodes Sond.				*
apodiscias Turcz.	*			
articulata Savigny	*	*	*	*
barrelieri L.		*		*
bifurca Lodd.	*	*		*
bowiei Herb. ex Lindl	*	*	*	*
'Giant Form'			*	*
brasiliensis G.Lodd.	*	*	*	*
caprina L.		*		*
ciliaris Jacq.				*
compressa L.f.	*	*		*
convexula Jacq.				*
corniculata L.	*	*		*
crassicaulis Zucc.				*
crenata Jacq.	*			*
debilis var *corymbosa* Kunth (DC.) Lourteig	*	*	*	*
'Aureoreticulata'			*	*
depressa Eckl. & Zeyh		*	*	*
eckloniana Salter				*
var. *sonderiana* Salter (C. Presl)				*
enneaphylla Cav.				*
fabaefolia Jacq.			*	*
flava L.	*	*	*	*
'yellow form'				*
'lilac form'				*
frutescens L.				*
furcillata Salter.			*	*
glabra Thunb.	*	*	*	*
gracilis Eckl. & Zeyh.			*	*
hedysaroides Kunth				*
'rubra'			*	*
helicoides Salter				*
herrarae Knuth				*
hirta L.	*	*	*	*
'deep pink'				*
'rosea'			*	*
'rosea compacta'			*	*
'salmon form'			*	*
incarnata L.	*	*	*	*
imbricata Eckl. & Zeyh.			*	*
kamiesbergensis Salter				*
latifolia Kunth	*	*		*
luteola Jacq.		*		*
magellanica (*lactea*) G.Forst.	*	*		*
'flore pleno'			*	*
'Nelson'			*	*
mallobolba Cav.	*	*		
massoniana Salter			*	*
megalorrhiza (*carnosa*) Jacq.		*	*	*
melanosticta Sonder			*	*
namaquana Sonder				*
obtusa Jacq.	*	*	*	*
orbicularis Salter				*
orthodopa Salter				*
palmifrons Salter				*
pardalis Sond.				*
perdicaria (*lobata*) (Molina) Bertero		*	*	*
'double form'			*	*
'lobata'				*
pes-caprae L.	*	*		*
'double form'			*	*
phloxidiflora Schlechter				*
plicata ?				*
plumieri Jacq.				*
polyphylla Jacq.	*	*		*
var. *pentaphylla* Jacq. (Salter)	*	*		*
var. *heptophylla* Jacq. (Salter)		*		*
purpurata Jacq.		*	*	*
purpurea				
(*variabilis*) L.	*	*	*	*
'alba'				*
'Giant White'			*	*
'Giant Pink'			*	*
'Ken Aslet'			*	*
'Nigrescens'				*
'Pale Pink'			*	*
'Purple Leaves'				*
ssp. *purpurea*				*
'silver leaf'			*	*
'white'				*
regnellii Miq.			*	*
rubra (*rosea*) A. St. Hil.		*	*	*
semiloba Sond.		*		*
sp. aff. *exilis*				
(glabrescent) *sensu* G.W Carr	*			
stricta L.		*		*
succulenta Barn.			*	*
tenella 'alba' Jacq.				*
tenuifolia Jacq				*
tetraphylla (*deppei*) Cav.	*	*	*	*
'Iron Cross'			*	*
tompsoniae B.J. Conn and Richards	*	*		
triangularis A. St. Hil.			*	*
truncatulata Jacq.				*
tuberosa Molina		*	*	*
'Red'			*	*
'Gold'			*	*
vallicola (Rose). Knuth	*	*		
valdiviensis Bernard			*	*
versicolor L.	*	*	*	*
violacea L.		*		*
zeyheri Sond				*
zeekoevleyensis Knuth.				*

lists. *Oxalis magellanica* although native to Australia is represented in horticulture by forms introduced from New Zealand.

Many genera known to contain weedy species are presently cultivated and sold in Australia. Searches similar to that carried out for *Oxalis* may prove as useful in clarifying what species are present and the location of these species. Preliminary searches on several other genera and families gave interesting results. Some of these genera and families included *Allium*, *Artemisia*, *Buddleia*, *Carex*, *Cyanella*, *Echium*, *Erica*, *Geranium*, *Oenothera*, *Pelargonium*, *Poaceae*, *Salvia*, South African Iridaceae (*Babiana*, *Ferarria*, *Freesia*, *Gladiolus*, *Ixia*, *Moraea* and *Romulea*), and *Viola*. All the families and genera listed above have collectors in Australia with several, most notably *Ixia*, South African Iridaceae, *Salvia* and *Viola*, having particularly dedicated collectors with notable collections.

The question of 'How to discover new weeds?' may in part be answered by careful examination of the literature, catalogs of nurseries and the internet. These purposeful searches can lead us to discover the 'Point Sources of Infection' but also to quantify the problem.

This study, from start to finish, took exactly 32 hours. The results indicate that there are a small number of point sources of infection. There are relatively few commercial and private growers for the majority of taxa. It may prove cost effective to individually approach the growers and develop working relationships with them so that they may be included in the process of assessment and, if needs be, eradication of specific taxa.

This study raises questions about the effectiveness of current legislation regarding quarantine and movement of plants into and out of Australia and between the states and territories. It also points to possible points to initiate investigations into illegal activities.

Acknowledgments

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Table 2. Commercial growers of *Oxalis* in Australia

Al-Ru Farm Nursery
PO Box 270
One Tree Hill, SA 5114
Phone: (08) 8280 7353
(Mail order)

Berrima Lavender Farm
15-17 Market Place
Berrima, NSW 2577
Phone: (02) 4877 1329
(Mail order)

Blyth Cottage Gardens
326 East Derwent Highway
Gellston Bay, Tas 7015
Phone: (03) 6243 5660
(Mail order)

Coffield's Nursery
Lot 40E Daylesford Road
Creswick, Vic 3363
Phone: (03) 5345 2268
(Mail order)

Daley's Fruit Tree Nursery
PO Box 154
Kyogle, NSW 2474
Phone: (02) 6632 1441

Dicksonia Rare Plants
646 Mt. Macedon Road
Mt. Macedon, Vic 3441
Phone (03) 5426 3075

Garry and Sue Reid
RMB 6270
Via Wodonga, Vic 3691
Phone: (02) 6027 1514
(Mail order)

Gordon Julian (Oxalis specialist, 70 species)
PO Box 264
Deloraine, Tas 7304
Phone: (03) 6362 4099
(Mail order)

Forrest Bulbs and Seeds
5 Forrest Street
South Geelong, Vic 3220
Phone: (03) 5229 1667
(Mail order)

Glenbrook Bulb Farm
28 Russell Road
Claremont Tas 7011
(Mail order)

Larkman Nurseries Pty. Ltd.
7 Jurat Road
Lilydale, Vic 3140
Phone: (03) 9735 3831

Leo Cady
5 Weir Street
Kiama, NSW 2533
Phone (02) 4232 2188

Merry Garth
Davies Lane
Mount Wilson, NSW 2786
Phone (02) 4756 2121

New Gippsland Seeds and Bulbs
Queens Road
Silvan, Vic 3795
Phone: (03) 9737 9560
(Mail order)

Nutshell Perennial Nursery
'Softhaven'
Campbell Street
Newbridge, NSW 2795
Phone (02) 6368 1035
Email: nutshellperennials@ix.net.au
(Mail order)

Perennial Charm Nursery
Hoopers Road
Barmah, Vic 3639
Phone: (03) 5869 3227

Windy Hollow Nursery
2 Cooks Road
Fish Creek, Vic 3959
Phone: (03) 5683 2343

Woodbank Nursery
2040 Huon Road
Longley, Tas 7150
Phone: (03) 6239 6452

Weed Alert Rapid Response performance, results and what can be achieved

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Summary The Weed Alert Rapid Response (WARR) program has been up and running since January 2002. The program is managed by the Department of Sustainability and Environment (DSE), and Department of Primary Industries (DPI).

The main aim of the WARR program is to prevent the establishment of serious new weeds in Victoria, and eradicate priority species where feasible.

Keywords Weed alert rapid response, weed incursion.

Progress to date

WARR Plan Victoria A draft 'Weed Alert Rapid Response Plan Victoria: A surveillance and response plan for potential, new and emerging weeds in Victoria' has been developed. The plan details the requirements for preparedness, surveillance, collection, identification, assessment and response to these weeds and ensures the timely implementation of effective management measures for the protection of Victorian environments and industries and other social values. The plan is being used as a national model for a weed incursion management guide by the CRC for Australian Weed Management.

Statewide positions Three Statewide positions have been appointed: Project Leader WARR, Implementation Officer WARR, and Weed Compliance Officer. Five Regional Coordinators WARR have been nominated to coordinate surveillance and on-ground response to potential and new weeds at the regional level. The training of some of these staff has been initiated with more planned.

Weed Spotters There are now almost 290 registered Weed Spotters who will be asked to look for and report targeted potential, new and emerging weeds. They will be trained in the collection and submission of weed specimens and field information. Weed Spotters receive the 'Under Control' newsletter including WARR information and are subscribed to an email discussion group.

Weed identification services Priority weed identification services have been established with the National Herbarium of Victoria. All specimens submitted as part of the WARR program have been identified and lodged promptly.

Information management Records of all new incursions (either commercial, garden, agricultural or environmental) are being recorded on the Integrated Pest Management Information System (IPMS) by DPI and DSE. Registry files have been established to store all hard copy information. The National Herbarium of Victoria records all specimens on their database.

Relationships to other programs and agencies Within DPI and DSE, WARR links with programs including the Pest Plant Distribution Prevention Strategy, the Pest Plant Impact Assessment program, the Pest Plant Communication Strategy, Weedbuster Week, the Dirty Half Dozen project, and others. Links are being strengthened with Water Watch, and Land for Wildlife. Formal links have been established with Parks Victoria and the National Herbarium of Victoria.

Other influences

New noxious weeds In May 2003, an additional ten State Prohibited Noxious Weeds were proclaimed by the Victorian Government under the *Catchment and Land Protection Act* 1994. All are target weeds under the WARR program. They are all under surveillance and some are targeted for eradication where they are naturalised in the State.

Incursion management

A number of new weeds have been identified in Victoria and more are being investigated. Some of the new and existing weeds being managed by the WARR Team include:

Environmental incursions The plant is established in a natural ecosystem in Victoria when it is prohibited entry to Australia or has not been assessed by AQIS and/or is prohibited entry to Victoria by the CaLP Act 1994 and/or is considered a serious threat to Victoria's economy, environment or society:

- *Erica versicolor*, shrub: on private property near Grampians National Park, western Victoria. New record for Australia.
- *Erica glandulosa*, shrub: on private property near Grampians National Park, Western Victoria. New record for Victoria.
- *Hypericum canariense*, Canary Island St. John's wort, shrub: on public land at Flinders, and roadside at Drysdale.
- *Hieracium aurantiacum*, orange hawkweed, herb: Falls Creek.
- *Centaurea montana*, perennial cornflower, herb: Falls Creek. New record for Australia.
- *Cytisus multiflorus*, white Spanish broom, shrub: Creswick.

Commercial incursions The plant is available commercially or is traded or is exhibited in Victoria when it is prohibited entry to Australia or has not been assessed by AQIS and/or is prohibited entry to Victoria by the CaLP Act 1994 and/or is considered a serious threat to Victoria's economy, environment or society:

- *Equisetum* species, horsetail, herb: sold and grown in numerous outlets.
- *Hieracium pilosella*, mouse ear, herb: Glenthompson and others.
- *Hieracium aurantiacum*, orange hawkweed, herb: Lara and others.

Agricultural incursions The plant is established in an agricultural system (e.g. cropping or pasture) in Victoria when it is prohibited entry to Australia or has not been assessed by AQIS and/or is prohibited entry to Victoria by the CaLP Act 1994 and/or is considered a serious threat to Victoria's economy, environment or society:

- *Nassella charruana*, lobed needle grass, grass: Epping.

Garden incursions The plant is established in a private, public or commercial garden in Victoria when it is prohibited entry to Australia or has not been assessed by AQIS and/or is prohibited entry to Victoria by the CaLP Act 1994 and/or is considered a serious threat to Victoria's economy, environment or society

- *Acacia karroo*, karroo thorn, tree: Melbourne Zoo, Victoria's Open Range Zoo at Werribee, Royal Botanic Gardens Melbourne.
- *Nassella tenuissima*, Mexican feather grass, grass: private garden at Frankston, nursery grounds at Dromana.
- *Equisetum* species, horsetail, herb: Geelong Botanic Gardens, Mt. Macedon, Bulleen, Dromana, Richmond, Pt. Henry.
- *Hieracium pilosella*, mouse ear, herb: Geelong Botanic Gardens, various Beaufort gardens, Glenthompson.
- *Hieracium aurantiacum*, orange hawkweed, herb: Falls Creek.
- *Fallopia japonica* var. *compacta*, Japanese knotweed, herb: Falls Creek.
- *Fallopia japonica*, Japanese knotweed, herb: Bulleen.
- *Fallopia sachalinensis*, giant knotweed, herb/shrub: Foster, Narbethong.

Acknowledgments

Thanks to the WARR Team members and participants, Weed Spotters, DPI/DSE staff and interstate and overseas colleagues for sharing information.

The attributes for weediness and weed prediction locally and Victoria wide

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Summary All land managers have to deal with weeds, often with limited funds. Victoria has just over 1200 naturalised introduced plant species or weeds, a total of 25% of its flora. Land managers need to identify the present and future priority weeds so that resources can be focused on them. A generic prioritisation process or ranking system is required that can be used locally, regionally or statewide. This paper describes the process by which Victoria's present and future noxious weeds are been assessed.

Keywords Weed risk assessment, prioritisation, decision support system.

Introduction

Despite the large amounts of time and money that have been spent by private and public land managers over many years, weeds are still one of the major land degradation problems. Further, there is the risk that existing weed infestations will spread within the country and that other weeds, not currently found here, will cause serious damage if they are introduced from other countries. It is unrealistic and unnecessary to expect that all weeds can and should be controlled. Williamson and Fitter (1996) estimated that only approximately ten percent of naturalised plant species become weeds of significant economic and ecological impact.

It is also unrealistic to expect the community or government to be able to eradicate all weeds in the country, given the enormous costs involved. Control programs have to be targeted to priority weeds (those that are or have the potential to impact on high social, environmental or agricultural values).

Management of weeds is principally the responsibility of each land manager. Land managers are usually motivated to control those weeds having an obvious impact on their use of the land. This generally occurs when numbers and impact are already high (at the right end of the Figure 1). The costs of control may then become an ongoing land management investment. By contrast, government intervention is most effective in preventing the impact of weeds reaching this level, that is, intervention is most effective when weed numbers are low and infestations are few.

To make informed decisions about the best way to control weeds on public and agricultural land, it is necessary that the relative importance and potential impact of each species be determined prior to the allocation of priority works or funding.

Weed Risk Assessment (WRA) has predominantly concentrated on the biological properties of a weed that make it invasive. However the invasive component of a weed is only one component of a WRA. If we want to determine or prioritise weeds an assessment must take into account the impact of the weed on social, environmental and agricultural values (or resource conditions). As these values change depending upon the land managers involved, the scale of the assessment (national, state, catchment or local level) has to be adaptable to account for these differences.

The three major components in predicting weed status are:

1. Assessing the plant's invasiveness,
2. Its current and potential distribution and
3. Impacts of the plant on land use and ecosystems.

The decision making process may also include:

- The value of threatened ecosystems, and
- The feasibility of successful control.

All plants are invasive to some extent. That is they all have strategies to enable themselves to establish, grow, compete for resources, produce propagules and disperse. If they were not able to do this they would become extinct very quickly. However what we call 'weeds' tend to be more invasive than others for a variety of reasons. Each species has their own particular method for ensuring its survival and future. Some may rely on mass propagule production, others on long lived seeds, while others use allelopathy to reduce competition. The difficult issue is to develop a standard or generic process so that the large number of weeds can be assessed and compared.

Materials and methods

Victoria (Weiss and McLaren 2002) has developed a risk assessment process that can work independently or utilises a GIS based system to determine resource conditions and then the risk or threat that weeds pose to these values.

This Decision Support System (DSS) is an Expert System relying on multi-criteria analysis/analytical hierarchical process (AHP). The AHP is a method that assists with decisions about priorities using qualitative and/or quantitative information. AHP 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 synthesising the judgements to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. AHP also provides an effective structure for group decision making by imposing a discipline on the group's thought processes.

Results

Two workshops in June 1998 decided on a set of criteria to assess the biological

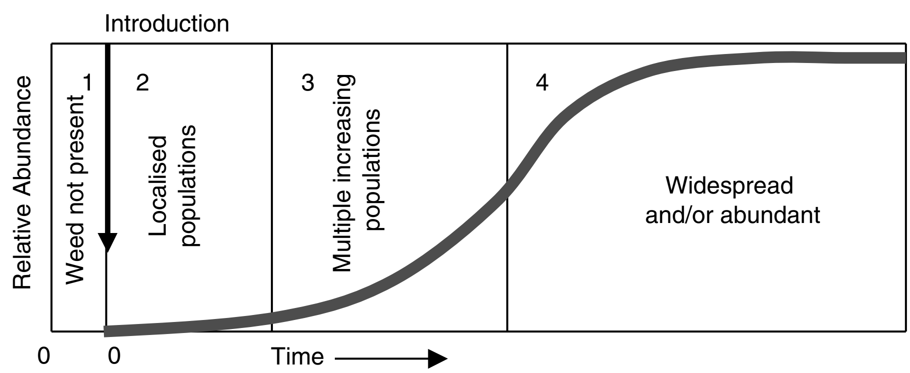

Figure 1. Four generalised phases of a plant invasion (after Hobbs and Humphries 1995)

properties of a plant to indicate its potential to be an invasive weed. The main criteria and groups are shown below.

Criteria to assess potential as an invasive weed

Establishment

Germination requirements?
Establishment requirement?
How much disturbance required?

Growth/competitive ability

Life form?
Allelopathic properties?
Tolerates herbivory pressure?
Normal growth rate?
Stress tolerance?

Reproduction

Reproductive system?
Number of propagules produced?
Seed longevity?
Reproductive period?
Time to reach reproductive maturity?

Dispersal

Number of mechanisms?
How far do propagules disperse?

Further workshops in 2002 and 2003 identified criteria to assess impact potential on social, agricultural and environmental values. These are shown below:

Social values

- To what extent could the weed restrict human access?
- To what level could this weed reduce the 'tourism/aesthetics/recreational use of the land?
- To what level is the plant injurious, toxic, or spines affect people?
- How much damage is done to indigenous or European cultural sites?

Natural resources

- To what extent could this weed impact on water flow within watercourses or waterbodies?
- To what extent could the weed impact on water quality (i.e. dissolved 0_2, water temperature)?
- To what extent could the weed increase soil erosion?
- To what extent could this weed reduce the biomass of the community? (NB. biomass acting as a carbon sink).
- To what extent could the weed change the frequency or intensity of fires?

Fauna and flora/vegetation

- To what extent could this weed impact on the vegetation composition on the following:
  - a. High value vegetation
  - b. Medium value vegetation
  - c. Low value vegetation
- To what extent could this weed effect the structure of a vegetation community?
- What effect could the weed have on threatened flora spp.?

Threatened flora and fauna

- What effect could the weed have on threatened fauna spp.?
- What effect could the weed have on non-threatened fauna spp.?
- To what extent could this weed provide benefits or facilitates the establishment of indigenous fauna?
- To what extent is the plant toxic, its burrs or spines affect indigenous fauna?

Pest animals

- To what extent could this weed provide a food source to assist in success of pest animals?
- To what extent could this weed provide important habitat or harbor for serious pests?

Agriculture

- To what extent could this weed impact on the quantity or yield of agricultural produce?
- To what extent could the weed impact on agricultural quality (e.g. contamination)?
- To what extent could this weed affect land value?
- To what extent could this weed cause a change in priority of land use?
- To what extent the presence of the weed increases the cost of harvest?
- To what extent could this weed act as an alternative host or vector for diseases of agriculture?

Discussion

Pest Plant Prioritisation and Weed Risk Assessment is a complex issue and is still relatively in its infancy. Many organisations in Australia, New Zealand and in the USA are or have developed weed assessment processes. Hughes and Madden (2003) called Weed Risk Assessment an 'imperfect warning system, but it is probably the best we are going to get.' The WONS process (Thorp and Lynch 2001) enabled weeds to be prioritised at a national level, however there is a need for more detailed prioritisation processes at a state, regional or park level. Western Australia (Randall 2000) and South Australia (Virtue 2000) have processes that land managers can use to identify priority weeds but neither presently allows land managers to value their social, environmental and agricultural values differently or at different scales.

The AHP process allows for consultation with land managers to allow them to determine what land values are important to them and by how much. Weeds then can be assessed as threats against these values.

A plant can be assessed for its biological properties that make it more invasive and its potential impacts however a powerful weapon against weed invasions is early intervention. Early intervention can significantly reduce the social cost of weed invasions and the chance of eradication (Groves 1992). For example weeds still in the localized populations (zone 2 in Figure 1) or early in increasing stage (zone 3) where eradication is feasible need to be given a higher priority.

In the assessment process this is determined by comparing the present and potential distribution. In the past, priority has often been given to projects or weeds where a clear weed problem already exists. Areas where early intervention is urgently required generally go unfounded or are ranked as being of low priority until weed infestations become critical, by which time action is often too late. A much higher weighting should thus be given to small infestations that have the potential to expand greatly.

The overall assessment of a plant depends upon a combination of its invasiveness and a ratio of its present and potential impact on what land managers (local, regional or statewide) value. Thus a less invasive plant may rank as a more important weed than a highly invasive plant, if for example:

- The overall area and/or the number or value of ecosystems at risk are greater;
- The present distribution is small but its potential distribution is very large; and
- Its impact is much greater than the more invasive plant.

Acknowledgments

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SESSION 3
Weed control technologies

Mechanical weed control – tillage, soil structure and physical management for weed control

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Summary The cost of weeds in productive systems and the emergence of herbicide resistance make non-chemical options for weed control increasingly important. Reduced seed bank recruitment and seed bank rundown are key ingredients to a control program. Use of tillage and other physical methods are considered as well as issues of hygiene. Any tillage inputs must be balanced against soil structural damage. Reliance on any one method will not provide a long term solution to the challenge of weed management.

Keywords Tillage, soil structure, weed management, stubble retention, seed contamination.

Introduction

Everyone associated with crop production is well aware of the significant costs of weeds and their control. Their competition with crop plants results in lower yield and crop product quality. Our intervention to reduce their competitiveness requires a significant outlay of cash, generally to supply an appropriate herbicide.

Of course, we have not always had herbicides at our disposal. Back in the 1960s farmers coped with weed problems through the use of soil cultivation and pasture phases, to varying degrees of success. The availability of the soil-incorporated herbicides from the late 1960s (e.g. trifluralin, triallate) introduced farmers to chemical weed control. Rather than replace tillage, however, these chemicals required the soil surface to be fined down to enable proper mixing of the herbicide with the soil. The consequences to soil surface structure were increasingly felt as we moved through the 1970s and early 1980s.

The availability of the knockdown glyphosate (Roundup®) and the post-emergent selective diclofop methyl (Hoegrass®) transformed farming practice with respect to weed management. These were followed by numerous other herbicides with excellent efficacy for grasses and broadleaf weeds. This, combined with a significant reduction in tillage, provided a way forward to increased productivity and reduced environmental damage.

So good has been this chemical technology that, over two or three decades, crop producers have become almost totally reliant on herbicides for weed management. It is probably fair to say: that a level of complacency set in; that the panacea of weed management was considered to be everlasting; that new chemicals were always in the pipeline.

Mother Nature, however, does not like to be taken for granted. She does not like to be thought of as simplistic. She does like checks and balances. Thus, herbicide resistance has occurred as a check, to remind us that the ecology of any system is complex and we have to be vigilant to avoid the pitfalls that are ever present.

Herbicide resistance has made us take stock, to reflect and to rethink. We clearly need to review what we are doing and what we are trying to achieve.

The weed seed bank

The weed plant population will be derived from the weed seed bank in or on the soil. The larger the seed bank, the higher the population of weeds that can be expected so the focus in any weed management strategy must be to reduce the size of the seed bank. The tactics to achieve this are, logically:

- **Minimise recruitment to the seed bank**, i.e. prevent as far as possible seed production from weeds even if it means sacrificing some crop. That brings in techniques such as spray topping and crop topping, hay and silage production as well as slashing and ploughing in the crop or pasture. The expectation is that a good result will reduce seed production by 70–80% but timing of the operation will influence the outcome. Ploughing in (including green manuring) should provide 100% reduction in recruitment. When a mix of weed species occurs, the focus will need to be on the least desired or the most populous as differences in maturity of the species will make the non-ploughing processes less efficient for all species. This was clearly demonstrated in Wagga Wagga by Bowcher (2003) where pasture cut in early October produced subterranean clover/ryegrass pastures whereas early November cuts produced vulpia and late November Paterson's curse in the following year.

Recruitment to the seed bank may be more significant depending on the dormancy characteristics of the species involved. For example, seed production from some annual grasses tends to provide the basis of the weed population in the following growing season. Thus, while the seed bank may build up quickly, it can also be run down quickly because of the quick turnover. However, in many broadleaf weeds there can be a high dormancy capacity that prevents all but a relatively small proportion of last season's seed germinating in this year's growing season and beyond. Thus, recruitment of, for example, Paterson's curse or wild radish to the seed bank will result in those species establishing for several to many years.

Recruitment may also be reduced through weed seed collection at harvest for species that have non-shattering heads prior to harvest time. In Western Australia chaff carts are used to collect all the chaff material as it exits the harvester. Up to 95% of annual ryegrass seed has been collected in trials (Walsh 2002) but care needs to be taken of its disposal.

- **Encouraging germination** thereby running down the seed bank. This is achieved by a light cultivation or 'tickle' such that seeds on the soil surface are covered with a minimal amount of soil, thus altering their light, water and temperature regime. This encourages the seeds to germinate, after which they can be controlled by a knockdown herbicide or by another cultivation. Species responding to this form of management include annual ryegrass and fumitory (Pratley 1995, Norton 2003).

When knockdown herbicide is used to control the weed germinations, the management of survivors of the herbicide is critical. Where survivors exist, full soil disturbance at sowing will prevent those survivors from reaching post-emergent herbicide times. These plants will be more advanced than the post sowing weed population and may survive such herbicide application thereby increasing the risk of knockdown herbicide resistance survivors. Stanton (2003 unpublished) has shown the benefit of full soil disturbance over narrow points for annual ryegrass control.

- **Reducing or avoiding germination.** This practice is associated with direct drilling where minimal disturbance of the soil occurs. Weed seeds from the previous season remain on the soil surface and can be inhibited and degraded by the extremes of wetting and drying and by temperature fluctuations. Such seed is also at risk of scavenging by birds and ants. Such an approach, however, will tend to encourage species adapted to this system, such as silvergrass (*Vulpia bromoides*, *V. myuros*) which is rarely a problem in cultivated situations (Dillon and Forcella 1984).
- **Preventing emergence** through burial. This is an old practice whereby disc and mouldboard ploughs bury seeds at a depth from which emergence is unlikely. Burial to sufficient depth would not be achieved by a tyned implement. In our conservation farming systems this would be an option of last resort because of the fragile structure of our soils and the risk of soil degradation. It should be restricted to species with short dormancy habits because those with long dormancy may well be brought back to the surface by a subsequent similar process.

The use of disc and mouldboard ploughs for the above purposes will necessitate further tillage to create a suitable seed bed for the crop to be grown. This then creates the risk of soil structure damage and also will encourage weeds adapted to that system. Thus skeleton weed, which proliferates from root and stem fragments created by the tillage, may respond (Cuthbertson 1967) as might silverleaf nightshade (Cuthbertson *et al*. 1976). One problem solved but two others are created

Altering the environment

There has been increasing interest in the adoption of stubble retention practices for the maintenance of organic matter and for moisture conservation. In the summer rainfall areas, crop residues have long been used to limit water erosion whereas in the marginal cropping areas, wind erosion is reduced by the presence of stubble. Impact of such residues is increasingly being recognised for its weed management role. The aspects to be considered are:

- **Interference with herbicide activity**. The presence of the straw makes it more difficult for applied herbicide to access germinating seeds of weeds or volunteer crop. Such seeds are concentrated in the stubble trails created by the header and need particular attention.
- **Creating an artificial emergence depth.** Seeds on the surface of the soil effectively need to find their way to the surface of the residue before they can establish and compete with the crop. This mulch effect has been used to great effect by no-till farmers particularly where they have solved the mechanical challenges of machinery passage through high stubble burdens. The effect can be both physical and chemical. Work by Bruce (2003) on canola establishment through wheat straw has shown that the seedling expends much of its energy extending the hypocotyl to reach the new surface. Consequently, those seedlings which succeed are much less competitive where the crop has been allowed to establish unimpeded. At the same time, the crop (or weed) residues can have a chemical impact where allelochemicals can leach out onto the surface soil and act as a herbicide to reduce seedling establishment (e.g. Kimber 1967, Lovett and Jessop 1982, Purvis and Jones 1990).
- **Altering the microenvironment**. The presence of the straw alters the light and temperature regime for seeds on the soil surface. The lower light regime produces the extended hypocotyl described in Bruce (2003) and a higher shoot:root ratio. Bruce (2003) also showed that the presence of stubbles led to greater diurnal fluctuations in temperature at the surface relative to bare soil. In cold conditions this difference was 2–3°C colder, sufficient to kill or slow down the growth of emerging seedlings.

To use these physical, thermal and light effects the challenge for crop producers is to ensure that the crop row is unencumbered by stubble to allow crop seedlings best growth conditions whilst the least favourable conditions are in the inter row spaces to inhibit weed establishment.

Hygiene

All the best laid plans for reducing seed banks or altering growth conditions count for little unless proper hygiene practices are implemented. Three aspects of hygiene are emphasised:

- **Weed seeds are transported in seed.** An easy way to introduce weeds onto the property is through contaminated seed. Registered or certified seed reduces the risk but there will always be minor contamination. A check of weed seeds graded out will highlight new weed species for the farm. Insistence on a herbicide resistance test on the cleanings will minimise the risk of introduction of resistant weeds, although this test is hardly ever requested.
- **Weed seeds are transported on machinery.** This is a particular issue at harvest when weed seeds are harvested or picked up. Such weeds are then spread out the back of the machine in the same field or subsequently from tyres or 'nooks and crannies' on the machine. This was clearly demonstrated by Heylin (2002) who showed that water plantain readily adhered to both the inside and outside of the rice header resulting in spread of this weed. Harvesting clean fields first together with meticulous machinery cleaning between fields become important practices.
- **Weed seeds are transported on and in animals.** Animals brought onto properties should be quarantined for a few days to ensure weed seeds in the digestive tract are expelled. Stanton *et al*. (2002) showed that livestock can excrete viable seeds for up to a week after ingestion.

Conclusions

No one method of weed control will suit all conditions. Whereas herbicides have been seen as the best way, we need to protect the efficacy of existing chemicals because there is limited new chemistry on the corporate horizon. Strategic use of cultivation remains an option with other techniques also contributing. Weed management is about reduced numbers and creating an environment less conducive to weed seedling establishment than to the crop seedlings with which they are competing.

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Cultural weed control: management of wild radish – a case study

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Summary Cultural control methods such as timing of cultivation, cultivation method, crop rotation, increased sowing rate and narrow row spacing all reduce wild radish numbers. However, adequate control has not been achieved with these methods without the use of herbicides. Improvement in on-farm hygiene and the use of competitive crop species, varieties and crop rotations will reduce the impact of wild radish. Using predictive seed bank models will also improve management.

Keywords Wild radish, *Raphanus raphanistrum* cultural control, crop rotation, emergence prediction.

Introduction

Cultural management techniques are by themselves rarely an effective mechanism to give sufficient reduction in weed pressure to alleviate yield loss or weed survival. However, they do provide an enhancement to other weed management techniques such as physical, chemical and even biological methods. Cultural weed management is an essential part of any integrated weed management package.

So what are cultural weed management techniques? These are practices that enable the promotion of the desired species to the detriment of the weed through the manipulation of normally undertaken practices (Lemerle and Murphy 2000). They include sowing rate and pattern, crop rotation, crop species, crop cultivar, timing of operations such as delayed sowing and time of windrowing. They are techniques that rely on an understanding of the biology and ecology of both the target weed species and the species that the weeds are affecting.

Cultural techniques are not exclusively used in cropping but have applications in all weed management situations. While in natural systems many techniques are unable to be manipulated, having an understanding of the ecology and biology of your wanted plants will allow protection of these plants at a time they are most likely to be vulnerable to invasion by unwanted species.

This paper considers the cultural techniques that are applicable to management of weeds in arable broadacre rainfed crops using wild radish as an example.

Biology and ecology of wild radish

Wild radish seeds are enclosed in a non-dehiscent pod. The pod itself breaks into pod segments usually with one seed per segment. The pod enclosure has been thought to be the main dormancy mechanism of radish (Reeves *et al*. 1981, Cheam 1986). However, it has since been shown that the seed coat imposes dormancy on the wild radish seed, though the pod does help ensure that the seedcoat remains intact (Young and Cousens 1999, Young 2001).

Wild radish seed dormancy is regulated by water, temperature and light (Young and Cousens 1999, Young 2001). Dormancy is alleviated during the autumn when temperatures and soil water levels are in optimal ranges. Germination outside these ranges is less than 10% of the population. Greater emergence occurs after light stimulation, though in the middle of winter 50% of seed can germinate without a light stimulus (Young 2001). Seedling emergence can continue to occur throughout the winter cropping season.

Seed persistence is greatest when seed is buried at depths greater than 5 cm (Reeves *et al*. 1981, Cheam 1986, Young 2001). Greatest emergence occurs from seeds at depths of 1–2 cm (Young 2001).

Radish is a major competitor to winter crops, with yield reductions of 10–50% in wheat (Code *et al*. 1978, Hashem and Wilkins 2002), 10–90% in canola (Blackshaw *et al*. 2002) and 30–90% in lupins (Hashem and Wilkins 2002).

Good agronomic practice

Good agronomic practices such as optimum sowing time, appropriate nutrient levels and plant spatial arrangement are important in ensuring the crop species has an advantage over the weed species.

Sowing time

For every week there is a delay in sowing there is a yield penalty. With wheat this has been estimated to be between 17 and 35 kg ha^{-1} day^{-1} (Anderson *et al*. 2000). Any delay in sowing after the opening rainfall will give weeds such as wild radish a competitive advantage as these weeds have a faster emergence rate than wheat. Where emergence was observed with or without a wheat crop present, it was seen that wild radish emerged at a faster rate initially than wheat but also had a long tail of continued emergence (Young 2001). Where crop canopy was not present, a higher amount of late emergence occurred. Ensuring that sowing misses do not occur will reduce later seedling emergence, which reduces replenishment of the seed bank by seed rain. The effect of these later emerging cohorts is conflicting in the literature with some data indicating that these later cohorts do not produce seed (Cheam 1998) while others have found some seed production still occurring in plants that emerged 10 weeks after canola (Blackshaw *et al*. 2001) and wheat (Cousens *et al*. 2001).

Row spacing
Decreasing row spacing has shown good suppression of wild radish and annual ryegrass when first implemented (Minkey *et al*. 1999) but after four years, no differences in supression were found due to row spacing (Minkey 2002). Narrow row spacing will disturb more soil, possibly stimulating more seedling emergence, whereas wide row spacing involves less soil disturbance but takes longer for canopy closure allowing greater competition between the crop and the weed.

Plant density
Increasing sowing rates to very high densities (400 kg ha^{-1}) can reduce wild radish populations in the crop (Minkey 2002). This effect varies with crop choice, oats being the most competitive followed by barley, wheat then triticale (Peltzer 1999). Even though radish populations were reduced, yield loss exceeded 20% in all crop species apart from oats (Peltzer 1999). A common concern of higher seeding rates in cereals is the increase of screenings. This was not observed by Minkey (2002) where no affect was seen in weed free areas and a decrease in screenings as seed rate increased, where weeds were present.

Nutrient application
Different nutrient applications have had a variety of results with the use of broadcasting fertilisers giving equal advantage to the weeds as well as the crop. Placing the fertiliser close to the crop (intrarow) and using slow release formulations will allow the crop to have ready access to the fertiliser, but not too much, at the early phases of crop growth. Nutrient in excess to crop requirements can be used by weed species. The effect of nitrogen on wild radish has not been consistent with 50 kg ha^{-1} urea increasing emergence but 100 kg ha^{-1} either having no effect or decreasing emergence (Murphy *et al*. 1999).

Tillage practices
The type of tillage practice employed will affect the seedbank turnover of most weed species including wild radish. Tillage not only can stimulate wild radish emergence (Cheam 1986, Young 2001, Peltzer and Matson 2002) but also affects seed longevity through the different depth placement by different implements (Reeves *et al.* 1981, Cheam 1986, Young 2001). Young (2001) further investigated the response to tillage, with a seasonal light response being determined. The response to tillage in early autumn has proven to be an effective means of reducing the seed bank of both wild radish and annual ryegrass (Cheam *et al*. 1998, Peltzer and Matson 2002). Using the knowledge of tillage to stimulate wild radish emergence and burial to reduce emergence has led several authors to suggest the use a mouldboard plough to bury seeds at depth followed by shallow cultivation to stop further emergence (Reeves *et al*. 1981, Young 2001). Having two cultivations can significantly reduce wild radish numbers in a crop (Code and Donaldson 1996).

Emergence prediction
Being able to predict weed emergence allows the manager to more effectively target other weed management techniques such as chemical or physical control. For wild radish two models have been developed both of which use daily temperature and rainfall as their inputs. The most readily available is WeedEm, which gives a prediction of emergence from time of sowing or autumn break (Walsh 2002). The other model is WREM (Young *et al*. 2002), which predicts emergence on a calendar year basis allowing pre-crop management decisions to be made.

Crop rotations
Having different crop sequences changes the dynamics of the field ecology by differing the amount of bare soil, the nutrient level within the soil, the type of herbicides being used hence the levels of seed production from uncontrolled weeds. Generally it has been found that a wheat pasture rotation can reduce wild radish numbers (Minkey and Bowran 1999). Where lupins or other legumes (Code and Walsh 1987, Minkey and Bowran 1999) are in the rotation radish numbers have increased. With the use of in-crop herbicides wild radish can be controlled, though the crops themselves are not very competitive against wild radish (Code and Donaldson 1996, Hashem and Wilkins 2002).

Crop species
It is well known that different crops have different competitive abilities. This can change for each crop weed interaction but generally the order of competition is oats, barley, wheat, canola and pulses. As there are relatively good herbicide options in cereal crops for wild radish management these crops should be considered where radish is a major problem. With the advent of herbicide tolerant varieties this has allowed greater wild radish management in canola, though Lemerle *et al.* (2000) did find a greater percentage of radish in TT canola than non-TT (triazine tolerant) canola where the opposite was expected.

Crop varieties
The work being conducted by Lemerle *et al.* (2001) on evaluating competitive crop cultivars in wheat has been extended to other crop species. As crop varieties have different disease susceptibilities they also differ in their ability to compete against weeds. A clear case is the habit of the barley varieties Gairdner and Arapiles. The former having a more prostrate habit hence is more likely to smoother weeds and even prevent seed germination. Arapiles has an upright habit allowing more sunlight to reach the soil surface causing an increase in soil temperature and light interception which in turn increases the likelihood of weeds in this space reaching maturity causing immediate yield loss and continuation of the weed problem.

Alleolopathy
Many of the Brassica species are known for their fumigation abilities. It is not known if wild radish has the ability to cause alleolopathic reactions in other species, though Cheam (1986) reports that green radish pods caused decreases in germination in wheat and lupins.

Stubble burning
Although stubble burning is a physical control method, the timing of burning is a cultural control method. Stubble burning has been shown to be effective in controlling annual ryegrass though levels do change depending a number of factors which affect either the fire intensity and/or duration (Matthews *et al*. 1996, Roy 1996). The effect of fire on wild radish has not been investigated.

Quarantine
Wild radish is a hard species to screen out of wheat as the size and weight of the pod segment is similar to that of a wheat grain. Hence headers are a common source of weed seed movement. The other is in seed. Various seed box surveys (Moerkerk 2002, Niknam *et al*. 2002) have shown that farmers are still sowing weed seeds with their crops, with wild radish being common in pulse seed and present in cereals as well.

Where low levels of radish are present, continual scouting of a paddock is an appropriate action to consider. With the improvement in electronic weed surveillance this many be able to done mechanically during other operations such as top dressing.

Harvest techniques
Wild radish pods do not dehisce but do readily drop off the plant at maturity. The level of pods actually present on plants at crop harvest will depend on the relative maturity of the radish plants to the crop.

The use of chaff carts in Western Australia has increased the amount of seed being captured from 42% up to 95% of the seed entering the header (Walsh and Parker 2002). However, initial studies in Victoria indicated that between 60–90% of the wild radish seedpods had already fallen off the plant and not entered the header (Henskens unpublished results). Between 50–60% of these had fallen off the plant prior to the header entering the paddock, the remainder falling during the harvest process.

Early windrowing of crops such as canola and pulses may allow for the capturing of non-mature radish pods. The trash from the header can then be collected and disposed of by burning at a designated site, which can be monitored for future radish emergence.

Where a large infestation of wild radish does exist in crop, management decisions on whether to harvest the crop or green manure, bale and burn the residues need to be made.

Conclusion

The present techniques that have had the most success in managing wild radish are increasing seeding rate, good crop rotation, targeted early cultivation and competitive crop species. The implementation of these methods in conjunction with herbicides and physical control methods are required to improve our present management of wild radish.

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Eco-grazing – the use of diversified grazing ecosystems as part of integrated weed management

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Summary This paper argues for a more diversified grazing system that includes animals that eat weeds left by sheep and cattle. This system is called eco-grazing. Using goats as the example, the potential to control weeds of national importance and other pasture weeds are discussed. The ecological reasons for the success of goats relative to sheep in controlling weeds is examined. Published Australian examples of the successful use of goats in weed control are given. References are made to the few economic analyses of the use of goats for weed control, all of which are positive. Benefits of the use of eco-grazing are provided and contrasted with problems encountered with chemical means of weed control. Strategies for the successful adoption of this technology are summarised along with potential areas for further research and development of eco-grazing.

Keywords Eco-grazing, goats, sustainability, chemical-free, risks, biological control, blackberry, serrated tussock, thistles.

Background

Since European settlement of southern Australia the predominant grazing pressure on pastures have come from sheep, cattle, horses and rabbits. Numerous exotic weeds have established, most without their natural insects and mammal predators and consequently some weeds have expanded their range over large areas. Weeds in pastures are plants that provide little economic benefit to land managers. Weeds usually impose costs by way of reduced or suppressed pasture production, product contamination or tainting, may be toxic to livestock, invade land removing it from production or by blocking access, are expensive to control (e.g. chemicals and labour) and provide harbours for vermin. Pasture weeds can also spread to other areas reducing biodiversity and environmental values. In many cases, pasture weeds are basically plants that occur in monocultures of sheep and cattle, animals that avoid eating these plants for as long as possible.

High risks of chemical methods of weed control

While chemical methods for controlling weeds have been advocated for many years there is general agreement that chemical methods often fail, sometimes with great financial loss for farmers. For example, in New South Wales the average chemical kill of scotch thistle is now only 60% (personal communication Jim Dellow NSW Agriculture). Advocates of chemical control often overlook reasons for the failure of chemical methods of weed control (Table 1). Chemical methods of pasture weed control have large inherent risks. It is not surprising that some farmers have given up on the chemical option as they either do not have the skills, persistence or resources to adequately carry out these complex activities or they seek organic methods of production.

Eco-grazing for pasture weed control

What is possible in many areas is a more dynamic approach to pasture weed control, using methods which are more persistent, less prone to the vagaries of the weather, equipment and terrain and which do not endanger the health of operators, produce quality nor livestock. Clearly the classic use of biological control by the importation of diseases and insect parasites of weeds is an established part of integrated weed management. This paper suggests a wider approach be considered by the use of grazing animals that consume the plants that sheep and cattle leave flourishing as weeds i.e. a more biologically sustainable weed control strategy, here referred to as 'eco-grazing'. The farm animal considered will be the use of goats.

While dairy goats arrived in Australia in 1788, mohair and cashmere goats did not arrive until the middle of the nineteenth century and Boer goats arrived only in the past decade. Since 1970, renewed interest in farming goats for mohair, meat and cashmere production has prompted investigations into their dietary habits and potential for weed control. There is good technical knowledge available about the commercial farming of goats in Australia (Simmonds 2001). As early as 1920 McFadzean (1920) noted the value of goats for the control of blackberry. Since then, weed control authorities have shown little interest in using goats for weed control despite numerous inquiries and programs to control weed expansion in Australia. This may suggests some sort of 'speciesism' or live stock prejudice exists.

Ecological adaptation of goats for weed control

Goats and sheep have a common ancestor, and are still similar sized animals. Goats and sheep have evolved and adapted to use the environment differently. In southern Australia, most of the grazing pressure on pastures comes from sheep and cattle, and most farmers and advisers compare enterprises with sheep production so this discussion will follow the same tradition.

There are three ecological adaptations that differentiate goats in their dietary selection compared with sheep and cattle.

Morphological adaptations

Goats have a narrower muzzle compared with sheep, a curved front lower jaw, a split mobile upper lip and relatively longer legs. These attributes allow goats to nibble young shoots and leaves of prickly bushes providing a higher nitrogen and

Table 1. Common reasons for the failure of chemical methods of weed control

Inappropriate equipment
Inappropriate chemicals
Application in windy weather
Equipment failure
Failure of chemical to fix to leaves
Application prior to rain or frost
Poor maintenance or inaccurate calibration of equipment
Failure to store, handle or mix chemicals properly
No application in steep, rocky or inaccessible portions of pasture
Long germination period making a single application ineffective
Failure to apply chemical at correct concentration
Not all weeds killed resulting in continued flowering and seeding
Incorrect timing of application
Development of resistance
Unacceptable residues in products

energy diet than that obtained by sheep. Goats can strip the bark from stems more easily than Merino sheep.

Biochemical and physiological adaptations

Goats are able to tolerate a wider range of plant chemicals than sheep including alkaloids, sour and bitter tastes. Goat's superiority in urea recycling via increased salivary production provides higher levels of rumen buffering leading to higher digestibility of lignin and cellulose compared with sheep. They are able to neutralise the negative effects of tannins providing a wider range of palatable herbage. Goats also have specific rumen microorganisms which are absent in sheep and cattle that are more tannin tolerant and improve digestion of lignin and cellulose in high tannin diets.

Behaviour

There are many behavioural adaptations used by goats to help control weeds. Goats can stand for long periods on their hind legs to reach up 2 m into plants. Goats also use their legs to cause mechanical damage by bashing down plants. Goats are inquisitive and investigate many new plants. Goats are agile being able to climb into some plants and also easily navigate rocky areas, a habit not appreciated if appropriate fencing is not erected. Three aspects of the behaviour of grazing animals were used by Demment and Longhurst (1987) to show how the behaviour of goats differs from the behaviour of sheep:

- **Selectivity** Generally goats are more selective compared to sheep. Goats often demonstrate their ability to pick out plant parts left by other animals when grazed on both pastures and scrublands.
- **Degree of grazing/browsing** *Browsing* refers to the consumption of shrub and tree herbage while *grazing* is consumption of herbs and grasses near ground level. Goats tend to browse more than sheep but are better described as intermediate or mixed feeders. Goats can be grazed on pastures without browse. In my studies, when goats and sheep were grazed together on annual pastures, the species showed different selectiveness (McGregor 1990, Gurung *et al.* 1994), but at very high unsustainable grazing pressures when the pasture was short and in very limited supply, the sheep out-competed the goats (McGregor 1990). On annual improved pastures goats spent more time grazing than sheep during winter but spent less time grazing during summer than sheep (McGregor 1987). Studies in environments where there is plenty of browse have shown that increasing the stocking rate of goats leads to a reduced intake of browse as the more palatable plants are eaten and animals spend more time grazing. **It is not correct to describe goats as browsing animals and sheep as grazers.** Sheep can be kept on browse pastures such as salt bush and mulga. Why are sheep kept out of plantations if not to protect the growing trees and shrubs? Why do pastoralist fell trees for sheep during drought? The fact that goats can browse more than sheep does not mean goats are exclusively browsers, any more than the fact that sheep can browse means sheep are exclusively browsers. Browsing is a better description for the behaviour of giraffe, koalas and some antelope. Goats are best described as intermediate or mixed feeders.
- **Flexibility** Goats consume a wider variety of plants including very prickly plants and some bitter tasting plants compared with sheep and cattle. Goats are far more flexible in their feeding habits than sheep and cattle. Goats can change their preferences quite quickly. For example goats may avoid a growing plant but will eat the plant when it begins to flower. These flexible habits apply to both selectivity and grazing/browsing. Goats can eat with high or low selectivity on browse plants and with high selectivity on pasture, very flexible! The ecological adaptations that enable goats to be flexible are described above.

Studies of the nutritional value of thistles and blackberries have shown that the nutritional value of these 'weeds' can be as high or higher than the nutritional value of spring pasture (McGregor 1992). In almost **all cases the goats selected the most digestible part,** with the highest digestible energy, with values for thistles ranging from 10.5 to 11.0 MJ ME kg^{-1} DM (Table 2). It is misleading to claim that goats will eat anything, unless the animals are being deprived of adequate feed resources. Such a claim is a misinterpretation of the inquisitive behaviour of goats that results in a high frequently of sampling potentially new feed resources. Their ability to be selective, to browse and to be flexible has enabled goats to survive in many environments. So why don't sheep and cattle eat the nutritious parts of weed plants? The answer is that they have evolved to primarily graze. The issue is that in goats we have a farm animal that has evolved to eat plants that are now classified as weeds.

How do goats control weeds?

Holst (1980) has described the principle methods used by goats to control weeds as follows:

- Preventing flowering and subsequent seed development and dispersal;
- Preferentially grazing the weed and placing it at a competitive disadvantage relative to other plants;
- Mechanically damaging plants by ringbarking or structurally weakening or destroying the plant.

Australian examples of the successful use of goats in weed control

Goats, have successfully controlled and assisted in the elimination of a wide variety of exotic weeds in Australia including:

- serrated tussock (*Nassella trichotoma*, Campbell *et al.* 1979);
- gorse (*Ulex europaeus*, Harradine and Jones 1985);
- blackberries (*Rubus* spp., McFadzean 1920, Vere and Holst 1979, McGregor 1996a);
- briar (*Rosa rubiginosa*, Vere and Holst 1979);
- scotch broom (*Cytisus scoparius*, Allan *et al.* 1995);
- saffron thistle (*Carthamus lanatus*, Pierce 1986);
- variegated thistle (*Silybum marianum*, Campbell *et al.* 1979, Stanley *et al.* 2000);

Table 2. Nutritive values of introduced weeds grazed by goats in southern Australia (adapted from McGregor 1992)

Weed	Plant part	Energy (MJ ME kg^{-1} DM)	Crude protein (%)
Saffron thistle *Carthamus lanatus*	Leaves	12.1	14.4
Artichoke thistle *Cynara cardunculus*	Leaves	11.5	14.8
Boxthorn *Lycium ferocissimum*	Leaves	12.4	28.3
	Stem	9.2	11.6
Horehound *Marrubium vulgare*	Leaves	10.9	23.3
Spear thistle *Cirsium vulgare*	Leaves	11.3	20.2
Sweat briar *Rosa rubiginosa*	Leaves	10.5	20.7
Blackberry *Rubus fruticosus*	Leaves, young stems	10.6	21.0
	Old stems	7.4	6.1
	Dead stems	6.4	7.9

- nodding thistle (*Carduus nutans*, Allan *et al.* 1995);
- spear thistle (*Cirsium vulgare*, McGregor *et al.* 1990, 1996b);
- Illyrian thistle (*Onopordum illyricum*, Torrano *et al.* 1999); and
- artichoke thistle (*Cynara cardunculus*, McGregor *et al.* 1990).

Goats can effectively stop regeneration of some species of indigenous Australian plants such as *Acacia armata, A. diffusa, A. pycnantha* that 'invade' recently cleared 'pasture' (McGregor and Couchman 1988a). The role of goats in some of the semi-arid plant communities of Australia has been investigated but usually with the focus on control of indigenous woody 'weeds' following damage to the pasture caused by poor management of sheep or cattle (Holst 1980). Heavy grazing of some indigenous plant communities can result in animal production losses and welfare problems (McGregor and Couchman 1988b).

Goats have also been used to assist in the management of *Pinus radiata* forests by reducing herbage growth to allow easier access during pruning and thinning and in reducing the amount pruning required (Browne 1990). Goats also offer the potential to control weeds in forage crops such as lucerne and for pasture seed production.

Goats as a potential agent in serrated tussock control

Serrated tussock is a weed of National economic importance. Campbell *et al.* (1979) and Holst and Campbell (1987) reported on the use of goats in controlling serrated tussock on tablelands in central New South Wales. Goats were grazed with cattle initially at high stocking rates. Over a three year period stocking pressure was reduced by about 50%. Grazing with goats reduced the height of the serrated tussock from 40 cm in 1975 to 7 cm in winter 1978. Goats damaged the root system of serrated tussock plants in winter 1978 by partly pulling sections of the plant up and breaking the attached roots. This allowed the subterranean clover pasture, to over grow the weakened serrated tussock reducing their light supply and eventually killing 80% of the plants. The goats reduced the seed head production of serrated tussock in summer by up to 95%. Holst and Campbell (1987) concluded that serrated tussock is only controlled by goats if the weed constitutes a small portion of the total pasture, presumably less than 20% based on their data (Table 3).

Given the ability of goats to substantially reduce serrated tussock seed production at low levels of infestation, and the knowledge that there are many varieties of serrated tussock in Australia, opportunities may exist elsewhere in Australia to evaluate goats to develop improved technologies for the control of serrated tussock. Given the:

- differences in environmental conditions between the tablelands of NSW and southern Victoria;
- major advances in our knowledge of the husbandry requirements of goats over the past 20 years; and
- improved fencing technology;

it appears justified to undertake appropriately resourced demonstration trials to evaluate methods for control of serrated tussock by using goats in association with other control agents. The impact of goats on Chilean needle grass, another weed of National importance in the Nassella family is unknown.

Table 3. Effect of goats on the ground cover of pasture species and on seed head production by *N. trichotoma* compared to that on the adjoining paddock grazed by sheep at a lower stocking rate (Campbell *et al.* 1979)

Date	*N. trichotoma* (% ground cover)	Improved species (% ground cover)	Reduction in summer seed heads (%)
Start 10/75	18	52	
9/76	12	43	80
11/77	10	42	77
10/78	4	65	95

Goats as a control agent for other weeds of national importance

Gorse (*Ulex europaeus*) and blackberries (*Rubus* spp.) are readily controlled using grazing goats (Harradine and Jones 1985, McFadzean 1920, Vere and Holst 1979, McGregor 1996a). Control of these weeds is improved using integrated methods of grazing, pasture management and fire (e.g. Allan *et al.* 1995). Goats have destroyed unmanageable and expanding infestations of blackberries in hillside and undulating pastures in Victoria and New South Wales (Vere and Holst 1979, McGregor 1996a). It has been demonstrated that goats preferred to eat the nutritious leaves and growing new stems of blackberry (Table 2) destroying the plants as soon as 18 months after introduction.

Eco-grazing turns weeds into a valuable resource

In Victoria, graziers and land managers spend tens of millions of dollars destroying weeds that have a forage value equivalent to at least $50 million annually. The application of eco-grazing will provide a more sustainable environmentally friendly, chemical free method of weed control. Land managers seeking more sustainable production systems should evaluate the potential benefits of using eco-grazing (Table 4).

Requirement for further development of goats as a weed control agent

As with all technologies, just because goats can do the job in one environment does not mean that the technology is right for direct transference to another environment. There needs to be refinement of the technology. Important issues relating to the management of goats in plantations need to be clarified, current knowledge documented and deficiencies researched and developed for practical use. The best methods of introducing these practices onto farms also need to be refined.

Table 4. Potential direct and indirect benefits from weed control programs using goats

Continual dynamic control
Prevention of seed set
Delays need for pasture renovation
Control in inaccessible country
Improved product quality
Access to inaccessible areas
Residue free production system
Improved pasture quality
Turn weeds into feed resource
Control bush invasion of pastures
Reclamation of pasture land
Harbours for vermin eliminated
Reduced labour and machinery costs
Increased stock carrying capacity
Reduces chemical usage

Economic use of goats for weed control

The limited number of economic studies of using goats for weed control incorporate only some of the benefits listed in Table 4 and not all include the production of agricultural products such as fibre and meat. Vere and Holst (1979), Krause *et al.* (1984), Arnott (1985) and Davies (1996) provided estimates of economic performance for various enterprises and all indicate reasonable managers can achieve profitable outcomes. Krause *et al.* (1984) concluded that goats offered the most economic method for gorse control in New Zealand hill country. The introduction of goats onto a property does require provision of appropriate infrastructure and on some sheep properties complementarity of facilities exist. Little attention has been paid to using goats for weed control in cropping systems in drier regions. The following issues must be attended to for an efficient production system: 1) farmers need to be educated and trained into managing goats; 2) fencing and yards must be appropriate before goats arrive and be properly maintained; and 3) appropriate stocking rates, herd health and animal welfare practices must be used.

Strategies for the successful adoption of eco-grazing

This article argues that a more diversified grazing ecosystem will provide benefits in sustainable weed control. The use of goats as part of integrated weed management has been used as the example to demonstrate the principles of eco-grazing. Managers in Government Departments (DPI), the CRC for Weed Control (CRC) and in catchment management authorities (CMAs) should seriously consider their professional position regarding eco-grazing and the use of goats to achieve sustainable long term practice change in weed control. To further develop eco-grazing the following strategies are suggested:

1. Train appropriate DPI, CRC and CMA staff in the use of goats for effective weed control.
2. Alter DPI, CRC and CMA recommendations and advisory material to include adequate advice on the use of goats to control weeds.
3. Incorporate the use of goats for weed control into Landcare and Water Catchment and Land Management Boards programs.
4. Develop targeted cultural change problems for landholders and staff of government authorities.
5. Invest in and evaluate the use of goats to control weeds in all regions by including appropriate treatments in field experiments.
6. Undertake economic studies on the use of goats for weed control.

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Biological control of weeds in Victoria

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Summary The importance of biological control in alleviating the reliance on pesticides is once again being realised as the Victorian community and government strives towards ecologically sustainable development. Whilst biological control is recognised as an integral component of local, regional, state and national weed strategies, the role that biological control plays and the process of its implementation is less clearly understood by many weed management practitioners.

This paper provides a brief introduction to biological control of weeds, with an emphasis on the role of biological control in the integrated management of weeds at a local and regional scale. It concentrates on outlining strategies aimed at enhancing the effectiveness of biological control through appropriate selection of release sites, community engagement and integration with other techniques.

Keywords Weed biological control, integrated weed management, community engagement.

Introduction

The classical approach to biological control of weeds is based on the ecological principles that herbivores and diseases can limit populations of a plant, and that in the native range of that plant, there will have evolved a specialised guild of herbivores, some of which are highly host specific (Briese 2000). When released from this herbivore pressure, as often happens when plants are deliberately introduced into a new range, the plant is given a competitive advantage, that ultimately may lead to it becoming a problem weed.

In classical biological control, the aim is to restore some degree of the ecological balance between the weed and its natural enemies by selecting herbivores and pathogens that appear to inflict the most damage on their host. We call these natural enemies 'biological control agents' and they are mostly insects although other organisms such as mites, fungi and nematodes may also be effective.

Biological control programs consist of many stages as outlined by Shepherd (1993) and Briese (2000). One of the most critical phases is the implementation of biological control, which involves the widespread release of agents throughout the invaded range of the weed. The primary purpose of this paper is to outline a strategy for the effective implementation of biological control as developed and utilised in Victoria.

Implementation of biological control

The degree of success of a biological control project and the speed at which it can be achieved is greatly dependent on both scientific and social factors. Scientific factors include the degree and type of damage inflicted by the agents on the weed, the ability of the agents to establish throughout the range of the weed and the rate of natural spread of the agent. Social factors include the level of general public and end user awareness of biological control, the rate of adoption by land managers and the process of implementation at the local and regional level. Hence, land managers and community extension officers play a vital role in the implementation phase of a biological control program.

The most effective way to implement biological control is for it to be incorporated into the strategic formulation and implementation of local and regional weed action plans as follows.

1. Map the weed infestation and determine priorities for control based on short and long-term goals

Assess the extent of the weed infestation in the management area. Well established weeds will generally consist of three types of infestations: a) small, isolated satellite infestations, b) the core of large infestations and c) infestation perimeters. Satellite infestations may expand to affect more area than the expansion of one large infestation (Moody and Mack 1988) and therefore should be considered a high priority for eradication. The perimeter infestations contribute to the advancing front of core infestations and therefore these areas should be targeted for containment to reduce the rate of spread. The core infestations are typically dense and may have large reserves of soil-stored seeds. These infestations will be more difficult and expensive to control and priorities for controlling these infestations will be dependent on a range of factors as discussed in the next section.

2. Prioritise sites suitable biocontrol sites

Biological control is most suited to the large, core infestations where over time it can contribute to the suppression of growth rate and reproductive capacity of the target weed. A ranking system has been developed to provide land managers with a framework for deciding on the suitability of sites for biological control. Four main factors are considered.

i. The extent of the weed problem. As the density and area of a weed infestation increases, so too does the cost of control by conventional means (e.g. cultivation, physical removal, spraying). Where the infestation occurs over many neighboring properties or land management boundaries (i.e. private and public land), then coordinated control of the weed becomes more difficult to manage. Dense, large and persistent weed infestations are suitable for biological control.

ii. The agricultural and/or environmental value of the area. For agricultural weeds, an initial focus on higher productivity areas will give greater economic gains from weed control in the short-term. Therefore, biological control should target weed infestations on agricultural lands of relatively low productive potential. For environmental weeds, priority for immediate control should go to protect areas of high conservation or heritage value. Given the slow acting nature of biological control, it is best suited to areas of low conservation significance or very degraded native vegetation.

iii. Technical feasibility of conventional control. Conventional methods of weed control may not be feasible or too expensive in certain areas. The accessibility of infestations will have a major impact on the ability of using spray equipment or slashers. Riparian areas are often difficult to access and have restrictions on herbicides registered for use. Some areas may be subject to erosion if a dense weed infestation is cleared, due to soil type and/or slope. Some effective control techniques may pose too great a risk of damage to agricultural or native plant species. Sites where conventional control is very difficult to achieve due to accessibility, legal restrictions, erosion risk and/or likely off-target damage should receive high priority for biological control.

iv. Suitability as a nursery site for future redistribution. To make the best use of a new biocontrol resource, the agent should be located where it will reproduce well and where it can easily be accessed for monitoring and redistribution. Some agents may require specific environmental conditions that must be considered when selecting sites for agent release. For example, the St. John's wort beetle, *Chrysolina quadrigemina* will not lay eggs in shaded conditions, while the bridal creeper leaf hopper, *Zygina* sp. establishes more successfully in locations that receive summer moisture to prolong the weed's growing season. The landholder should be prepared to abstain from using conventional weed control within the release area until the agents are well established. Ideally the landholders should be prepared to enter into an agreement that outlines their responsibility in managing the biological control release site as part of an overall property management plan. The landholder should also be willing to accept frequent visits to the area for monitoring, public field days and redistribution.

3. Establish a community-based network for the release and redistribution of biocontrol agents

The implementation of biological control as part of local and regional weed management plans can be accelerated if a concerted effort is made to spread the agents throughout the weed infestation (Bruzzese 1993). We are fortunate in Australia to have well established and supported networks of community groups tackling land management issues. These networks provide a valuable resource to fast-track the release of agents and provide feedback on agent progress (Briese 2001).

In Victoria, biological control programs are implemented through Community Biocontrol Networks (CBN), which consist of a three-tiered structure as represented in Figure 1.

The Biocontrol Services Team is responsible for the production and supply of biocontrol agents, and coordinates the establishment of regional CBNs through the training of network participants in the techniques of biocontrol implementation.

Nursery Site Coordinators generally consist of state and local government pest plant extension officers, Parks Victoria rangers and community group coordinators. Their role is to facilitate the planning of biocontrol implementation at a regional or catchment level, taking into consideration the selection of suitable sites based on the priorities for control as previously outlined.

The Nursery Site Managers consist of community group members and landholders and are responsible for the management of biocontrol agent nursery sites. These nurseries provide a local source of agents, which in time can be harvested for future redistribution throughout the management area.

In addition to speeding up the delivery of biological control, participation by community groups in biological control has many advantages (Andrews *et al*. 1992, Darby and McLaren 1993, Briese and McLaren 1997, Briese 2001, Kwong 2003). It provides a framework for education and awareness of the benefits and limitations of biological control, and through active involvement in the process, reinforces their ownership of the problem while providing ownership of the solution. An exciting initiative called 'Weed Warriors', enables CBN members to act as mentors for local schools, providing an effective vehicle to increase the awareness of weed issues within the wider community (Kwong 2002). Weed Warrior schools throughout Victoria have been breeding and studying biological control agents for boneseed, ragwort, bridal creeper and gorse, enabling students to appreciate and participate in tackling real-life weed problems.

4. Evaluation

As with other control works, evaluating the progress and success of biological control is a critical step in biological control implementation. Each tier of the CBN should undertake some form of evaluation commensurate with their role within the CBN and the skill level of participants.

Initially, it is important to know if the biocontrol agent is successfully reproducing and spreading from the nursery site. For the Nursery Site Managers this

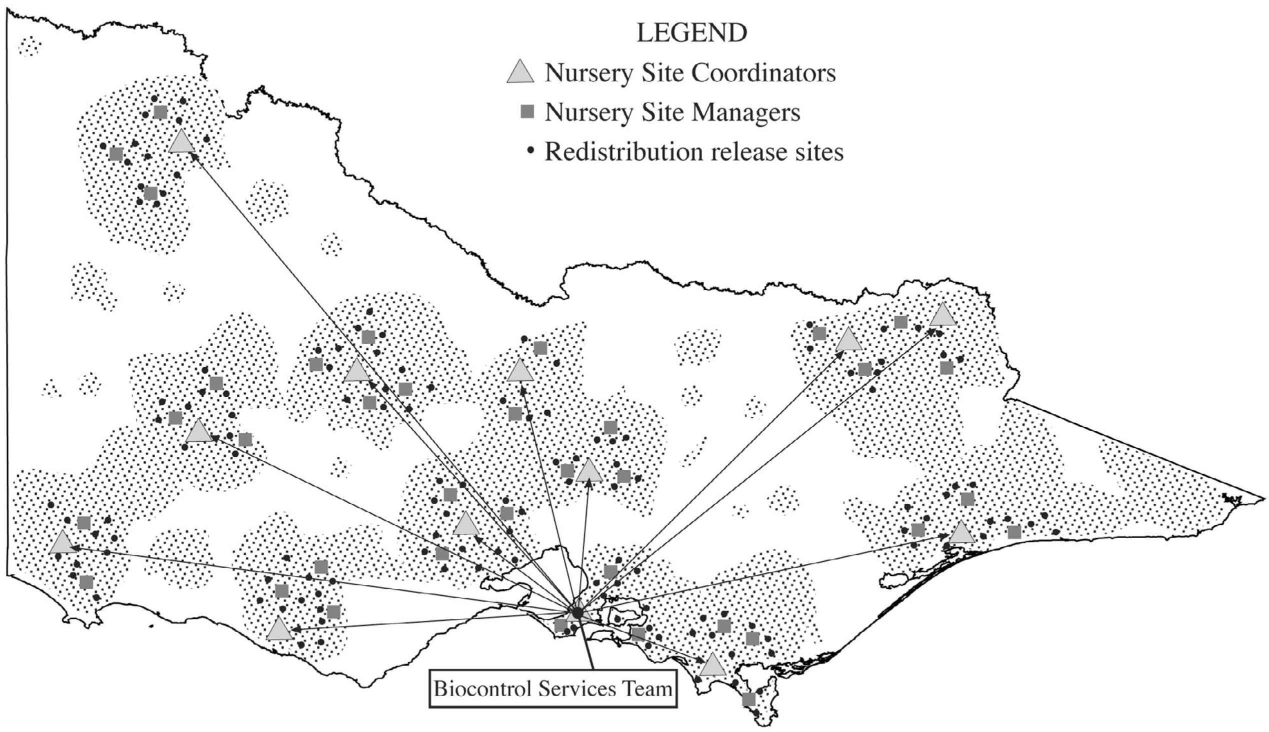

Figure 1. Conceptual representation of the release and distribution of biological control agents in Victoria through Community Biocontrol Networks. The Biocontrol Services Team mass rear biocontrol agents for release throughout Victoria. Nursery Site Coordinators (▲) plan the selection of suitable release sites throughout the weed infestation (shading) and coordinate the redistribution of agents from established nursery sites. Nursery Site Managers (■) maintain nursery sites (●) to encourage agent establishment.

information is important in determining if the agent has established and if not, should a second attempt be made or the site discontinued. Nursery site managers need to be able to recognise the biocontrol agent and its various life stages so as to perform basic monitoring such as agent presence/absence and spread. This type of basic monitoring usually commences one year after the initial release and ideally should be continued on an annual basis. The Landcare Note series published on the internet site: http://www.nre.vic.gov.au/notes/ provide information, including descriptions, of a range of biological control agents for Victorian weeds.

For the Nursery Site Coordinators, monitoring the abundance of agents at the site helps decisions to be made on whether the site is ready for harvesting and redistribution. The agent must be sufficiently abundant to allow thousands of individuals to be collected within one day. Depending on the rate of increase of the agent population, it may take between three to five years for the site to become ready for redistribution purposes.

For the biocontrol research officers, quantitative assessments of the level of damage caused by biocontrol agents coupled with changes in weed density relative to the surrounding vegetation provides a more accurate estimation of the impact of biological control (Kwong and Morley 2003). Two types of studies may be performed. The first type of study tracks the changes in weed populations before and after the release of biocontrol agents. Alternatively, 'exclusion' trials may be conducted once the agent has become well established to compare weed populations with and without the presence of biocontrol agents (Dhileepan 2002).

At the very least, photo points should be set up, with photos taken before and in subsequent years following the release of agents. These can provide a visual account of changes in weed populations over time and serve as a reminder of what the weed problem used to be like before biocontrol was instigated.

5. Integrating biological control with other techniques

So far, this paper has promoted a 'purpose-specific approach' to integrated weed management (Cullen 1996). This means that biological control is used exclusively at infestations that have been deemed low priority for immediate control. However, over time the agents will spread out from these designated biocontrol areas. If biocontrol is not providing sufficient control in these areas, other techniques will need to be employed, but how do we integrate these techniques with biological control to gain the best results? Cullen (1996) distinguished a further two approaches: 'ecological' and 'physiological'.

Ecological integration refers to situations where different approaches are used on the same weed infestation at the same time or at different times of the year. For example, the ragwort plume moth, *Platyptilia isodactyla* damages the crowns of ragwort rosettes (*Senecio jacobaea*) during spring and summer. If herbicide applications can be timed during winter or early spring when the adult moths are in hibernation, there will be little direct impact on the biocontrol agent population. When the adults emerge in spring, they will attack any remaining ragwort rosettes not killed by herbicide treatment.

In other cases, it may not be feasible to alter the timing of control applications to minimise disturbance to biocontrol agents. If the agent population is likely to be wiped out due to the use of other control techniques, it may be necessary to provide refuges to enable the agents to recolonise the area. This strategy is being used in citrus orchards throughout the Sunraysia region on the Victorian/New South Wales border, where bridal creeper (*Asparagus asparagoides*) has become a difficult weed. Pest and disease management practices within orchards can cause local extinction of bridal creeper biocontrol agents (the leafhopper, *Zygina* sp. and rust fungus, *Puccinia myrsiphilli*). Hence the agents are released into bridal creeper infested roadside vegetation and shelter belts adjoining citrus orchards, to provide a reservoir of agents should they be wiped out within the orchard. By reducing the reproductive potential of bridal creeper within these unmanaged areas, this strategy also helps to reduce the rate of re-invasion of bridal creeper into the orchards.

Described as a national first, Huwer *et al.* (2002) have commenced a multi-site experiment in New South Wales to test the relevance of an integrated weed management approach to broadleaf weeds in perennial pasture using herbicide strategies, biological control and pasture and grazing management.

Physiological integration refers to the synergistic interaction between biological control agents and sublethal doses of herbicides. Physiological integration aims to bring about a sublethal change in the biochemistry of the weed so that the effectiveness of biocontrol is enhanced. This strategy is similar to the technique of spray-grazing, where sublethal herbicides are used on broadleaved weeds to make them more palatable to livestock. There are few examples in Australia where the physiological integration of biological control and sublethal herbicides have greatly improved the level of control. However, Smyth and Sheppard (1996) demonstrated that sublethal rates of 2,4-D and MCPA to Paterson's curse (*Echium plantagineum*) to simulate spray-grazing did not adversely affect survival of the crown weevil (*Mogulones geographicus*). For a thorough review on the integration of herbicides with weed biological control agents, refer to Ainsworth (2003).

Discussion

Within Australia and around the world there are many success stories of biological control bringing a weed under effective control (Syrett *et al.* 2000). McFadyen (2000) lists some 44 weeds that have been successfully controlled somewhere in the world. In Australia, of 15 completed programs, 12 have resulted in complete control, representing an 80% success rate. Of 21 on-going programs commenced before 1986, four have achieved complete control and three substantial (and still improving) control, i.e. a 33% success rate. The overall success rate of biocontrol projects conducted in Australia is therefore 51% (McFadyen 2000, analysed from data by Briese 2000).

Given that it generally takes on average 10 to 20 years to achieve success, it is too early for many current Victorian programs to evaluate their degree of effectiveness. Never-the-less, many projects are beginning to show promising results either in Victoria or elsewhere in southern Australia, particularly St. John's wort (Mahr *et al.* 1999), Paterson's curse (Morley 2003), certain genotypes of European blackberry (Mahr and Bruzzese 1998, Pigott *et al.* 2003), ragwort (Ireson *et al.* 1999), slender thistle (Groves and Burdon 1996), skeleton weed (Cullen 1978, Hanley and Groves 2002), nodding and *Onopordum* thistles (Swirepik and Smyth 2002), horehound (Ainsworth unpublished data), gorse (Davies unpublished data) and bridal creeper (Batchelor and Woodburn 2002, Morin *et al*. 2002).

I have attempted to show in this paper that through a well-planned and effective implementation program involving the integration of biological control at a local and regional scale, the impact of biological control can be enhanced and realised sooner. This can only be achieved through strong and effective partnerships involving biocontrol practitioners, weed extension officers, community groups and land management agencies.

Acknowledgments

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What can I and can't I do with herbicides in Victoria?

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Summary The Agricultural and Veterinary Chemicals (Control of Use) Act 1992 is the head of power for control of agvet chemical use in Victoria. The Act prohibits certain practices and uses, prescribes certain practices and uses, and permits a degree of flexibility in chemical use.

Chemical users in Victoria should be familiar with the controls over the chemicals they use to ensure they comply with their legislative obligations, and adhere to the principles of Good Agricultural Practice in chemical use.

Keywords Agricultural, veterinary, chemical, controls, legislation, Victoria.

Introduction

In 1995 the National Registration Authority for Agricultural and Veterinary Chemicals (the NRA) took over responsibility for all activity in relation to agvet chemicals, up to and including the point of sale or supply. The States retained control over use of agvet chemicals, and each State enacted Control of Use legislation that reflected chemical use practices and issues that were relevant to the State. In Victoria, the Agricultural and Veterinary Chemicals (Control of Use) Act 1992 became operational on August 1, 1996, and that Act sets the rules for chemical use in Victoria.

Since 1996, a number of amendments have been made to the Act to improve its operation. Earlier this year the NRA changed its name to the Australian Pesticides and Veterinary Medicines Authority (the APVMA) to better reflect the range of activities conducted by the authority.

Supply of chemical products

The APVMA is responsible for all aspects of agvet chemical manufacture, importation, registration and review, up to and including the point of sale or supply of the products. In recent years the APVMA has developed a system of restricted supply chemical products for high risk chemicals to ensure that supply of these chemicals is restricted to 'authorised persons' who have successfully completed accredited training in their handling and use.

It is a condition of registration of these products that supply is only made to persons authorised by the State, and it is an APVMA offence to permit supply of these products to other than authorised persons.

There are currently no APVMA restricted supply chemicals that are herbicides, however it is possible that there may be APVMA restricted supply herbicides in the future. If this occurs, potential users of these herbicides will need to ensure they meet the supply requirements for these products.

CAN'T DO: be supplied with APVMA restricted supply products unless the specific State authorisation requirements are met.

Restricted chemical use in Victoria

The Victorian Department of Primary Industries (DPI) has a system of restriction of use of certain high risk chemicals, and a number of the DPI restricted use chemicals include herbicides.

The list of restricted supply chemicals (APVMA), and the list of restricted use chemicals (DPI) are different. A product may have state use restrictions but not APVMA supply restrictions.

Restricted use chemicals in Victoria are:

- Schedule 7 Poisons that are agricultural chemicals;
- ester formulations of 2,4-D, 2,4-DB, MCPA and triclopyr;
- formulations of atrazine; and
- formulations of metham sodium.

DPI restricted use chemicals MUST be used in strict accordance with label instructions.

Users of these DPI Restricted use chemicals must be the holder of an Agricultural Chemical User Permit (ACUP), or be working under the direct and immediate supervision of an ACUP holder, and must make and keep for two years, certain specified records of use. Note that different arrangements apply to Commercial Operator Licence holders, and to chemical users who are operating within a recognised Quality Assurance program that is externally audited at least every two (2) years.

If a person proposes to use a DPI restricted use chemical for a use that is not listed on the label of the product, then an application for a permit should be sought from DPI. On receipt of an application DPI conducts a risk assessment of the proposed use. This may require the applicant to collect data. DPI may or may not issue a permit depending on the outcome of the risk assessment.

Some categories of off-label use are restricted nationally, such as use of a chemical at a higher rate than that listed on the label, or more frequently than the frequency listed on the label, or contrary to a specific label statement. In these cases, a permit issued by APVMA is necessary to legalise the use.

CAN DO: use DPI restricted use chemicals only if you are the holder of an ACUP, or are working under the direct and immediate supervision of an ACUP holder, or are a licensed Commercial Operator, or are operating under a recognised QA program that is externally audited at least every two years.

CAN DO: only use DPI restricted use chemicals in strict accordance with the label.

CAN'T DO: use DPI restricted use chemical in an off-label manner without a permit authorising that use.

Record keeping

Any person using DPI restricted use chemicals is required to make and keep for a period of two years certain specified records of the chemical use.

The records that must be made and kept are:

1. Name and address of chemical supplier;
2. Name and quantity of the chemical product used;
3. Batch number and where applicable, the expiry date of the product;
4. Any specific written precautions received with the product in addition to the label;
5. Withholding period;
6. Address or location of the treated areas;
7. Type of vegetation in the treated area;
8. Name of the pest or disease to be controlled;
9. Weather conditions at application, including wind speed and direction, and temperature;
10. Date and time of application;
11. Rate and method of application;
12. Name and address of the person applying the chemical, or if applicable the person supervising the application;
13. Any Permit issued under Schedule 1 of the Act, or Part 7 of the Agvet Code (this is different to an ACUP).

DPI does not specify the format in which these records must be kept. This is in order to provide a degree of flexibility to users who may wish to keep records on computer, or in hard copy, or a combination of both. An important feature of any record is that it is readily available to a DPI authorised officer upon request.

Chemical record books that comply with the Regulations are available commercially, and a record keeping sheet that complies with the Regulations is available for free download from the DPI website.

CAN DO: must make and keep for a period of two years specified records of use for DPI restricted use chemicals.

Off-label use of chemicals in Victoria

Off-label use of chemicals is any use that is not specified on the label of the product. It may be use of the chemical on a different weed, or to protect a different host, at a different rate of use, or in a different manner to that listed on the label. Any variation from the label Directions for Use constitutes an off-label use.

For chemicals other than DPI restricted use chemicals (S7s; the ester formulations of 2,4-D, 2,4-DB, MCPA and triclopyr; and formulations of atrazine and metham sodium), off-label use is **NOT** illegal in Victoria provided that:

- the maximum label rate for that use is not exceeded;
- the label frequency of application for that use is not exceeded; and
- any specific label statements prohibiting the use are complied with (i.e. **DO NOT** statements).

While the off-label use of non DPI restricted use chemicals is permitted under certain circumstances, any person who chooses to use such a chemical in an off-label manner does so accepting total responsibility for:

- Efficacy – whether the chemical achieves the desired result or not;
- Residues in the environment;
- Residues in produce; and
- Occupational Health and Safety issues.

CAN DO: use chemicals (except DPI restricted use chemicals) in an off-label manner under certain specified circumstances.

CAN'T DO: use DPI restricted use chemicals in an off-label manner.

Chemical control areas

On August 1, 1996 eight Chemical Control Areas (CCAs) were established in Victoria. These replaced the former 'Declared Hazardous Areas'.

At specified times of the year the spraying of certain chemicals within these areas is prohibited.

These controls aim to protect sensitive crops such as grapevines, vegetables, and fruit trees that are grown within the Chemical Control Areas. Figure 1 below shows the locations of the eight current CCAs.

The Chemical Control Areas that came into operation on August 1, 1996 are: Melbourne, Lindenow, Orbost, and Boisdale. These areas operate continuously throughout each year.

The Chemical Control Areas of Mallee and Mid-Murray also operate from August 1 each year, and continue through until April 30 the following year.

Three other areas, Goulburn Valley, Rutherglen and North-Eastern, operate from September 1 each year through to April 30 the following year.

Use of the chemicals listed below is prohibited by the application methods specified while the Chemical Control Area is in operation:

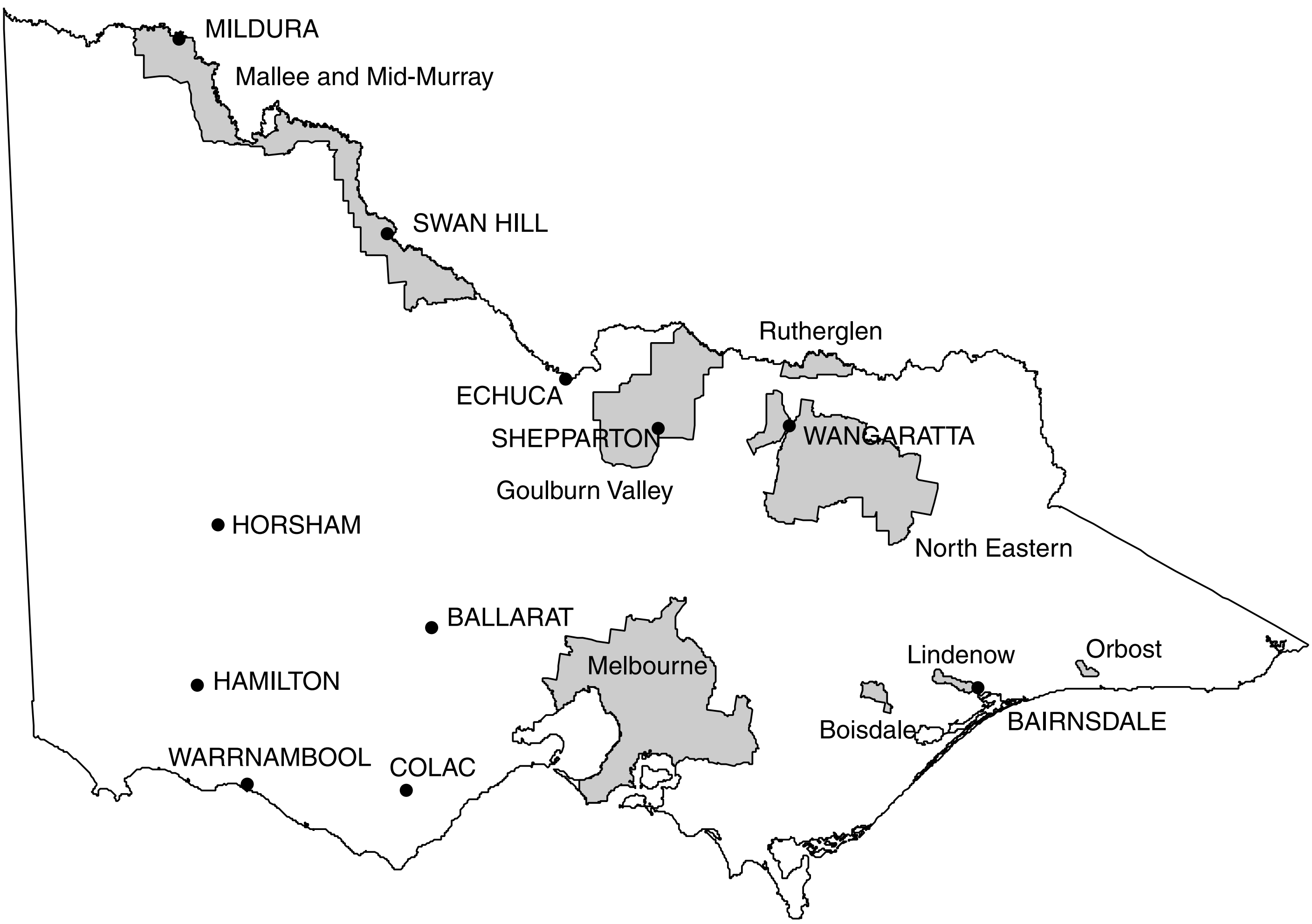

Figure 1. Locations of CCAs.

- any formulation of picloram, sulfometuron methyl, esters of triclopyr, and formulations of hexazinone when applied as a liquid. (These chemicals are prohibited only when applied by aerial application or by mister).
- the ester formulations of MCPA, 2,4-D or 2,4-DB. (These chemicals are prohibited by any method of application).

The following agricultural chemicals may be applied by aerial spraying or mister, but only by the issue of a permit from DPI:

- chlorsulfuron, clopyralid, glyphosate, metsulfuron, and the amine formulations of MCPA, MCPB, 2,4-D, 2,4-DB, dicamba, mecoprop and triclopyr. [Types of equipment classified as misters are defined in the Agricultural and Veterinary Chemicals (Control of Use) Regulations 1996].

Note: The permit issued for this use is different to an Agricultural Chemical User Permit (ACUP).

Chemical Control Areas are defined by Parish boundaries, and the Lot numbers within those boundaries. Knowing this information for a property will help determine whether or not it is within a Chemical Control Area. Accurate maps and descriptions of Chemical Control Area boundaries are available from DPI offices.

CAN'T DO: use CCA restricted chemicals within a CCA, by specified methods of application, while the CCA is in operation.

CAN DO: use formulations of chlorsulfuron, clopyralid, glyphosate, metsulfuron, and the amine formulations of MCPA, MCPB, 2,4-D, 2,4-DB, dicamba, mecoprop and triclopyr by aerial spraying or mister within a CCA, only by Permit issued by DPI.

Code of practice

Victoria has developed a Code of Practice for Farm Chemical Spray Application that has been written to provide a standard for the safe and effective application of chemicals for farmers and other chemical users.

While compliance with the Code is voluntary, users of chemicals in Victoria should aspire to comply with the requirements of the Code to ensure their chemical application is consistent with Good Agricultural Practice.

CAN DO: comply with the requirements of the Code of Practice for Farm chemical Spray Application to ensure good agricultural practice in chemical use is achieved.

Conclusions

DPI encourages the on-label use of agricultural chemicals, while acknowledging that this may not always be possible, especially in the area of environmental weed control. DPI also encourages the use of Integrated Weed Management (IWM) techniques wherever practicable to ensure better, longer lasting weed control.

Before using any chemical, users should read and familiarise themselves with the label, and should obtain the product Material Safety Data Sheet (MSDS). MSDSs are available free upon request from chemical resellers.

Chemical users should also familiarise themselves with the Control of Use legislation in Victoria to ensure they meet their obligations under the legislation. Chemical users should aim to comply with the Code of Practice for Farm Chemical Spray Application to ensure good agricultural practice in chemical use is achieved.

Being able to demonstrate awareness of and compliance with all of these factors would be considered a users' 'duty of care' obligation.

CAN DO: read the label and MSDS of the chemical before use.

CAN DO: apply chemicals according to the standard set by the Control of Use legislation, and the Code of Practice for Farm chemical Spray Application.

Acknowledgment

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Further information

- DPI Chemical Information Service 03 9210 9379;
- DPI Chemical Standards website www.dpi.vic.gov.au/chemicalstandards;
- APVMA website www.apvma.gov.au;
- Regional Chemical Standards Officers:
  Alan Roberts, Bendigo 03 5430 4416
  David Stewart, Benalla 03 5761 1532
  Les Toohey, Hamilton 03 5573 0715
  Jim Stranger, Traralgon 03 5172 2174;
- Chemical manufacturers;
- Chemical resellers and agronomists.

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Victorian Agricultural and Veterinary Chemicals (Control of Use) Act 1992.

Victorian Agricultural and Veterinary Chemicals (Control of Use) Regulations 1996.

Code of Practice for Farm Chemical Spray Application (Victoria).

Basic herbicide formulations and emerging trends in formulation technology

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Summary Few active ingredients (a.i.s) of herbicides can be applied successfully in water. Formulation technology is critical to optimise the proportion of the a.i. that reaches the target site in the weed. This paper explains and compares the major formulation types used in Australia and outlines the trends for future formulations.

Keywords Formulations, formulation inerts and formulation aids.

Introduction

Herbicides consist of two components; the active ingredient (a.i.) and the inerts or formulation aids. Most herbicides we use differ greatly from the a.i. on which they are based. The a.i.s do not make very good herbicides when applied in their own right. It is the formulation which greatly increases the weed killing power (efficacy) of the a.i.

The purpose of the formulation is to optimise the proportion of the active ingredient that reaches the plant's target site. This site was once largely the leaf surface but is now likely to be a specific point in a plant's biochemical pathways. It is essential that herbicides can be applied with minimum risk to both user and the environment.

The main factor influencing the type of formulation used is the physical and chemical properties of the a.i. Other factors considered by the formulator include; regulatory, safety, environment, ease of manufacture, reliability, storage stability and cost.

History of formulation

Until the 1940s almost all herbicides were inorganic dusting powders. During WWII both sides strove for the biological weapon that could be used to attack the food production of the other side. The phenoxy acid herbicide group, which includes 2,4-D and MCPA, were jointly invented in the US and the UK and were the first organic herbicides. They interrupted the hormonal response of plants and could be applied at far lower rates than the previous inorganic herbicides. Dusting powders were not suitable for the application of these products and formulations were developed to allow these herbicides to be diluted in water and sprayed onto the target plants.

Formulation aids

Formulation aids are, generally, the inerts within the formulation. They assist performance without being biologically active in their own right. There are hundreds of registered inerts. The most common types are solvents, surfactants/wetters, dispersants, binders, fillers/carriers and anti-foams.

Solvents

Solvents are prominent in emulsifiable concentrates. Most weed surfaces are waxy and solvents increase the a.i.'s ability to stick to and cross this waxy layer. Solvents are also used to dissolve the a.i., making solid a.i.s into a liquid.

Surfactant/wetter

Surfactants are molecules that have two ends, one designed to mix freely with a polar substance such as water and the other designed to mix freely with non-polar substances such as an oil or a wax. These products allow a non-soluble substance to become emulsified or mixed in water. Wetters are a specialised form of surfactant that aid the wetting of surfaces. These surfaces can be either the surface of a powder, in the case of a wettable powder or granule formulation, or a waxy leaf surface. Both of which could normally repel water.

Dispersants

Dispersants are used to increase the rate of disintegration of granules or a lump of powder when put into water or to assist in keeping the powders suspended in the spray tank.

Binders

Binders are used in granular and tablet formulations to adhere the powders (of which they are composed) together.

Fillers/Carriers

Fillers are usually used to dilute the a.i. to a useable concentration and to allow for more user friendly application rates. Users prefer working with a 'round' application rate e.g. 1 kg ha^{-1} rather than 0.97 kg ha^{-1}. Carriers are most commonly used to absorb liquid a.i.s into powders thereby allowing liquids to be formulated into powders, granules and tablets.

Anti-foams

Many surfactant based products form foam when added to water, making them difficult to use. These inerts address this problem.

Major formulation types

Farmers are now faced with a bewildering range of formulation types and concentrations without explanation of whether differences affect performance or safety. It is important to remember that the purpose of the formulation is to provide a product that efficiently controls weeds while juggling all the other formulation considerations mentioned previously.

Dustable Powders (DPs)

DPs date back to fungicides used by the Romans and Egyptians. They are a simple formulation consisting of a finely ground powder that is applied to the plant as a dust. They tend to blow around on the wind. They were popular in the times of the 'crop duster'. Today they generally represent too great a health and environment risk and no longer feature in broadacre agriculture.

Wettable Powders (WPs)

WPs were amongst the first of the post war formulations. The a.i. is milled finely and with the aid of wetters and dispersants the powder wets up quickly on addition to water. It can then be sprayed onto the weed.

Although a cheap formulation the dust presents inhalation problems to the user and WPs are messy to measure out. Poor wetter selection results in a powder that floats in the spray tank. Inadequate dispersant and poor powder milling will result in a powder that falls to (or near to) the bottom of the spray tank or suspends close to the bottom of the spray tank. They have an increased risk of blocking nozzles and resulting in variable application rates. They tend to need more agitation and may cause more wear on pump parts than other formulations. Despite this well manufactured WPs perform very well. Water soluble bags that are thrown into the tank intact and dissolve to release the powder can solve the dust problem but poor quality bags can exasperate the other problems. Dispersion of WPs can be markedly affected by cold water and flocculation can occur in hard water where the formulator's choice of surfactant has been inadequate.

Emulsifiable Concentrates (ECs)

EC development was most popular during the 1960s to the 1980s but they are falling from favour with a move away from liquid and solvent based products. An oily solvent is used to dissolve the a.i. and surfactants are added so that when the product is mixed with water it forms a characteristic milky emulsion. In most cases the emulsion consists of very small droplets of the dissolved a.i. in solvent, surrounded by surfactant. These droplets are suspended within the spray water. ECs made up approximately 50% of all pesticides used in the world in 1994 (Smith 1995)

ECs are cheap and easy to produce and handle and are generally used for low melting point, water insoluble a.i.s. The solvent in most ECs can dissolve the waxy leaf surface allowing for more rapid penetration of the a.i. resulting in more rapid rainfastness and improved efficacy.

ECs are generally flammable and can be explosive. They often damage rubber hoses, gaskets. They are usually classed as Dangerous Goods and the solvent often increases the likelihood of the a.i. passing through the skin. Accidental spills of ECs tend to be hard to clean up and control and cause more environmental risk than other formulations.

Suspension Concentrates (SCs)

SCs have become more popular as users and suppliers show a preference to move from solvent based formulations to water based ones. SCs consist of very finely milled a.i. powders suspended in a liquid in which they are not soluble. A thickener is often added to SC formulations to keep the powder in suspension during storage. Most SCs are made from water insoluble a.i.s that are suspended in water. They are generally easy to mix providing they have not become too viscous.

Manufacture can be difficult, as SCs tend to be more sensitive to a.i. purity and source. The water in SCs can also freeze. Mixing can also be affected by cold water. Being a liquid they also represent an environmental problem with accidental spills but as they contain no solvents this risk is less than for ECs. They also tend to present less risk than ECs when splashed onto the skin.

Water Dispersible Granules (WDGs), Wettable Granules (WGs) and Dry Flowable granules (DFs)

There is no real difference between these formulations which are now classed as WGs in Australia. There is a strong trend towards the use of WGs. They are made from finely milled powders that are then granulated, by one of a range of methods, to form the granules. A much higher rate of dispersants and wetters are used than in WPs to ensure that the granules quickly wet, break up and disperse when added to the spray tank.

WGs can be made from a wide range of a.i.s, they are not dusty and can be readily cleaned up in an accidental spill. They are easy to measure and dispense, contain no solvents and do not freeze. Generally used for higher melting point solid a.i.s, they can also be manufactured from some lower melting point a.i.s.

They are more expensive to manufacture than most standard formulations. High quality granules require expensive capital equipment to manufacture. Substandard manufacture results in unacceptably dusty or fine material. The use of poor quality or cheap dispersants and wetters results in products that floats for a long time and do not completely break up. The result is poor herbicidal performance and blocked nozzles.

Minor formulation types

Ultra Low Volumes (ULV)

ULVs are applied at very low volumes and are used by aerial applicators. Many are oil based concentrates and do not need to be diluted in water but rather are sprayed neat. Being sprayed in a more concentrated form, drift causes more damage. They require specialised application equipment. They can be less efficacious than other formulations but offer the convenience of application by air.

Aqueous Concentrates (ACs) and Soluble Liquids (SLs)

ACs and SLs are liquid a.i.s that are soluble in water and dissolve readily when added to the spray tank. A very cheap and easily manufactured formulation, these products still have their problems. They are prone to freezing, they can have trouble sticking to and penetrating the leaf and generally have poor rainfastness.

Capsule Suspensions (CSs), Micro Capsules/Micro Encapsulations (MCs)

These products have a polymer coat. They are not dusty, have less solvent than ECs and are easy to handle. They are often used with more toxic a.i.s as the polymer coat offers another layer of protection to the user. They are also associated with some controlled release products. They require expensive equipment to manufacture and are usually affected by high and lower temperatures. Being a liquid they pose a risk with accidental spillage.

Granules (Gs)

Solid granules applied directly to the soil without being diluted are common in the USA but not in Australia. Their major use is probably in forestry and industrial areas where they offer advantages of reduced drift and leaching risk. They require specialised application equipment.

Emerging trends in formulation

For some time now the main focus of herbicide formulation has been user and manufacturing safety, minimisation of environmental impact, reduced costs, improved performance and market segmentation. The Australian herbicide market is dominated by off-patent products. The cost of bringing a new molecule to the herbicide market is only within the financial capacity of a few of the world's largest agchem companies. Formulation technology offers the next level of product differentiation and the means of offering a customer product improvement. By comparison formulation developments are highly cost effective.

Liquids to solids

There continues to be a marked trend from liquid to solid formulations. In 1990 WGs made up 4% of the pesticides market and this had increased to about 20% by 2000. The benefits offered by WGs will ensure that this trend continues into the future.

Higher active content

Over the last five years there has been a marked trend towards the release of products that contain higher loadings of the active ingredient. This reduces production costs, storage and transport requirements and the number of pesticide containers. This trend will continue, although most of the easier targets have already had their concentration increased.

Solvent removal

There has been (and will continue to be) a move away from solvents or towards less volatile and less hazardous solvents. This trend is partially driven by the spiraling cost of insurance of solvent based products during storage and transport.

Safety

There will continue to be considerable forces for formulations that are safer for the user and the environment. We will see more CR, ME, WG and SC formulations.

Controlled Release (CR) and Micro Encapsulation (ME)

Heralded as the likely new age formulation technology of the 80s, CR products have been slower to reach the market than expected. The major limitation is added cost. They can offer considerable advantages. ME based products are making some inroads as they offer reduced user toxicity. A new CR hexazinone product was successfully released into the forestry market by Macspred last year. It offers longer and more reliable weed control. With increasing regulatory pressure it is likely that more use is made of these technologies in the future.

Bioherbicides

Herbicides based on environmentally benign biological a.i.s have been keenly pursued for over a decade but problems with stability, reliability and flexibility will likely mean few new entrants into the market in the foreseeable future.

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Herbicide use in riparian areas

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Summary A few herbicides are registered for use in specified aquatic situations, the most familiar being some of the glyphosate products. Labels of these products give details of exactly how they may safely be used. A few of the products that are NOT for aquatic use carry exact instructions on how they must be applied to avoid contaminating watercourses, e.g. products containing atrazine specify minimum distances from a watercourse. The great majority of herbicide products however carry a general instruction to avoid contaminating watercourses but do not give much further detail on how this obligation should be complied with or exactly where their use might be acceptable. There are some clear-cut situations in which obviously only herbicides that are registered for aquatic situations may be used e.g. weeds emerging directly from water. Often however cases occur in the vicinity of waterways where there could be advantages in using products not registered for aquatic use and where (in the absence of specific label directions or local regulations) it is up to the user to assess the risk and decide whether contamination of the watercourse can be avoided in that specific case. This paper describes the roles of the different agencies concerned with riparian herbicide use, discusses the factors that herbicide users should take into account when assessing risk and outlines general good practice to protect waterways when using herbicides in close proximity to them.

Keywords Herbicide, surfactant, contamination, aquatic, toxicity, persistence, leaching.

Introduction

At present there is some uncertainty about what is allowable when using herbicides in riparian situations. An immediate difficulty is that the term 'riparian' is not used on any herbicide labels or in control of use legislation. So although riparian management and restoration including weed control is commonly promoted, it is difficult to directly relate published material on these matters to statements on herbicide labels. A variety of definitions of 'riparian' have been suggested based on proximity to water or frequency of flooding. Malanson (1993) uses the description: 'in and near river channels and directly influenced by river-related processes'. Under this definition riparian zones of larger rivers could be hundreds of metres wide in the lower reaches. However private landholders usually think of riparian zones as being equivalent to the Crown frontage reserves, typically 20 to 30 metres on each bank and the State Environment Protection Policy Waters of Victoria (see later) defines riparian as: 'Inhabiting or situated on a river or stream bank'.

Herbicide users generally have no difficulty in identifying strictly aquatic situations such as treatment of submerged weeds, weeds that emerge from water or weeds that grow out over water as a floating mat. There are many other cases however where the situation is not so clear-cut. Between the strictly aquatic situation on one hand and land that is well removed from any waterway on the other, there is a zone where herbicide use needs special care. This is the situation mainly addressed by this paper, with the aim of providing some useful information to people concerned with weed control in the vicinity of watercourses. As a further contribution to assisting responsible herbicide use in these situations the Weeds CRC is preparing guidelines for good practice, due to be published next year.

Areas of responsibility

An extensive review of pesticide use in Australia by Radcliffe (2002) contains detailed information on legislative and regulatory arrangements in Victoria and other States and Territories. The following relates to Victoria only.

Department of Sustainability and Environment

In Victoria the Department of Sustainability and Environment (DSE), formerly part of the Department of Natural Resources and Environment (DNRE), is responsible for implementing the Catchment and Land Protection Act (1994). This Act includes provision for a system of controls on noxious weeds. Each of the catchment regions in Victoria recommends to the Minister which plants should be declared noxious and in which category, via the Catchment Management Authority (CMA) for the region. Each CMA determines which species and locations are the highest priority for enforcement activities. Riparian weed control to comply with the CALP Act provisions usually involves blackberry but a number of other declared noxious species are sometimes also problematic in riparian situations e.g. boxthorn, gorse, tutsan and watsonia. A number of important riparian weeds are not currently declared noxious and there is no legal requirement to control them, examples include arum lily, blue periwinkle, willows, and Spanish heath.

Department of Primary Industries

The Department of Primary Industries, also formerly part of DNRE, is responsible for implementing the Agricultural and Veterinary Chemicals (Control of Use) Act 1992. Enforcement of the provisions of this Act is carried out by the Chemical Standards Branch of DPI. The functions of the Chemical Standards Branch include: investigation of cases of chemical misuse, chemical risk management of agricultural and horticultural produce, issuing licences and permits for certain activities, and operating the Chemical Information Service.

Environment Protection Authority.

The Environment Protection Authority (EPA) works under statutory instruments derived from the Environmental Protection Act (1970). Key amongst the Acts requirements is that:

> 'A person shall not cause or permit any waters to be polluted so that the physical, chemical or biological condition of the waters is so changed as to make or be reasonably expected to make those waters –
>
> - Poisonous, harmful or potentially harmful to animals, birds, wildlife, fish or other aquatic life;
> - Poisonous, harmful or potentially harmful to plants or other vegetation or;
> - Detrimental to any beneficial use made of those waters.'

The EPA in Victoria does not have a direct role in controlling herbicide use, with the key regulatory agency being DPI's Chemical Standards Branch. However, the EPA does have a significant role in ensuring that water quality guidelines are met and may become directly involved through enforcement action if herbicide use results in pollution of the environment or presents a significant risk of causing pollution. The relevant water quality guidelines are those developed by the Australian and New Zealand Environment and Conservation Council (ANZECC), see ANZECC and ARMCANZ (2000).

State Environmental Protection

Policies (SEPP) have been developed by the EPA, most relevantly here the Waters of Victoria SEPP and associated schedules. There are regulations that require approvals for certain works and licensing of sites where certain activities take place e.g. sewage treatment. Licensed sites cannot exceed SEPP water quality objectives and infringements could result in a pollution abatement notice, a pollution infringement notice or a prosecution. Indirect and intermittent sources of pollution such as agricultural land on which herbicides are used are not required to be licensed. The current SEPP Waters of Victoria does however contain provisions for stream and stream side spraying. The relevant water quality objective must not be exceeded for more than 12 hours and the level reached must not be more than 100 times the chronic limit for the relevant herbicide.

The proposed revised Waters of Victoria SEPP contains objectives based on use of percentile ecosystem protection triggers and will employ a risk assessment process based on ANZECC and ARMCANZ (2000). It is proposed that in-stream and riparian spraying must not occur unless it is consistent with a new Protocol for Environmental Management (PEM). The PEM must ensure protection of beneficial uses, must be based on good/best practice and should aim to minimise herbicide use.

Australian Pesticides and Veterinary Medicines Authority

The Australian Pesticides and Veterinary Medicines Authority (APVMA) was formerly known as the National Registration Authority. The following information is from the APVMA website http://www.apvma.gov.au/index.html. The APVMA operates the national system which evaluates, registers and regulates agricultural and veterinary chemicals. Before an agricultural or veterinary chemical product can enter the Australian market, it must go through APVMA's rigorous assessment process to ensure that it meets high standards of safety and effectiveness. Any changes to a product which is already on the market must also be referred to the APVMA. Under the National Registration Scheme, companies must supply the APVMA with extensive data about the product. These are independently evaluated to ensure that the product is safe for people, animals and the environment and that it won't pose any unacceptable risk to trade with other nations.

The APVMA also reviews products which have been on the market for many years to ensure that they meet contemporary standards. It manages a national compliance program to ensure that products supplied in Australia continue to meet the conditions of registration. The APVMA also issues a number of different permits. A permit allows a person or an organisation to use products in situations that would, if it were not for the issue of the permit, be an offence either against certain provisions of the Federal legislation (Agvet Code) or of appropriate State control of use legislation. Permits can only be issued, in response to an application for: a minor use, an emergency use or for research purposes. Permits are publicly available on the APVMA website. An important point is that the issue of permits by State authorities or by the APVMA is not intended to operate as an alternative to the herbicide registration process. If the need for a permit is expected to continue then registration of this use should be sought or if this is not feasible a non-chemical control option should be developed. Some permits have been for use of herbicides in aquatic situations when their label does not include such uses.

Products registered for aquatic uses

The herbicide that most people are familiar with for aquatic use is glyphosate. Unlike the other herbicides with aquatic use registrations aquatic-approved glyphosate products are registered for a very wide range of weeds and situations. Glyphosate is a non-selective herbicide that may be applied as a foliar spray or cut-stump/stem injection treatment to a wide range of woody, grass and herbaceous weeds, including some emerged aquatic weeds, but not submerged weeds. Although the active ingredient of this herbicide has very low toxicity to non-target organisms the polyoxyethylene amine surfactants included in some commercial formulations were found to have unacceptable effects on amphibians (NRA 1996). Subsequently new glyphosate formulations that contained different surfactants were introduced for products with labels covering aquatic uses. Other glyphosate products that retained the former surfactants had labels amended to exclude aquatic uses. Despite their registration for aquatic situations, use of the newer glyphosate formulations is restricted with respect to potable water intakes, and other recommendations are also included on the label to minimise potential harm to aquatic systems. A moderate reliability trigger value for freshwaters to protect 99% of species has been set at 370 µg L^{-1}, based on technical grade glyphosate, but this is reduced to 9.25 µg L^{-1} when glyphosate is used in formulations not approved for aquatic situations i.e. containing the more harmful surfactants.

The fact that only some of the available glyphosate products are registered for aquatic situations is well understood by most herbicide users. What is sometimes not appreciated is that the organosilicone penetrant recommended for addition to glyphosate for some weeds is **not** approved for aquatic situations. Therefore any mixtures of glyphosate products with penetrants are also not approved for aquatic situations.

Total vegetation kill leading to bank destabilisation after large scale use and the damage to non-target vegetation if spray is misdirected are the major drawbacks to glyphosate. Glyphosate alone also has poor effectiveness on some important riparian weeds.

Some of the other herbicides registered for aquatic uses include diquat (for a number of strictly aquatic mainly floating and submerged species), amitrole (cumbungi, phragmites, nutgrass, water couch and water hyacinth in a variety of aquatic areas) dichlobenil (various weeds in standing water only) and 2,2-DPA (rush, sedge, cumbungi and water couch in irrigation channels, drains and bore drains). Generally the uses are more restricted than for glyphosate e.g. dichlobenil cannot be applied to water intended for irrigation, livestock watering or human consumption, which will prevent its use in many situations.

Notwithstanding the aquatic uses listed, all of these herbicides still carry the direction 'DO NOT contaminate streams, rivers or waterways with the chemical', which can appear to be illogical. Labels of glyphosate products approved for aquatic use follow this instruction with a reference to further label directions on minimising entry of spray into the water. Due to the potential for adverse effects on aquatic ecosystems and other water users, anyone inexperienced with truly aquatic herbicide use is strongly advised to seek expert advice before commencing control work.

The remainder of this paper deals with riparian use of herbicides rather than the approved aquatic uses. In these riparian situations users have to ensure that contamination of aquatic systems will be avoided. A few herbicides, such as products containing atrazine, have specific label directions on measures to be taken to avoid contaminating watercourses or groundwater e.g. minimum distances to be maintained from a watercourse. Any such instructions must be strictly observed; whatever the conclusion from the process of assessing risk described below it does not remove the obligation to comply with all label directions.

Assessing the risk of contamination

Application of herbicide in a riparian situation, especially application as a foliar spray, will almost inevitably result in minute amounts of the herbicide entering the waterway. What a herbicide user needs to assess is whether the amount of herbicide likely to reach the waterway as a result of their intended use will result in significant contamination that affects aquatic life or irrigated crops or other beneficial uses of water. In order to do this the mobility, persistence and toxicity of the herbicide must be taken into account. If in any doubt about whether an intended use is safe then expert advice should be sought and if this does not resolve the uncertainty then an alternative approach to controlling the weed should be found.

Mobility

A portion of herbicide applied will reach the soil, either directly as spray, after being washed off treated weeds or by being released when treated vegetation decomposes. Some herbicides have a strong tendency to become bound to soil particles and therefore are more likely to remain close to the site of application. Toxicity or long persistence may then be less of a concern because it is much less likely that the herbicide will reach the watercourse. One way to compare herbicide mobility is by their sorption coefficients (K_{oc}). See Holland (1996) for definitions of this and other technical terms used to describe pesticides. A high sorption coefficient shows that a herbicide has a strong tendency to bind to the particular soil being tested. Generally soils that contain large amounts of organic matter have less tendency for herbicides to be leached from them than other soils. Sandy soils tend to allow more leaching. These are generalisations and other factors such as pH may also be important for particular herbicides. A herbicide with a high K_{oc} applied to a soil high in organic matter may still be transported into a watercourse if the soil particles it binds to are moved there by surface water flow.

In practice it is very difficult for non-specialists to access and compare the physical and chemical properties of different herbicides and then relate them to the particular soil conditions at a site. The manufacturers of herbicides can provide advice for their products based on research and on feedback from many different users and should be consulted for detailed advice on the potential for leaching.

Herbicide used in riparian situations can also reach the water without coming into contact with soil. Spray may drift or be misdirected into the water, may drip from treated foliage into the water or herbicide may land on rock, gravel, concrete structures, dead wood or other hard surfaces and later be washed into the water. Behaviour of herbicides deposited on hard surfaces is not well known and until more research has been completed it may be safest to assume that much of the herbicide on these surfaces will wash into the water with the first rain.

Persistence

Highly persistent herbicides are those which remain chemically unchanged for a long period of time after application. Persistence is often expressed as the soil half-life, which is the average time taken for half of the amount of herbicide originally applied to become broken down to other compounds. Sometimes the term dissipation half-life is also used: this refers to the rate at which the concentration at the site of application decreases and therefore includes leaching and volatilisation losses in addition to actual breakdown of the herbicide. One complication is that the initial breakdown may produce another compound that is biologically active, and therefore the half lives of both the herbicide and its breakdown products may have to be taken into account. Triclopyr ester, for example, initially breaks down rapidly to triclopyr acid, which is less toxic to fish and other aquatic organisms but degrades more slowly.

Different processes are important depending on the herbicide involved and the environment. Sunlight causes breakdown of some herbicides, a process known as photodegradation. Triclopyr and picloram are examples of herbicides that are strongly affected by photodegradation. Obviously the intensity of sunlight the herbicide is exposed to affects the rate of photodegradation, so whether the herbicide has been applied beneath a canopy, and whether it has remained on leaf or soil surfaces or been washed into the surface soil, can be important factors. In water the presence of dissolved or suspended substances that absorb ultraviolet light can reduce the rate of photolysis.

Microbial degradation occurs when microorganisms in soil or water cause chemical breakdown of the herbicide. This process happens fastest in warm moist conditions and where high levels of organic matter support large numbers of microbes. Chemical hydrolysis is the breakdown of herbicides by chemical reactions with water that do not depend on microorganisms. Frequently more than one process is responsible for the breakdown of a particular herbicide. Metsulfuron methyl for example is mainly broken down by chemical hydrolysis if the soil is acid, but in more alkaline soils this process is much slower and microbial breakdown is the main decomposition process (Black *et al.* 1999).

Because of the strong influence of environmental conditions averaging studies in different situations to produce a single value for the half-life is not very informative and so a range of representative values is sometimes quoted. Highly persistent herbicides are generally a greater risk for contamination of water than ones with low persistence, although they may be acceptable if high persistence is combined with low mobility and/or low toxicity. Information on soil persistence is available on some labels in the form of plant-back periods for sensitive crops, or from the manufacturer. A number of online databases provide figures for half-lives but as noted earlier these can be strongly influenced by local conditions and it is safer to consult experts who are familiar with the herbicide in conditions similar to the ones you are dealing with.

Toxicity

The extent to which herbicides or other chemicals have harmful effects on animals is often assessed by administering a range of doses to different groups of animals. Death of animals over the following few days is recorded and used to calculate what is known as an LD_{50}; the dose that killed 50% of the test organisms within this time. Oral administration is not appropriate for aquatic animals; they absorb herbicide directly from the water across their gills or skin, so the amount their bodies absorb is determined by the concentration in the water. Test organisms are placed in a range of herbicide concentrations and the number of deaths recorded. Results are expressed as an LC_{50}; the concentration that caused 50% of the organisms to die during the test period. Sometimes instead of death the appearance of some clear harmful effect, such as abnormal behaviour is used instead, and the figure is then called an EC_{50}; the concentration that caused the effect to appear in 50% of the organisms during the test period. A high LD_{50} or LC_{50} (listed on Material Safety Data Sheets) therefore indicates that large amounts of the herbicide are required to cause death of the organisms tested; higher numbers equals less toxic. Herbicides with low LC_{50} values for particular aquatic organisms carry additional label warnings in the section headed 'Protection of wildlife, fish, crustacea and environment' such as: 'Dangerous to fish' or 'This product is highly toxic to fish and other aquatic organisms'. Many herbicides however do not require these warnings because they have quite low toxicity.

Relatively short-term tests used to define lethal concentrations have some important drawbacks as measures of hazard to the environment. First, only a small range of test species are used and it is always possible that some of the organisms that are actually exposed to the herbicide will be much more sensitive than the test species. Secondly, there may be effects of the herbicide that do not show up in short-term tests in artificial conditions. Until more information has been gathered on effects of long-term exposure to low levels of herbicides, the standards set to protect aquatic systems are in many cases based on maintaining a concentration that is only a small fraction of the LD50 for sensitive organisms. Due to the weaknesses of current ecotoxicology data it is highly desirable to keep all herbicides out of aquatic systems, even those with low toxicity in the tests done to date.

If a choice of registered herbicides is available it is sensible to select one with low toxicity to aquatic organisms when working in riparian areas, unless you are very confident that no significant amount will reach the watercourse.

Application method and amount
Problems of direct drift or misdirection of spray resulting in contamination are more likely with high volume foliar application by hand gun than with knapsack spraying, basal bark application, wick wiping or cut-stump/stem injection application. High volume spraying may sometimes be the only feasible way to treat large dense weed infestations. However the other techniques that offer more precision in herbicide placement should be favoured when products registered for application by these methods are available for the target weeds.

Applying large amounts of herbicide at one time e.g. by treating both banks along several kilometres of a small creek is a higher risk for causing significant contamination than treating the area in several phases either spread over the appropriate season or over several years. It is in any case often good practice to treat infestations progressively, starting from the edges, because this maximises the chances of desirable species regeneration or replanting being able to fill the area when the weeds have died.

Other site conditions
Risk of contamination is increased if any of the following apply: steep slopes, a history of frequent flooding or surface runoff, dense vegetation making the banks of the waterway or tributaries difficult to see. Presence of a belt of vegetation between the application site and the watercourse will reduce contamination risk from spray application by intercepting some spray drift. Of course it is important to consider whether any such drift will damage the vegetation that is acting to protect the waterway.

Good practice to protect waterways

The following practices should be used wherever applicable to reduce the risk of waterway contamination resulting from riparian herbicide use. These suggestions are in addition to and are **not** a replacement for label directions and the Code of Practice for Farm Chemical Spray Application published by the Department of Primary Industries.

If possible select a herbicide with a low tendency to leach, with low persistence and with low toxicity to aquatic organisms. Selection of herbicide and application technique should also take into account the need to avoid damage to non-target vegetation, particularly where such vegetation is important in stabilising banks or providing wildlife cover. Carry out mixing of chemicals and cleaning of equipment well away from the water. Ensure that equipment is properly maintained and adjusted and not leaking. Do not spray weeds overhanging a waterway or where an expected rise in water level will cover the ground. Direct spray away from the waterway if at all possible. If spraying away from the waterway is completely impractical consider placing marker posts a safe distance from the edge of the waterway. Spray only up to the markers and then complete treatment of the weeds right on the edge of the bank at a later date using other methods. If using a contractor provide them with a spray map showing the exact location of waterways, including feeder streams and ditches leading into them. Move upstream when spraying, rather than downstream, to avoid the potential for a 'slug' of herbicide to enter the stream and to maximise dilution. If the riparian land is cultivated do so across the slope to minimise the chance of surface flow into the waterway and ideally maintain a grass buffer strip too. Spray when rain is not expected for some time. If applying herbicide as a foliar spray use the minimum volume of spray required to achieve the degree of wetting specified on the label. Where labels provide alternative application methods for the target weed then if possible choose one such as stem injection that minimises the amount of herbicide required. Certain records must by law be kept by commercial operators and by users of restricted chemicals but it is also good practice for everyone to keep accurate records, which would usefully include notes of the sources of information consulted, the risks identified and the measures taken to reduce them. The Chemical Standards Branch of DPI has produced a number of publications that may be of assistance, relating to matters including record keeping, spraying on target and using vegetation as a barrier to spray drift.

Disclaimer

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Herbicide use in pastures

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What I have to say is more along the lines of weed alert. Mullumbimby couch (*Cyperus brevifolius*) is invading the perennial grasses of the Goulburn Valley and the Murray Valley. These pastures have been the backbone of milk production for many years. I appreciate there is a trend towards summer cropping, but Mullumbimby couch may still invade these crops and there is a low level of recognition of this plant among farmers.

There is very little information on control measures. Mostly what I call a lolly job i.e., suck it and see. I would like to see a research program for Mullumbimby couch and Parramatta grass (*Sporobolus africanus*) and also folded rush (*Juncus imbricatus*). Funds could possibly be available from a Dairy Industry Research Levy although political input from either UDV/or VFF would be necessary for this scheme.

Moving on: this year (2003), post the 2002 drought, pastures have in general been good, however plenty of capeweed (*Arctotheca calendula*) is present. Musky storksbill (*Erodium moschatum*) and long storksbill (*E. botrys*), plus a new weed tall mallow (*Malva sylvestris*) show in pastures this year.

We now have a year similar to 1983, post the 1982 drought, but the mallow is a new phenomenon. A small amount of control has been achieved in lucerne stands in other years; this year some control in pastures is evident. If the situation continues next year a lot more work will need to be undertaken to address the mallow problem. Control: Broadstrike at 25 g ha^{-1}, Bromoxonyl 200 at 0.7 L ha^{-1} and Uptake at 0.5 L per 100 L water, applied in 100 L water appears to be useful.

Water volumes per hectare for contractors

I attended the Ground Operators Association meeting in Goondiwindi, Queensland, in July 2002. The discussion on water volumes focussed on a standard 50 L ha^{-1} plus a charge of 10 cents per L ha^{-1} for volumes above 50 L ha^{-1}.

Patterson's curse (*Echium plantagineum*) control in irrigated pastures (sub and rye) on dairy farms

Early control is difficult due to high temperatures i.e. +20°C. Perhaps Broadstrike is the answer. Later control with terbutryne and MCPA has great danger with the level of damage to clover perhaps being unacceptable. It is possible to achieve a satisfactory result with careful timing post grazing. Terbutryne and MCPA have shown very good results in dryland annual pastures. I am anti-glyphosate for Patterson's curse control in spot spraying. Glyphosate provides an ideal seed bed for the next generation of Patterson's curse. Control requires one good general selective spray including fence lines, around trees and any other areas difficult to access. A follow up is required late spring. I would favour metsulfron methyl for this control.

Tree plantations

Simazine at 6 L ha^{-1} plus Spray.Seed at 1.8-3 L ha^{-1}. This procedure is very cost effective and a far better option than post planting weed control.

Industrial weed control

We perform about 14 unit days per year in this category. In recent years a number of quarries have inquired about an inspection with a documented weed control program. I assume some pressure is being applied by DPI or the Mines Department. It is logical for quarries to undertake weed control for the environmentally unfriendly weeds. Most quarries would export their product over 100 kilometres radius or more. The major weed identified has been Patterson's curse. Some others at a low level are prairie ground cherry (*Physalis viscosa*), some silver leaf nightshade (*Solanum elaeagnifolium*) and mignonette (*Reseda* spp.). Control measures mostly are a winter spray for Patterson's curse with terbutryne and MCPA with a follow up of metsulfron methyl. There are some fence lines and tree lines where the procedure would include simazine at 6 L ha^{-1} plus Spray.Seed at 2.5 L ha^{-1}. For the area surrounding the explosives magazines, which must be totally weed free, we would use Arsenel at 4 L ha^{-1}. On one quarry site where the surrounding cover was capeweed and Patterson's curse the choice of chemical was metsulfuron methyl. The intention was to leave the capeweed behind to provide ground cover. The follow-up spray would then be 2,4-D amine.

I am reliably informed that Victoria has 450 Licensed Commercial Operators. The last available figures to me showed that there are 30 to 40 paid up members of VGA (Victorian Ground Sprayers Association). In the last 25 years there have been many Legislative changes with very little input to improve this industry. I urge all Contractors to join VGA and through them to be part of Australian Ground Sprayers Association.

Disclaimer

These comments on herbicides are not recommendations. Always read and follow label instructions before applying herbicides.

Herbicide application – guidelines for best practice

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Summary Economic and environmental concerns have made the selection of herbicide application equipment more important than ever. Best practice herbicide application involves an understanding of the chemical mode of action, the target species, application volumes, droplet size, nozzle selection and the weather conditions.

Keywords Nozzles, herbicide application, spray drift, BCPC, droplet size, VMD, drift reduction.

Introduction

Best practice herbicide application is highly dependent on correct application methods and equipment, especially now that economic and environmental concerns have made the precise application of herbicides more important than ever.

Having determined the appropriate herbicide given the weed species, timing and weather conditions, the applicator must select the appropriate nozzle to deliver the spray effectively to the weed. The nozzle needs to produce the optimum size droplets for uniform capture and distribution on the weed. Importantly this must be achieved whilst minimising the risk of off-target spray drift.

There are a number of factors that effect the performance of nozzles including nozzle design, operating pressure, liquid properties and weather conditions. Whilst many of these factors are well known to the industry, some are not. The intent of this paper is to discuss some of the lesser-known influences on nozzle performance and how these can effect best practice herbicide application.

Droplet size

To make informed decisions about nozzles, applicators must have an understanding of droplet size.

Droplet size is probably the single most important factor to consider because this will determine how efficient, effective, or efficacious the application will be, and also how much spray drift will occur. We must select an application method that gives us an optimal droplet size that will maximise efficacy and minimise spray drift.

Unfortunately there is considerable confusion within the industry surrounding the terminology used to describe droplet size, particularly surrounding the use of the popular descriptor for droplet size, namely the 'Volume Median Diameter' (or VMD, or Dv0.5).

The VMD

The VMD is the droplet diameter such that 50% of the *volume* sprayed is contained in droplets *larger* and *smaller* than the stated VMD value. The diameter is measured in microns (or µm). There is 1000 µm in a millimeter (0.001 mm = 1 µm), and our visibility threshold is around 30 µm.

For example, Figure 1 shows the XR110015 nozzle has a VMD of 200 µm at 3 bar pressure. At this same pressure, this nozzle is spraying around 0.6 litres per minute. Therefore 0.3 litres will be contained in droplets smaller than 200 µm, and 0.3 litres will be larger than 200 µm.

Being a volume based measurement; we can also relate the VMD to application rate. Using the XR110015 example above, if our application volume was 50 L ha^{-1} (at 14 km h^{-1} at 3 bar – approx.), then 25 L ha^{-1} will be less than and 25 L ha^{-1} will be greater than 200 µm.

The droplet spectrum

It is important to note that all nozzles produce a range of droplet sizes, and whilst the VMD is an accurate descriptor of the *median* droplet size, it tells us nothing of the breadth or width of the entire droplet spectrum. What is often more important is to understand the volume likely to drift (fine end) and/or the volume likely to miss the target, splash and be wasted (coarse end).

Put another way, two nozzles with very different droplet spectrums (or distributions) can have the same VMD (Figure 2). Therefore it is important to understand that when a nozzle is described as producing droplets of a certain VMD, it does not mean that the majority of droplets will have diameters similar to the VMD.

Nozzle classifications

To avoid the confusion surrounding the VMD and help applicators select nozzles that are appropriate for particular pesticides and circumstances, international standards have been developed to define spray quality in a more practical way.

The droplet size classification standard developed by the British Crop Protection Council (BCPC) and later adopted/modified by the American Society of Agricultural Engineers (ASAE) uses reference nozzles against which all manufacturers compare their nozzles.

The VMDs of the reference nozzles are measured, along with a range of other parameters (Dv0.1, Dv0.9) such that the entire spectrum is classified. Depending on the nozzle design and its operating pressure, the classification may range from very fine to extremely coarse.

This classification system enables regulators, researchers, applicators and growers to standardise the description of nozzle systems and thus spray quality.

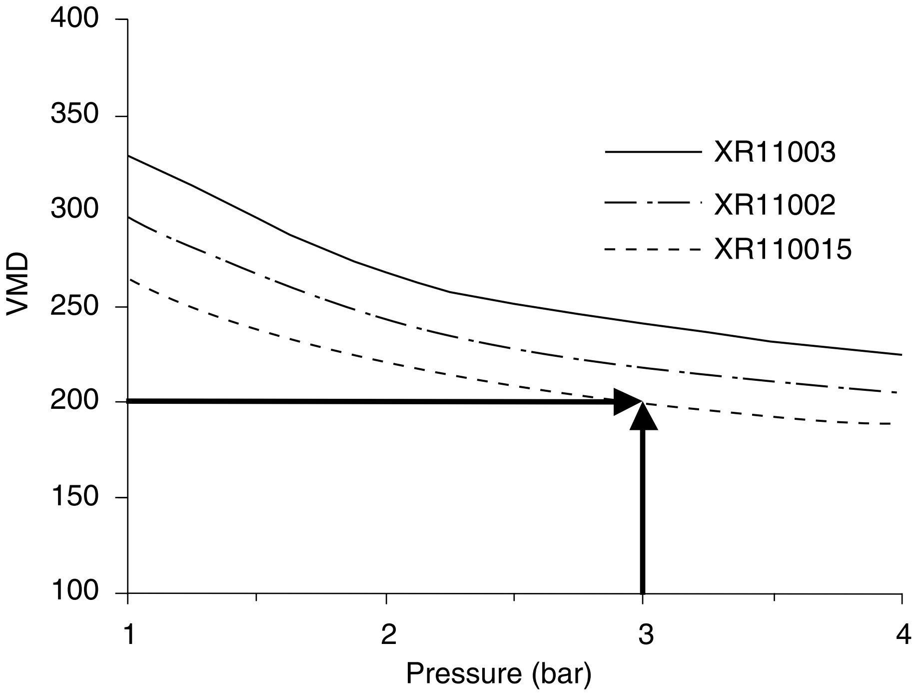


Figure 1. VMD vs. pressure for three nozzle capacities

Spray quality is one of the best ways an agrochemical company or regulator can communicate via the label to the farmer and applicator. Rather than quoting a VMD, herbicide labels in many parts of the world refer to a BCPC droplet size classification (Figure 3).

Effect of nozzle design on droplet size

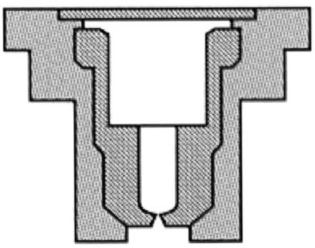
Nozzles are available in many different designs, materials and capacities. Traditional designs include Tapered Flat Fan, Hollow Cone, Anvil or Flooding, Full Cone, Evenspray Flat Fans, Off Centre and Straight Stream.

There is an increasing challenge to the traditional nozzle designs by new designs offering improved performance, drift control and efficiency. Most of the new nozzle designs have been developed to reduce drift and improved 'usability' such as wear reduction, blockage prevention and providing a wider operating pressure range.

These drift reduction nozzles include pre-orifice, air induction and flat fan/ flooding nozzle hybrids.

Extended Range Flat Fans

These produce larger drops for drift control at lower pressures (less than 2 bar), and finer drops for better coverage at pressures above 2 bar. An example includes the TeeJet XR.



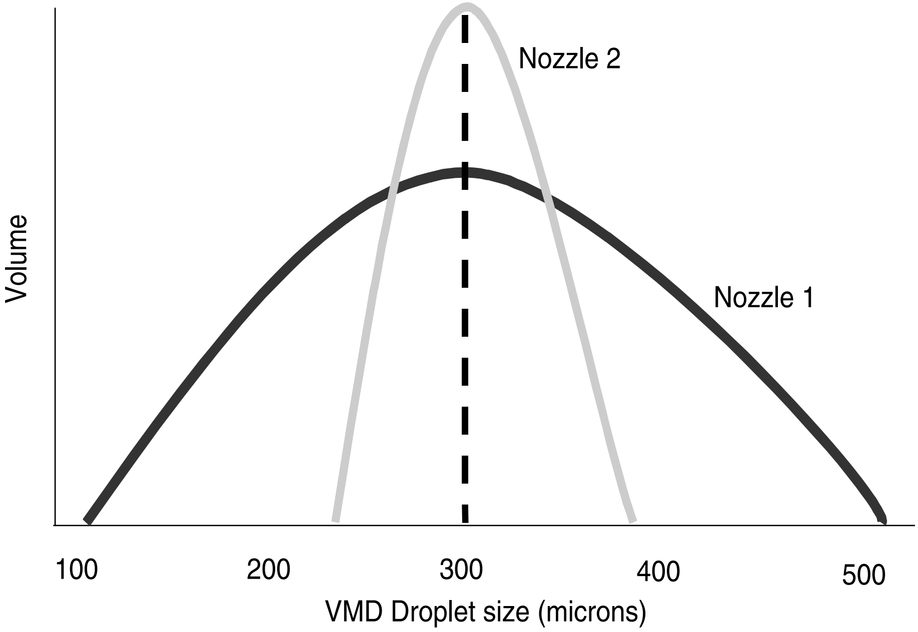


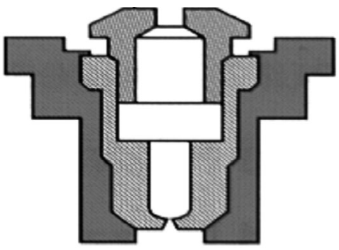
Figure 2. Depiction of two nozzles with same VMD but with different droplet spectrums

	bar										
	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
TT11001	C	M	M	M	F	F	F	F	F	F	F
TT110015	C	C	M	M	M	M	M	F	F	F	F
TT11002	C	C	C	M	M	M	M	M	M	M	F
TT11003	VC	C	C	C	C	M	M	M	M	M	M
TT11004	XC	VC	C	C	C	C	C	C	M	M	M
TT11005	XC	VC	VC	VC	C	C	C	C	C	M	M
TT11006	XC	VC	VC	VC	C	C	C	C	C	C	M
TT11008	XC	XC	VC	VC	C	C	C	C	C	C	M

Figure 3. BCPC Classification for the Turbo TeeJet (F = fine, M = medium, C = coarse and VC = very coarse, XC = extremely coarse)

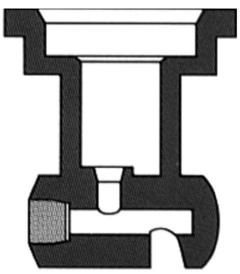
Pre-Orifice Flat Fans

These use a pre-orifice (or restriction before the main orifice) to reduce liquid pressure and velocity prior to reaching the primary orifice. This results in larger droplets and less mist or fines.



Flat Fan/Anvil Hybrids

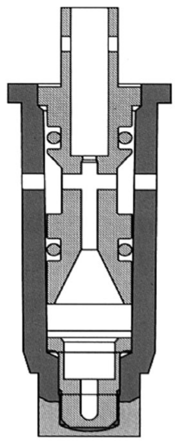
These are a cross between the traditional flat fan and anvil type nozzles. An example is the Turbo TeeJet (TT) which provides a very wide pressure range (1–6 bar), less fine drops and excellent blockage resistance.



Air Aspirated Nozzles

These nozzles are designed to draw air into the liquid stream through a venturi. These are claimed to produce larger air-included droplets that shatter on impact.

The amount of air found in the drops depends on the liquid properties such as the addition of surfactants and oils. Other considerations include the high operating pressures (3.5–8 bar), the potential evaporation rate of the air-included drops and the many factors that can effect the behavior of droplet on impact such as leaf surface, droplet trajectory and velocity need to be considered.



Whilst the performance of these nozzles in reducing drift is excellent, coverage can be poor. Compared to Extended Range nozzles, Air Induction nozzles should be operated at higher pressures and higher application volumes.

Extended Range nozzles are effective 'all round' performers, however drift reduction nozzles when used correctly can provide spray drift control with no loss of efficacy (Figure 4).

Nozzles are available in a wide range of materials such as ceramic, polymer, and stainless steel, but the material has no effect on the droplet size, only wear rate.

Nozzle condition is very important as worn nozzles significantly effect droplet size distribution and spray angle. Generally the droplet spectrum and spray angle is widened so it is important not to use worn nozzles.

Smaller capacity nozzles produce smaller droplets and wider-angle nozzles (i.e. 110 degree) also produce smaller droplets compared to narrow angled nozzles (i.e. 80 degree).

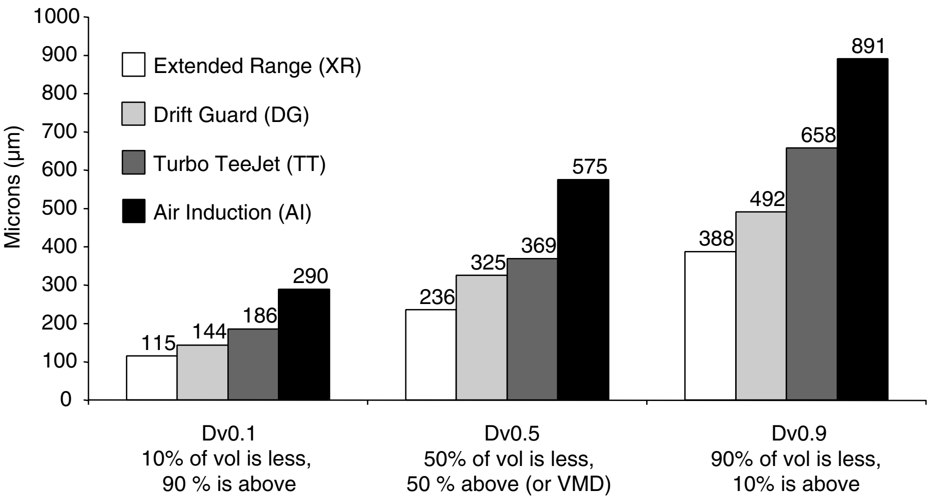


Figure 4. The droplet spectrum of four different 11003 nozzles

The relationship between droplet size and spray volumes

The smaller the droplet size, the greater the number of droplets produced. Known as the volume/diameter relationship, if we halve the droplet size for the same volume, we increase the number of droplets by a factor of eight.

The minimum amount of water required to provide adequate cover to a target is determined by droplet size. Figure 5 illustrates that theoretically we could reduce the spray volume without sacrificing coverage by using nozzles that produce very small, mono-sized droplets (bearing in mind increased drift associated with smaller droplets).

However in the real world nozzles produce a range of droplets sizes, so larger spray volumes are needed to compensate. Spray volumes can be increased to improve coverage when using drift reduction nozzles that produce coarser drops.

Effect of liquid properties on droplet size

Whilst there are always exceptions, as a general rule:

- Oils increase liquid viscosity and result in coarser droplet size. Oils can also have an anti-evaporant effect.
- Common surfactants and wetters result in smaller droplets because the liquid surface tension is decreased.
- Anti-drift adjuvants (such as polymers, PVAs etc.), modify liquid properties by changing elasticity, dynamic surface tension, and/or viscosity. Consequently, the modified properties will effect atomisation, evaporation, and/or droplet retention.

Evaporation

In Australia we tend to spray in weather conditions conducive to evaporation. As water based droplets travel through the air they rapidly evaporate, obviously reducing in size and mass as they fall.

At 25°C and 30% RH, a 100 μm droplet will loose half its size (and therefore 1/8 of its volume) after traveling only 75 cm. Obviously as temperature increase and RH falls, the evaporation effect increases exponentially. In fact in these conditions, droplets smaller than 100 μm are unlikely to reach the target.

The losses due to evaporation can be significant when spraying with Very Fine and Fine droplets.

The need for accuracy

Worn nozzles are not the only source of application errors. Very small changes in ground speed, spraying pressure and driver accuracy can translate into significant errors as the following examples show.

- Speed: At 16 km h^{-1}, a 1 km h^{-1} change = 10% error
- Pressure: At 16 km h^{-1}, a 0.25 Bar (3.6 psi) change in pressure = 10% error
- Driving accuracy: 90 cm over/underlap on an 18 m boom = 10% error
- Nozzle wear: 65 mL min^{-1} extra from a 02 nozzle at 2 bar = 10% worn

A 10% over application per 100 ha may represent a loss of $300 to $1500 (not including potential crop damage). This is significant when technology such as sprayer controllers and GPS guidance systems are readily available at comparatively low cost.

No operator can consistently apply products within 10% of the target rate without the use of this technology.

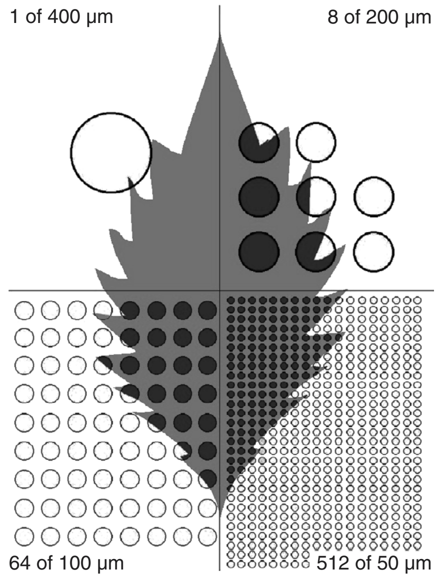


Figure 5. The Volume/Diameter relationship

Conclusion

Points to remember for best practice herbicide application include:

- Droplet size is probably the single most important factor to consider when spraying because this will determine how efficient, effective, or efficacious the application will be, and also how much spray drift will occur.
- We must select an application method that gives us an optimal droplet size that will maximise efficacy and minimise spray drift.
- When a nozzle is described as producing droplets of a certain VMD, this does not mean that the majority of droplets will have diameters similar to the VMD. The VMD is an accurate descriptor of the *median* droplet size (based on volume) only, and tells us nothing of the breadth or width of the entire droplet spectrum.
- An understanding of the droplet size classification standard developed by the British Crop Protection Council (BCPC) is useful when selecting nozzles.
- Remember that there will always be a trade off between droplet size/coverage and drift. Consequently there will be times that spraying should not

occur with fine and medium droplets until conditions change.

- The ideal droplet size will depend on the chemical mode of action, the water volumes, the target species and the conditions.
- The smaller the droplet size, the greater the number of droplets produced. If we halve the droplet size for the same volume, we increase the number of droplets by a factor of eight.
- Nozzle design and liquid properties will significantly effect the droplet spectrum.
- Nozzles do wear, so regular calibration is essential.
- Be mindful of droplet evaporation. Avoid spraying in hot dry conditions.
- Consider technology such as automatic rate controllers and guidance systems to improve application accuracy.

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SESSION 4
Integrated Weed Management

Reasons and underlying principles for IWM in grain cropping systems of southern Australia

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Summary Integrated weed management is often thought of as a collection of tactics employed against weeds to minimize weed numbers. However, IWM needs to be more than any assortment of weed control tactics. Instead, a planned response with the aim of managing weed populations, not weed infestations, is required. Weed management tactics are chosen that are appropriate for the situation and do not conflict with each other. In grain cropping in southern Australia, the widespread evolution of weed populations resistant to herbicides has driven the adoption of IWM strategies. Such strategies, where they are most successful, focus on reducing seed set of weeds as well as controlling seedling weeds. Frequently, crop rotations are altered to allow different tactics for managing weeds to be employed. It is the recognition of the need to respond rapidly to weed population increases that has allowed farmers to manage the evolution of herbicide resistant weeds. Despite the widespread evolution of herbicide resistance in weeds, herbicide use remains a vital part of IWM strategies in southern Australian grain cropping. New uses and application times for herbicides are being devised that assist the management of weed populations.

Keywords Integrated weed management, *Lolium rigidum*, weed seed bank, herbicide resistance.

Introduction

The concept of integrated weed management (IWM) evolved from that of integrated pest management (IPM). The latter concept was first articulated with respect to insects in the 1950s and recognized that maintaining insect populations below an economic threshold was a better basis for management than attempting to control pest outbreaks (Stern *et al.* 1959).

IWM can be defined as 'a sustainable management system that combines all appropriate weed control options' (Sindel 2000); however, it is important to realize that IWM is not just any assortment of weed control tactics. Any IWM system needs to be a planned application of appropriate management options to achieve the desired goal. Such a definition implies that not all tactics available, or even appropriate, are necessarily used. Rather the goal of achieving both short- and long-term reductions in population size is the focus of weed management decisions. This may mean that some available weed control options are not employed, either because they are unnecessary in achieving that goal, or they conflict with other, more effective tactics.

I will be using weed control in southern Australian grain cropping as an example to discuss the underlying principles and reasons for adoption of IWM, concentrating on grass weed management. This example will complement others given in this symposium, but will also illustrate how a profound shift in thinking about weed control in this sector has occurred.

The changing face of weed control in southern Australian grain cropping

The past 30 years has seen two revolutions in thinking about weed control in southern grains cropping. Prior to the widespread adoption of herbicides for grass weed control in cropping, two strategies were widely used to manage problem weeds. These were cultivation and rotation into pastures. The adoption of herbicides as the major component of weed management in grain cropping gained significant momentum in the 1970s and continued through the 1980s. The factors contributing to this are many and included: a recognition that cultivation needed to be reduced; a recognition that earlier crop seeding meant increased yields; a decline in the value of sheep necessitating an increase in cropping intensity; consolidation of farms increasing average farm size; and a recognition that cereal root diseases were significantly reducing cereal grain yields (Poole 1987). It was the availability of very effective grass herbicides, in particular herbicides that could be used selectively in wheat, which facilitated the coming of the herbicide age.

The widespread adoption of herbicides for weed control, along with other practices, also ushered in a period where average wheat yields increased. However, it was not very long before problems began to occur. In the early 1980s populations of annual ryegrass (*Lolium rigidum* Gaud.) with resistance to diclofop-methyl evolved (Heap and Knight 1982). Currently there are 26 weed species in Australia with herbicide resistant populations. Herbicide resistant weed populations are known from all states and it is estimated that more than half of all grain cropping farms harbors herbicide resistant weed populations (Table 1).

The second revolution in thinking was driven solely by the emergence of herbicide resistant grass weeds as a major problem. With the rapid loss of very effective herbicides, farmers had to resort to less effective herbicides or other weed control practices. When post-emergent herbicides could no longer be relied on as the main form of grass weed control other strategies need to be employed. Options such as cultivation or rotating to pasture and grazing have been suggested (Powles and Matthews 1991). While potentially useful,

Table 1. Incidence of herbicide resistance in annual ryegrass from field surveys in South Australia and Western Australia[A].

State	Populations resistant (% of tested)[B]		
	Diclofop-methyl	Chlorsulfuron	Both
SA	37	20	6
WA	23	38	13

[A] Collated from Preston (unpublished data) and Llewellyn and Powles (2001).
[B] Resistant populations are defined as populations where more than 20% of treated plants survived.

such strategies have been poorly adopted by farmers as a response to the evolution of herbicide resistance (Llewellyn 2002). Instead a number of other options, including novel uses of herbicides have been preferred. The widespread evolution of herbicide resistance has also resulted in greater consideration for managing weed populations rather than simply treating weed infestations.

Weed population dynamics and IWM

The focus of weed management in annual cropping systems has traditionally been the maintenance of yield. Therefore, the great majority of weed control options used in cropping systems target seedling weeds and rarely has any consideration been given to control of adult or flowering plants.

Many annual weeds persist as a result of prodigious seed production. Many of the major grass weeds of cropping do not have persistent seed banks with most of the seed germinating in the year after it was produced (McGowan 1970, Monaghan 1980, Medd 1990). Even if weeds are controlled exceptionally well by herbicides early in the season, the few surviving weeds often produce enough seed to repopulate the site. For this reason there has been a failure to eradicate grass weeds from cropping fields. There is now recognition that gaining extra weed control at the beginning of the season has much less impact on populations than does reducing seed set of surviving weeds at the end of the season (Medd 1990). An additional advantage that has been recognized is that if the surviving weeds are resistant to herbicides, then stopping seed set could also delay the onset of resistance.

One method of reducing weed seed set is through increasing competition from the crop. Research conducted by Lemerle *et al.* (1995) showed significant differences between crop types in their ability to reduce weed seed set of annual ryegrass. In general, cereals were better than canola, which was better than pulses. There were also differences between cereals with oats being more competitive than barley or wheat. It was also recognized that increasing seeding rates of cereals could reduce weed seed set of grass weeds (Medd *et al.* 1985, Lemerle *et al.* 1996).

Another option is to use herbicides to reduce seed set of weeds at the end of the season. For example, pulse crops can be treated with an application of paraquat at the end of the season to reduce seed set of annual ryegrass. This practice, termed crop topping, can reduce seed set of annual ryegrass by up to 80% (Powles and Matthews 1996).

An example of the importance of managing weed seed set on farms can be seen from the work of Craddock *et al.* (1999) with two farmer groups in South Australia. These farmer groups monitored weed seed banks over six years in autumn by collecting soil samples across a set transect within a cropping field. The study monitored the combined effects of specific crops and the management strategies employed within those crops on weed seed banks. One of the observations made from this monitoring program was how rapidly annual ryegrass populations can increase. Figure 1 shows an example where the population of annual ryegrass increased from about 540 seeds m^{-2} to over 16 000 seeds m^{-2} in a single year as a result of a weed control failure. It then took four years for the farmer to reduce the annual ryegrass population back to the original size. Had the farmer decided to stop seed set in that part of the crop with the heavy annual ryegrass infestation instead of harvesting the crop for grain, it may have been possible to continue cropping rather than putting the paddock into pasture.

IWM in southern cropping systems

IWM practices are being adopted by farmers in southern Australia usually as a response to the evolution of herbicide resistance in weeds. It turns out that the adoption of IWM does not involve an abandonment of herbicides, despite resistance. Instead, additional strategies are implemented to aid weed management. There is also greater willingness to employ strategies to reduce weed seed inputs.

The weed seed bank monitoring conducted in South Australia shows examples of the use of IWM strategies to manage annual ryegrass. Annual ryegrass seed banks were higher prior to barley, oats or pasture than for all other crops. Farmers were using barley, pasture and hay as tools to manage annual ryegrass populations. When annual ryegrass populations increased, these crops were sown.

Overall, annual ryegrass seed populations stabilized in barley and decreased slightly in pasture. Oats for hay was clearly the most effective method of managing annual ryegrass populations with the seed bank of annual ryegrass decreasing by an average of 80%.

One of the more surprising results was how poorly wheat performed. On average, annual ryegrass seed banks doubled when wheat was grown. This is most likely a result of widespread herbicide resistance and few remaining effective herbicides for annual ryegrass control in

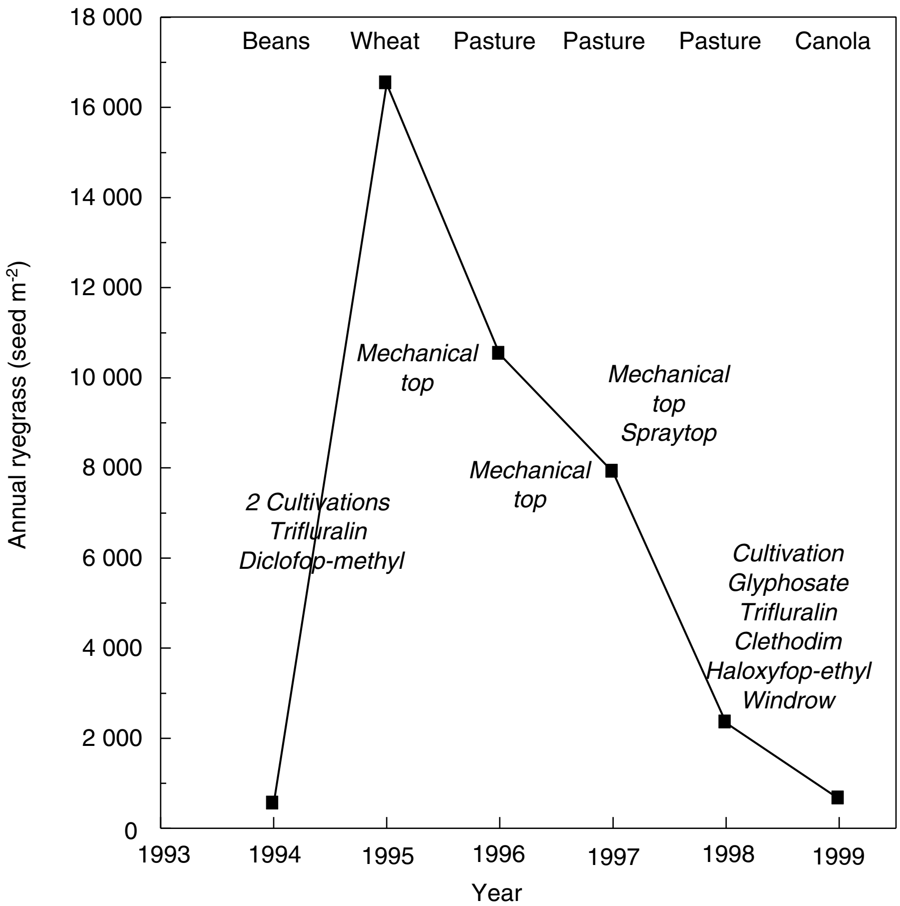

Figure 1. Changes in annual ryegrass seed bank for a single field monitored by the Alma and Tarlee Land Management Group (adapted from Craddock *et al.* 1999). The crops grown in each year are listed at the top and in italics are the weed management practices used in each year.

wheat. Farmers were growing oats, pasture and legume crops where herbicides or other tools could be used to reduce annual ryegrass seed set to compensate for the poor performance of wheat.

There is not a single IWM program that is suitable for all farmers. For example, pasture might be quite a useful option in some circumstances, but will be less appealing if the farmer has no stock or fences. Therefore, IWM strategies for controlling weeds in cropping systems consist of only a selection of the available tactics. The tactics chosen will be those that suit the soil type, rainfall pattern, crop rotation, equipment available and farmer preference. The latter may be just as important in determining the tactics used as all of the other reasons.

Table 3 lists possible tactics that could be employed in an IWM package for the southern grain growing area. These are collected into tactics for reducing annual ryegrass seed set in the year before the crop is sown, tactics employed prior to or at crop seeding and tactics used within the crop. An ideal IWM package should include tactics from each group.

Conclusions

IWM in southern Australian grain cropping is being adopted largely as a response to the problems of managing herbicide resistant weeds. A cornerstone of IWM strategies for annual grass weeds in cropping is reduction of weed seed set. This is vital as the weeds surviving early season control can repopulate the site and maintain, or even increase, weed populations. Where herbicide resistance is present and grass weed populations become too high, there may be a need to take a field out of cropping, solely to enable weed populations to be reduced. Farmers with severe grass weed problems are showing increasing willingness to take such drastic action.

Extending IWM to farmers who have not experienced herbicide resistance is often difficult. Even when resistance is present, farmers tend to adopt those tactics that they perceive offer other short-term value to farming systems (Llewellyn 2003). Therefore, there remains a significant challenge to obtain greater and more pro-active adoption of IWM strategies in southern Australian grain cropping systems.

Table 2. Annual ryegrass seed banks in the autumn prior to sowing the crop (before) and prior to sowing the next crop (after) for a variety of crops monitored by the Alma and Tarlee Land Management Group (collated from Craddock *et al.* 1999)

Crop grown	No. crops	Annual ryegrass (seeds m^{-2})	
		Before	After
Wheat	47	1192	2681
Barley	8	3023	3318
Oats for hay	6	2673	515
Pasture	27	6238	5337
Field peas	14	1318	1425
Faba beans	5	526	437
Canola	12	1255	702

Table 3. Integrated Weed Management strategies for southern grain cropping

Weed seed set control prior to crop	Weed control before or at seeding	Weed control in crop
Green or brown manure crop	Autumn tickle	Competitive crops and cultivars
Pasture topping	Cultivations	Increased crop seeding rate
Crop topping	Knockdown herbicide(s)	Decreased row spacing
(peas and lupins)	Pre-emergent herbicide(s)	Selective herbicides
Weed wiping	(where available)	(where available)
(lentils)		
Silage		
Hay		
Weed seed collection at harvest		
Burn stubble		

Acknowledgments

The Grains Research and Development Corporation funded some of the research that is reported in this paper.

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Integrated blackberry (*Rubus fruticosus* L. agg.) management: a Victorian case study

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Summary The effective control of blackberry (*Rubus fruticosus* L. agg.) requires the use of an integrated management approach. This paper presents an overview of current control techniques and describes factors that need to be considered when developing an integrated blackberry management strategy. A combination of slashing, grubbing, grazing, fire, competition, herbicide application and biocontrol will provide the best long term results. The combination of control techniques utilised will be determined by factors such as the size, accessibility and proximity to water courses of the infestation, available resources, climatic conditions, adjoining land use, *Rubus* spp. present and objectives of the management strategy.

Introduction

The aim of this paper is to provide current information on the integrated management of blackberry (*Rubus fruticosus* L. agg.) in Victoria. Successful integrated management of blackberry requires a holistic management approach and sound knowledge of the available control techniques and how they can be integrated into an overall blackberry management plan. There are many variables that need to be considered with an integrated plan to ensure that the objectives of the management strategy are met. Weed managers need to have a sound understanding of the relationships that exist between different control techniques in order to achieve the most effective outcomes.

Status

Blackberry is a *Weed of National Significance*. It is also a declared noxious weed in all Australian states and territories with the exception of the NT (National Weeds Strategy 2002). In Victoria blackberry is categorised as a Regionally Controlled Weed in all catchment management regions except for the Mallee, where it is not categorised (KTRI 1998a).

Under the *Catchment and Land Protection Act 1994* landowners and managers are responsible for taking all reasonable steps to control and prevent the spread of Regionally Controlled Weeds on their land and on leasehold land that they occupy.

Biology

Blackberry is a perennial shrub that often forms large, dense impenetrable thickets to 7 metres high. The only perennial part of the plant is the crown and root system. Canes or stems are biennial, erect or semi-erect, arched or trailing to 7 metres long (Amor *et al.* 1998, Bruzzese *et al.* 2000). First year canes, known as primocanes, emerge from buds on the crown each spring and grow rapidly in an arching manner. In autumn when their tips reach the ground they sprout roots and produce a bud that will produce a new primocane the following spring. These new plants at the rooting tips are daughter plants (Bruzzese *et al.* 2000) and it is this process that produces the rapid vegetative expansion of blackberry infestations. Canes in their second year develop short flowering branches, known as floricanes, over the growing period, which then die back after fruiting. Canes are 5-sided, finely hairy to hairless, soft and green at the tips, older growth is woody and dark green to reddish-purple and covered in large, sharp prickles (Muyt 2001).

Flowers are white or pink, 2–3 cm in diameter. Inflorescences are either cylindrical or pyramidal, depending on the species of blackberry (Bruzzese *et al.* 2000, Muyt 2001). The fruit is a highly palatable berry, 1–3 cm in diameter, which changes from green to red to black as it ripens. The berry consists of an aggregate of druplets, each containing one seed. Depending upon species blackberry can produce up to 13 000 seeds per square metre. About 1% of seed germinates in the year following production, whilst approximately 10% of seed germinates within the first three years. The longevity of seeds stored within the soil is currently unknown. The ingestion of seed by birds and animals, not only transports them but also increases germination to 30% in the first year (Bruzzese 1998).

Only *Rubus ulmifolius* produces seed sexually. Other blackberry taxa produce seed asexually, this seed that is produced is an exact genetic replica of the mother plant. Occasionally two blackberry taxa reproduce sexually, one taxon usually being *R. ulmifolius*. The resulting hybrids reproduce asexually. (Bruzzese *et al.* 2000).

Impact

Blackberry has considerable agricultural and environmental impact. This impact is caused by the invasive nature of the weed and its ability to form large thickets with a dense canopy that excludes light from the soil surface (Parsons and Cuthbertson 1992) thus limiting the potential for other species to germinate and provide competition.

In agricultural ecosystems blackberry infestations can invade poorly managed pasture and reduce the carrying capacity (Parsons and Cuthbertson 1992). The prickly nature of the plant makes it unpalatable to most stock, with the exception of deer and goats. As such blackberry has a considerable economic impact on agriculture through lost production and the costs of control (Bruzzese *et al.* 2000). There are currently no accurate estimates of the economic cost that blackberry is having within Victoria.

In natural ecosystems the presence of dense blackberry infestations can suppress the growth of some native plant species (Amor *et al.* 1998, Davies 1998). This reduces the floral biodiversity of infested areas. In areas where blackberry infestations are allowed to persist for extended periods the age structure and structural diversity of plant communities could also be adversely affected, which in turn would lead to a reduction in habitat niches for fauna.

Conversely blackberry also has some positive impacts which need to be considered when implementing a management plan. The fruit is highly valued, either as a fresh fruit or for use in jams, wines, liqueurs and pie making. Blackberry thickets are also known to provide nesting sites for some native bird species (Parsons and Cuthbertson 1992).

Variation

There has recently been a major taxonomic revision of exotic *Rubus* spp. in Australia, which is currently unpublished. The revision was undertaken using genetic and morphological taxonomic techniques. One of the major outcomes of the revision is the renaming of the most widely distributed taxon of the *R. fruticosus* L. agg. in Australia from *R. discolor* to *R. anglocandicans* Newton (Pigott *et al.* 2003, in press).

Control techniques

There are a variety of control techniques that can be utilised to control blackberry infestations. The more commonly applied techniques are detailed below. The choice of which control techniques to implement will be determined by factors such as the amount, density and accessibility of the infestation, available equipment, resources and knowledge, the compatibility with surrounding landuse and the objectives of the blackberry control strategy.

Grubbing

The removal of the above ground biomass and subsequent removal of crowns and roots is an effective technique for controlling blackberry. It is essential that as much root matter as possible is removed because of the tendency for blackberry to produce root suckers (Amor *et al.* 1998). This control technique is very labour intensive and as such is only suitable for individual plants, small infestations or for use in highly sensitive areas where other control techniques can not be utilised.

Slashing

Slashing or mowing of blackberry will not kill plants outright. Vigorous regrowth can occur from crowns and root fragments after slashing. Frequent slashing to ground level may reduce the density and spread of blackberry infestations. Crown and root reserves of plants can be depleted by frequent slashing as plants are forced to continually regrow from these reserves. Slashing can be useful to increase accessibility to infested areas for other control treatments (Bruzzese *et al.* 2000). The use of slashing to promote new growth at strategic times can also assist the efficacy of blackberry leaf rust fungus (*Phragmidium violaceum*), which predominantly attacks the younger leaves (Evans *et al.* 2003).

If slashing is going to be used in conjunction with the application of a herbicide, the choice of herbicides that are suitable will be restricted and will be determined by the interval between slashing and herbicide application. Removal of the aboveground biomass reduces the leaf surface area available for foliar uptake of herbicides. This reduces the amount of herbicide translocated to the roots and crown, which in turn can reduce the efficacy of the herbicide application. Slashing in the season before a planned foliar-uptake herbicide application is therefore not recommended. In the case of granular herbicides, results of some trials have shown that slashing before an application gives improved efficacy over using granules without slashing (Bruzzese *et al.* 2000). If blackberry canes are to be slashed after a herbicide application it is important to allow sufficient time to enable the herbicide to act. This will vary between herbicides with different active constituents. Always refer to the product label to determine what the recommended period is.

Grazing

Browsing animals such as deer and goats can suppress blackberry growth. Stocking rates must be sufficient and grazing pressure maintained continuously to ensure that regrowth is controlled. Fencing must be suitable to ensure that the animals only impact on infested areas of agricultural land. Because of the non-selective nature of browsing animals this control technique is not suitable for all situations, especially if there are areas of desirable native vegetation intertwined with blackberry infestations (Bruzzese and Lane 1996).

Fire

This technique is generally used as a follow-up to herbicide application to remove dead canes and allow access for rehabilitation of the treated area (Bruzzese and Lane 1996, Bruzzese *et al.* 2000), to allow access to untreated areas for upcoming herbicide applications and to remove fire hazards. The use of fire must comply with all fire regulations that apply to the area where and at the time the burn is intended to take place.

Blackberry will respond with vigorous regrowth to low intensity spring and autumn fires (Amor *et al.* 1998). Its response to high-intensity summer wildfires is currently unknown. Following the recent fires across north-eastern Victoria a study is being undertaken to record the regenerative response of blackberry to high-intensity summer wildfire events. This study will also attempt to assess the effects of browsing pressure exerted by deer on blackberry regrowth in the post-fire environment.

Herbicides

The use of herbicides to control blackberry infestations is one of the most widespread control techniques currently used. There is a range of herbicides registered for the control of blackberry in Victoria. These herbicides have a variety of active constituents and are classified into groups depending on the mode of action of each active constituent.

Under Victorian legislation there are controls on various aspects of the uses of agricultural chemicals. It is the responsibility of the chemical users to familiarise themselves with these controls and ensure that herbicide applications are conducted in accordance with the relevant legislation and herbicide label instructions (KTRI 1998b).

Efficacy

The efficacy of herbicide applications will depend upon factors such as the timing of application, application technique, application rate, the water quality used for mixing herbicides, the addition of any surfactants or penetrants and the species that is being controlled. No herbicide will eradicate blackberry infestations after one application. Therefore subsequent applications should be planned to control regrowth as part of an ongoing management strategy (Bruzzese and Lane 1996).

The optimal timing of herbicide applications will vary between different locations dependant upon localised climatic conditions, which taxon is being targeted and which herbicide is being used (Muyt 2001). Generally the most effective time to apply herbicides is early summer to mid-autumn, or during the active growing period. Blackberry that is exhibiting signs of drought or water stress, or severe attack by *P. violaceum* should be excluded from any herbicide applications as the efficacy of the application could be reduced. Herbicide applications during times of unseasonably hot or cold conditions should also be avoided for the same reasons. If blackberries are bearing mature fruit at the time of application then a persistent marker dye and suitable signage should be erected to ensure that contaminated fruit is not consumed by humans (Bruzzese and Lane 1996).

When preparing a herbicide mix use the cleanest water source available. The active constituent in some herbicides can be adsorbed on particulate matter in turbid water reducing the efficacy of the herbicide.

There is a range of equipment suitable for applying herbicides to blackberry. The equipment used will be determined by the accessibility of the infestation and the resources available. The use of high-pressure handgun spray equipment is suitable for large infestations because the high pressure provided enables sufficient penetration and coverage of the thickets. Low volume knapsack sprayers can be used effectively to apply herbicide to smaller infestations or areas of regrowth.

An important aspect of application technique is to ensure that the correct nozzle is selected for the situation and thus an appropriate droplet size is produced; an important part of minimising spray drift. Limiting the amount of spray drift limits the potential for off-target damage, reduces the amount of herbicide used and reduces the potential for contaminating watercourses. Herbicide application rates must adhere to the label instructions.

In areas where blackberry infestations are entwined with native vegetation particular attention needs to be paid to the manner in which the herbicide is applied. If the desirable vegetation is susceptible to the herbicide being applied then an alternative herbicide or control method should be considered.

Many herbicides specify the use of an adjuvant or surfactant. Operators should ensure that surfactants used in close proximity to watercourses are approved for aquatic use.

Some herbicides registered for blackberry control have strong residual properties. The degree of persistence will vary between different active constituents and will be influenced by factors such as soil type, soil pH, soil moisture and soil organic matter.

Native *Rubus* spp. display different responses to herbicide applications when compared to European *Rubus* spp. In general terms the native *Rubus* spp. are not as susceptible to herbicide applications as European *Rubus* spp.

Biocontrol

Biological control involves the use of organisms that are natural enemies of the target species to suppress the growth of the target to a level where it is less competitive than surrounding vegetation (Bruzzese and Lane 1996). The blackberry leaf rust fungus (*Phragmidium violaceum* (Schultz) Winter), was intentionally introduced to southern Australia in 1984 (unauthorized release) and officially released in 1991 and 1992 (Pigott *et al.* 2003, in press).

The blackberry leaf rust fungus is a defoliating disease that attacks the leaves of the blackberry plant. Younger, fully opened leaves at the cane tips are more susceptible to attack than older leaves (Evans *et al.* 2003). It can also be found on the inflorescence and green parts of the growing canes. The leaf rust fungus appears as characteristic purple-brown blotches, 2–3 mm in diameter on the upper leaf surface. In summer there are corresponding golden-yellow powdery spores on the underside of the leaf, in autumn and winter these spores take on a black, sticky appearance. Blackberry leaf rust fungus can be confused with three other fungal diseases, which are commonly found on blackberry leaves. The most important characteristic which distinguishes blackberry leaf rust fungus from the other three fungal diseases is the presence of the corresponding yellow or black powdery or sticky pustules on the underside of the leaf (Bruzzese and Lane 1996).

On leaves that are heavily infested with the leaf rust fungus, the blotches on the upper leaf surface will eventually merge, the leaves will die, shrivel and fall from the canes. This defoliation limits the growth of the plant and allows light to penetrate the blackberry thicket, which enables other vegetation to establish and compete with the blackberry (Bruzzese and Lane 1996). This winter defoliation, which happens to varying degrees, was not known to have occurred prior to the release of *P. violaceum*. Monitoring of rust infested blackberry infestations have shown that a significant reduction in daughter plant production can result (Mahr and Bruzzese 1998).

The impact of *P. violaceum* seems to be greatest in higher rainfall areas south of the Dividing Range in south eastern Australia (Mahr and Bruzzese 1998). The rust is most effective in areas that receive an average annual rainfall of 750 mm or above, that receive regular summer rainfall or have high summer humidity and have average maximum daily summer temperatures of around 20°C (Evans *et al.* 2003). These specific climatic requirements of the current rust strain means that the degree of impact that it has will vary considerably across the landscape.

There is a high degree of species specificity of blackberry taxa that are susceptible to the leaf rust fungus. The most widely distributed taxa of blackberry are more susceptible to the current strain of rust (see **Variation** section). Where blackberry infestations consist of mixed *Rubus* species, only the most susceptible species will be attacked, the other non-susceptible species will not be attacked to any significant degree. *P. violaceum* does not attack the majority of commercially grown *Rubus* species. It is possible that some commercial varieties of thornless blackberry derived from the European blackberry could be affected by *P. violaceum*. Native *Rubus* species are not damaged by *P. violaceum* (Bruzzese and Lane 1996).

Competition

Maintaining a high degree of competition for light and nutrient resources whilst blackberry is at the seedling stage is an important component of any integrated management strategy. Amor (1974) found no survival of *Rubus discolor* seedlings at sites receiving less than 44% full sunlight in December to February. Any blackberry control strategy that is implemented should endeavour to maintain the maximum amount of competition from desirable species as possible. High levels of competition from desirable species, reduces the ability of other weed species to take hold and reduces the potential for soil erosion and subsidence of stream and creek banks.

Integrating control options

The use of one particular control technique in isolation will not be as effective as combining a range of the available control techniques (Bruzzese and Lane 1996). A range of factors will determine the control techniques that are chosen and how they are integrated. Factors that need to be considered will include the objectives of the management strategy, available resources, accessibility of the infestation, proximity to watercourses and high-value horticulture crops and the current land management practices.

Integrated control strategies will vary markedly dependant upon the environment where the blackberry infestation is located. In general terms blackberry infestations can be classified as occurring in either agricultural ecosystems or natural ecosystems, both of these ecosystems can include riparian zones.

Agricultural ecosystems

In agricultural ecosystems *Rubus* spp. have the ability to invade poorly managed pastures. The degree of invaisiveness displayed will be determined by the species of blackberry that is present, the climatic and environmental conditions in which the blackberry is growing and the type and amount of grazing pressure that is being exerted on the infestation (Parsons and Cuthbertson 1992).

In pasture situations the use of a combination of herbicides, cultivation, pasture renovation and fertiliser application is effective in improving poor pastures and controlling blackberry infestations (Bruzzese and Lane 1996).

Natural ecosystems

Rubus spp. are considered to pose a very serious threat to a variety of vegetation formations. Carr *et al.* (1992) list the following vegetation formations as being invaded by *Rubus* spp., lowland grassland and grassy woodland, dry sclerophyll forest and woodland, damp sclerophyll forest, wet sclerophyll forest, riparian vegetation, freshwater wetland (seasonal), warm temperate rainforest and cool temperate rainforest.

If heavy rust infestations are present, then those infestations should be excluded from any herbicide applications for that season. Blackberry infestations that are not attacked by the leaf rust fungus should have a higher priority for control. If a herbicide application is intended to control blackberry infestations, particular attention should be paid to herbicide selection and application technique. Whilst a high degree of efficacy needs to be maintained, residual properties of herbicides and potential for off-target damage need to be carefully considered, especially in close proximity to watercourses, or in areas subject to periodic inundation (Davies 1998). Herbicide selection also needs to be compatible with the intended timeframe of any revegetation works. The use of a herbicide that has highly residual properties could result in subsequent revegetation works having limited success.

Control strategies that create a minimal amount of soil disturbance should be favoured for use in natural ecosystems. Soil disturbance creates a window of opportunity for other weed species to establish and increases the potential for soil erosion, which has detrimental impacts upon water quality (Bruzzese and Lane 1996).

Depending upon what seed is present within the soil, the use of fire to remove dead canes and stimulate the germination of fast growing colonizing species such as *Acacia dealbata* can be useful in providing a high degree of competition to blackberry. If the seed of desirable competitive native vegetation is not present it is possible that it should be physically introduced (Groves *et al.* 1998).

Because blackberry thickets are known to be harbours for pest animals, such as rabbits and foxes, the control of blackberry should be coordinated with any pest animal control that is occurring (Groves *et al.* 1998).

Regardless of whether the blackberry infestation is within an agricultural ecosystem or a natural ecosystem, blackberry control strategies should be developed with longer-term management objectives in mind. The use of multiple control or suppression techniques should form the basis for a well thought out integrated management strategy.

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Integrated weed management of horehound

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Summary Horehound is a widespread weed in Victoria, especially the north-western part, with serious impacts on pastures and natural ecosystems from displacement of pasture species and native vegetation and from fleece contamination. Existing plants can be killed by a variety of cost-effective techniques but long-term management is required because of horehound's tendency to re-establish quickly from a large seed bank. Two biocontrol agents have been established and one of them is now widespread and having definite impacts on the weed. Ways in which the other horehound control techniques may interact with this biocontrol agent are discussed. It is concluded that the effort required to develop IWM strategies that include biocontrol agents will in many cases be amply justified.

Keywords Herbicide, grazing, plume moth, biocontrol, integration.

Introduction

Marrubium vulgare (Lamiaceae), horehound, is a native of the Mediterranean region, now present as a weed in North America, New Zealand and Australia, particularly Victoria and South Australia. Horehound was possibly first introduced into Australia from Europe via a shipment of botanical plants sent by Sir Joseph Banks. A record from Sir Joseph Bank's diary states that *M. vulgare* was sent to NSW on board the ship Porpoise on 11 October 1798. It appears to have been introduced for use as a garden herb, medicinal and for beer brewing purposes (Parsons and Cuthbertson 2001). First recorded naturalisation occurred by the 1840s. Horehound is a drought tolerant perennial widely distributed in areas receiving a minimum annual rainfall of 200 mm (Carter 1990), preferring alkaline soils. Grazing animals avoid horehound if alternative food is available because of a bitter alkaloid, marrubin, contained in the leaves. Grazing thus tends to favour establishment and persistence of horehound by decreasing competition. Horehound as with most members of the Lamiaceae (mint) family is primarily bee pollinated.

The fruit or burr is well adapted for spread because it readily attaches to wool, fur, clothing and similar material and in this way has become widely dispersed throughout Australia. Sheep, rabbits, kangaroos and emus can easily spread the burrs, which readily attach to the fur or feathers. Water is also an effective dispersing agent, as may be seen along water supply channels in many areas. Horses are known to pass the seeds in a viable condition. As the seeds readily germinate, dispersal at any time will aid in the plants spread. Mature plants can produce in excess of 20 000 seeds per annum, although the more numerous smaller plants produce about half this number. Anecdotal evidence indicates that the seeds can survive in the soil for up to 7–10 years (Weiss *et al.* 2000). The seeds germinate opportunistically in favourable conditions, which usually follow autumn rainfall. A seed bank of 20 000 viable seeds per m^2 was reported by Weiss (1996).

Infestations of horehound occur in pastures, roadsides and conservation areas especially in north-western Victoria and south-eastern South Australia in semi-arid conditions. Lane *et al*. (1980) estimated the total infestation in Victoria to be 6 million hectares, including 100 000 ha of dense infestations. Because of its invasive nature and early introduction, horehound has most likely reached its maximum potential distribution across Australia. However, because of its drought tolerance, it has the potential for dense establishment in many more areas of Australia than is fully realised.

Horehound decreases pasture productivity and reduces the value of fleeces due to contamination with the hooked burr containing the seeds. Sloane *et al*. (1988) estimated the cost of horehound to Australian wool producers to be A$680 000 per annum. Once disturbance has permitted horehound establishment it can exclude native plants in certain situations. It is a considerable problem in Wyperfeld National Park in Victoria where annual expenditure of A$2000 plus 20 days labour on chemical control and hand-pulling is required to clear camping areas and roadsides, without attempting to control the majority of the infestation (Weiss and Sagliocco 1994).

This paper begins by reviewing the individual control techniques used for horehound. Ways in which different physical and chemical control options might best be integrated with one of the biocontrol agents are then discussed. The focus on biological control is because this technique is the most recently developed and its integration with other methods presents the greatest challenges and opportunities.

Individual control techniques

Biological control

A biological control program commenced in 1990. The horehound plume moth (*Wheeleria spilodactylus*) was first released in 1994 (known at that time as *Pterophorus spilodactylus*) and is now established at over 100 localities throughout south eastern Australia (Weiss *et al*. 2000). The plume moth is specific to horehound; the caterpillar (larva) feeds in the growing tips of the plants and then works its way down the shoot, progressively defoliating the stem. Defoliation and destruction of shoot tips weakens the plant and reduces the number of seeds and flowers produced. Feeding by the larvae at a sufficient density will reduce size and seed production and shorten the life of established plants. Clarke *et al.* (2000) predicted that where present for 4+ years at densities of at least two larvae per shoot (in areas with >400 mm rainfall) or at least one per shoot (in areas <400 mm rainfall) plume moths are having or will have some impact on the infestation. Larval densities should be assessed between late autumn and early spring when the whole population is present as larvae. Year-to-year variation in densities is to be expected, so unless the infestation is an immediate and severe problem, assessment of effectiveness should take place over several years before resorting to techniques that are incompatible with biocontrol. The presence of horehound plants stripped of all leaves is a sure indication of a substantial effect. The final horehound population at equilibrium with plume moths cannot yet be predicted and will probably vary according to individual site characteristics.

The horehound clearwing moth, *Chamaesphecia mysiniformis*, was released in March 1997. Larvae feed within the growing tissue of the root and lower stems. Larval infection affects the flow of water and nutrients through the plant, weakens it, reduces growth and increases the likelihood of the plant dying (especially when water stressed). Clearwing moths primarily attack young horehound plants, killing them completely and thus reducing the ability of the weed to replace losses of older plants or invade new gaps. The clearwing moth should work well in combination with the plume moth which suppresses larger plants. Population increase of clearwing moth will be slower than plume moth and its presence is more difficult to assess because the larvae are hidden in the roots. Success with this agent may be restricted to sites where maximum summer temperatures often exceed 30°C.

Chemical control
A number of different herbicides are registered for control of horehound in various situations in Victoria. Rather than attempt to discuss the details of how each herbicide is used under specific conditions there follows a general consideration of the role of herbicides in management of horehound. Information on the herbicides registered for horehound control in your particular situation can be obtained from the Chemical Information Service of the Department of Primary Industries. Always read the label and follow all directions on it.

A horehound infestation that has existed for several years will have formed a large seed bank so removing the adult plants by any method will produce mass germination of seedlings as soon as soil moisture is available. Rapid establishment of a cover of competitive species such as pasture grasses is required to prevent horehound re-establishing. If horehound does re-establish after initial chemical control and re-treatment is needed, it should be done before the new horehound produces seed. Young horehound plants are in any case considerably easier to kill than large mature ones. Repeated herbicide application over a number of years may be acceptable in some situations, e.g. a productive grass pasture where the value of the pasture justifies the expenditure and damage to legumes is not a concern. Often however in less productive pasture or in amenity/natural ecosystem situations repeated chemical control is excessively expensive, particularly if ongoing re-invasion of horehound from adjacent land is expected. Long-term herbicide use is also likely to degrade native vegetation, unless it is limited to small areas of careful spot-spraying. Steep, rocky or wooded situations further add to the cost of spraying due to access problems. It is therefore highly desirable that one or more alternative control techniques should also be used to reduce the frequency of chemical control and/or the area that needs to be treated each time.

Grazing
Sheep will generally avoid horehound due to the bitter taste but may eat it when other feed is scarce or when lush shoots are produced in spring. Temporary taint of meat will result from feeding on horehound. Grazing often favours horehound by creating gaps in which horehound seedlings can later establish without competition from other pasture species. Heavy grazing pressure will do little to suppress large horehound plants but can be effective on seedlings or short new shoots produced following slashing, burning, herbicide application or cultivation. Rabbits may reduce horehound seedlings in the same circumstances as sheep but are probably more likely to avoid small horehound plants. Feeding and digging by rabbits definitely create gaps for horehound seedling establishment and rabbits will also transport horehound seeds. Control of rabbits assists horehound management and pasture or natural vegetation re-establishment. At one site the author has seen many isolated small horehound plants eaten back almost to the ground early in the autumn when little other green material was available. Nearby large horehound plants next to trees and fallen branches were untouched. Hares were suspected of being responsible but this has not been confirmed.

Slashing, grubbing and cultivation
Manual removal by grubbing or hand-pulling is labour-intensive and will need to be repeated as new plants establish from seedlings. Very small patches are suitable for eradication by this technique, or it could be used as a containment measure to prevent spread from a larger infestation. Care is needed to ensure that hand-pulling does not spread seeds to uninfested areas. Slashing repeated at least annually, may restrict seed production and limit spread of established plants and the regrowth may be more attractive to sheep. Slashing is unlikely to achieve rapid reduction of horehound infestations unless combined with other techniques, and seed may be spread to uninfested areas on machinery. Where feasible deep cultivation will destroy existing plants especially if repeated in summer so that plants dry off. It is not advisable if the horehound is currently confined to relatively small patches, as it will disperse the seeds resulting in a larger infested area. Horehound seedlings will establish rapidly in the disturbed ground unless suitable follow-up measures are taken.

Fire
Burning is an effective means of killing larger plants where conditions are suitable but the large numbers of seedlings produced will require some other technique to be used afterwards. Where horehound occurs as separated patches in heavily grazed pasture a fire would not carry. Sites in the higher rainfall regions would have few occasions when the horehound was sufficiently dry, except in periods of high fire danger. Large numbers of horehound seeds may be killed by fire and many more germinate immediately afterwards so that the horehound seed bank is greatly reduced. Nevertheless, it seems unlikely that the seed bank could be decreased to the point where horehound seedlings would not rapidly reappear in suitable gaps, so fire would always have to be combined with some other technique. Regeneration of native species may be aided by fire if the circumstances are right. More detail on a case where integrated horehound control involving fire was tried is given by Weiss and Wills (2000).

Integrating biological control with other techniques
Effects of fire, slashing, herbicide etc are relatively predictable and immediately apparent and land managers are familiar with them. Therefore integrating them into an IWM program presents no special difficulties once the ecology of the weed and its responses to the individual techniques are known. Biological control has some features that have worked against its integration with other weed management techniques. The agent or agents involved may fluctuate greatly in numbers from year to year according to environmental conditions. Furthermore effects of different seasonal conditions are often not well known because the organism is new to Australia. Distribution of the agent may be highly patchy within a site due to subtle differences in the available habitat, so that some parts may need to be treated differently. Biocontrol agents are frequently difficult to see for all or part of their life cycle, making it hard to estimate how many are present and therefore how much control might be expected in the coming season. Where multiple agents have been introduced for the same weed further complications occur because the different species may be at different stages of population establishment, may affect each other in unpredictable ways and may respond differently to site conditions. Predicting the ultimate long-term outcome of biological control at a given site is therefore difficult.

In summary biological agents are less easily manipulated and their effects more unpredictable than the other techniques. There has been a tendency because of this to treat biological control as the technique of choice for places where all other techniques are unaffordable or impractical and to just let biocontrol agents 'get on with it by themselves'. Sometimes this approach has been all that was needed for success. It is of course also very attractive to a land manager to have a weed management plan that requires no work and no expenditure after initial establishment of the agent. There will always be some locations in which biological control is the only feasible approach and rejection of other techniques is a reasonable decision. However, there are good reasons to think that using biological control in combination with other techniques at a single location may frequently provide much more effective weed management. The integration may be very closely linked to the life cycle and aim to improve conditions for it in a highly specific way, or it may mean doing something very simple and fairly obvious such as preserving reserves for the survival of biocontrol during managed burns. The following discussion uses horehound as a case study from which ideas for integrated management of other weeds may be drawn. For reasons of space only the plume moth is discussed; there is in any case little information so far available on the clearwing moth. Worldwide integration of biocontrol agents with herbicides has also recently been reviewed by Ainsworth (2003), showing that uptake of such integration is still limited, despite some very successful examples.

Use of techniques that destroy horehound plants

Total death of horehound plants will result from fire, cultivation, grubbing or a lethal herbicide application. If the infestation is small and can feasibly be eradicated by such techniques then the fate of any biocontrol agents present is irrelevant. More frequently horehound will continue to be present at the site and therefore there could be benefits from a continued presence of the biocontrol agents. Key information required to develop an integrated weed management plan involving the biocontrol agents is; will death of the horehound plants kill the biocontrol agents present on them either immediately or due to later starvation? How rapidly will the biocontrol agent be able to recolonise areas where the horehound was killed once the weed re-establishes from the seed bank?

Fire is the simplest technique to consider from this point of view; it will immediately kill all life stages of the plume moth throughout the burned area. Cultivation or grubbing plants by hand would leave a period of time during which the plants were dying but still green. The duration of this would depend mainly on the weather. Eggs and early instar larvae would still die but late instar larvae or pupae that were able to develop further, together with existing adults would have the opportunity to fly to nearby live horehound.

Whether moths were actually able to reach alternative horehound plants would depend on the size and closeness of the patch of live horehound and on how quickly they abandoned the dying plants. Clarke *et al*. (2000) found that on average each of the three plume moth generations each year dispersed about 30 m at low rainfall sites and 90 m at high rainfall sites. Dispersal might be less where the moths have to cross areas without horehound, or could be more if it is enforced by death of host plants. Ainsworth and Morris (2000) found that in captivity most plume moths moved within a few days from herbicide-killed horehound to healthy plants 2.3 m away. These studies suggest that there is a reasonable chance that many plume moths would move a few tens of metres from horehound killed by grubbing or cultivation and reach untreated horehound, provided that they had reached or were very close to the pupal stage at the time of control.

When horehound is killed by herbicide the prediction of survival and dispersal of the biocontrol agents is a little more complex. There is the question of whether the herbicide is directly toxic to the biocontrol agent and also of whether it changes the plant tissues so that they are less nutritious in the interval between spraying and horehound death. Ainsworth (1999) did some work on these questions and the conclusion was that the herbicide investigated was not directly toxic and did not prevent continued development of larvae while the plant died.

Both the physical and chemical techniques that kill horehound outright could therefore be timed so that they are used when a large proportion of the plume moth population is at the late instar larva, pupa or adult moth stage, thus maximising the chances of successful dispersal. A relevant question is whether survival and dispersal of biocontrol agents after horehound treatment is of any practical consequence. If the treated area is a small part of the total infestation it probably does not matter whether biocontrol agents in the treated area die or move. There seems to be potential for an approach of cultivating or spraying the infestation in strips of maybe 20 m width, in the hope that displaced plume moths will increase the degree of attack on the adjoining untreated strips. Ideally in the following year when the previously untreated strips are dealt with the plume moths will disperse again, to attack the vulnerable young plants establishing after the first year's treatment. This idea is untested but at the very least spreading treatment of the infestation over two years will ensure that the plume moth survives at the site in large numbers to be a long-term part of the horehound management.

Issues of biocontrol agent survival become very important if the whole infestation is to be treated at once on a site where it is acknowledged that the horehound is going to reappear afterwards. This could arise if an area is burnt, cultivated or given an overall herbicide treatment for some pressing reason other than horehound control. Reintroducing the plume moth from another site is possible since this insect is quite easy to establish. Nevertheless it would take at least two or three years for a large population to build up across the site, during which time the horehound would be largely free from attack. Preserving part of the existing plume moth population *in situ* is a preferable approach. Based on the dispersal data referred to earlier it would be ideal to have most of the site within 100 m of a reserve for the plume moth. The reserved area would need to be sufficient to provide enough moths to quickly recolonise the whole site. Since the average annual increase in numbers is at least 100 fold (Clarke *et al.* 2000) the total combined area of reserves could reasonably be less than 1% of the infestation. Reserves are easy to establish for cultivation or ground based herbicide use, firebreaks could be used to control managed burns and perhaps temporary plastic sheet covers if aerial herbicide application is used.

Use of techniques that only damage plants

Grazing with sheep and slashing may as discussed earlier suppress horehound without actually reducing the infestation much, although in combination their effect may be greater because of the preference of sheep for new young shoots. Grazing is likely to have adverse effects on plume moths, at least in the short term because early instar larvae feeding in shoot tips will be removed and die. It is unlikely grazing could eliminate the plume moth from sites where it is well established unless applied intensively for a number of years in combination with other control techniques. Horehound growing on roadsides, on fence lines or amongst fallen trees is in any case likely to provide refuges for the plume moth.

Slashing would also kill the larvae present in shoots that were removed, although pupae might survive to produce adults. Ainsworth (1999) found that survival and egg production were greatly decreased in plume moth adults if they did not have access to horehound flowers for feeding. Slashing would therefore also have adverse effects on adults by depriving them of nectar. New young growth from slashed plants might attract a high level of feeding from both the larvae that survived below the level of the slasher and later from eggs laid by moths moving from adjacent areas. The combined effect on the plant of loss of its taller shoots and plume moth feeding on the remainder might be highly effective but this has not been tested. Slashing part of an infestation each year in strips, as discussed earlier for cultivation may be advantageous. One limitation may be that adult plume moths may not be strongly attracted to new growth to lay eggs until it has produced flowers.

Herbicide treatment intended to kill horehound may result in only sublethal effects due to poor coverage, unsuitable conditions or because some of the plants were larger and harder to kill than the rest. Herbicide applied to control other weeds could also result in sublethal effects on adjacent horehound plants. Provided that the herbicide is not toxic to the plume moth, and most herbicides have low toxicity to insects (Ainsworth 2003), the effect might be somewhat similar to slashing. Part of the plant would die and plume moth larvae would attack the remainder. Unlike slashing however there would be an opportunity for larvae to move from dying shoots to healthy parts of the plant. This amounts to concentrating the original number of larvae on to a smaller number of shoots, potentially increasing the impact of the larval feeding. Such an outcome would rely on the herbicide effect being sufficiently slow to allow movement and on the plume moths being present predominantly as larvae, rather than as eggs that would fall off on dying leaves. Unpublished field trials by the author have found that a highly successful combined effect of herbicide and plume moth feeding seemed to occur in at least one trial. Many aspects remain to be worked out, including whether the plume moth population might crash in the year following treatment of the whole site due to lack of flowers to feed the adults.

Conclusions

The best integrated weed management strategy will be one that is developed by local land managers adapting currently recommended best practice according to the results they achieve and the resources available. To enable this process of adaptive management to take place most effectively, land managers require information that allows them to avoid combinations of techniques that are doomed to failure by identifying the most likely outcomes of interactions. Because effects of biocontrol agents are more difficult to predict than those of other techniques there is a particular need for sound advice on how biocontrol agents are likely to perform under different management scenarios. Experience so far suggests that the additional problems of including biocontrol agents in IWM plans will be more than repaid by the potential for cost-effective sustainable weed management. Gaps still exist in our knowledge of how best to integrate the horehound plume moth in IWM but already strategies with a good prospect of success are emerging.

Disclaimer

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Victorian Serrated Tussock Management Program

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Summary Serrated tussock *Nassella trichotoma* has been declared as the worst weed for decreasing carrying capacity. In 1988, serrated tussock was estimated to cost the Australian Wool Industry approximately $12.9 million annually. A conservative figure given for the cost of lost grazing to serrated tussock in Victoria was $5 million per year. In 1997 the estimated area of serrated tussock in Victoria was 130 000 hectares but its potential spread has been predicted to be 4.6 million hectares in Victoria based on climatic models.

This very invasive wind dispersed weed competes with desirable species and is not eaten by grazing animals.

The major challenges with serrated tussock are halting its spread, and the establishment of land management systems that reduce the impact and reduce the spread from densely infested areas that have naturally low productivity.

The community driven Victorian Serrated Tussock Strategy provides a framework that sets direction and establishes a coordination process for the management of serrated tussock in Victoria.

Keywords Serrated tussock, weed management strategy.

Background

Serrated tussock (*Nassella trichotoma* (Nees) Hack. ex Arechav.) is native to South America. It was first found in Victoria in 1954 and now infests 130 000 ha to the west of the Melbourne metropolitan area. Serrated tussock has the potential to infest a further 4.6 million ha in Victoria. It is also a serious problem in New South Wales, New Zealand and South Africa.

Serrated tussock readily spreads when the mature seed heads break off and are carried by the wind to infest new areas. The seeds may also be carried in fodder and on livestock or farm machinery. Identification is difficult because serrated tussock is superficially similar to many native grasses including members of the Poa, Stipa and Danthonia groups. This has meant that many new infestations remain unnoticed until significant infestations develop.

Serrated tussock is a problem because pastures dominated by serrated tussock are virtually of no value for grazing. The foliage is low in protein and very high in fibre. Stock will starve on heavily infested pastures. Serrated tussock also invades and degrades native grasslands and bushland.

Government involvement in management is justified because of the public benefit obtained by preventing the serrated tussock spreading to other parts of Victoria. Landholders in infested areas need encouragement to undertake control because many infestations are on poor stony ground with relatively low rainfall where the cost of control frequently exceeds the productive value of the land. However, a high level of control is required for the protection of the clean areas of the State.

Landholders, municipalities and the Department of Primary Industries (DPI) are working in partnership to control serrated tussock infestations and to prevent this weed from invading new areas.

Community Led Program

The Victorian Serrated Tussock Management Program was established in 1995 on the recommendation of consultants, Inland Agriculture Pty. Ltd. The Program represents a partnership between DPI, catchment authorities and the community. It is managed by the community led Victorian Serrated Tussock Working Party (VSTWP). The majority of the program's activities are conducted within the Melbourne – Geelong – Ballarat infestation area although monitoring and control work occurs in other areas of the state.

The Program has conducted and/or sponsored a wide range of serrated tussock research and development, education, extension and enforcement activities. Program staff and management has worked closely with Landcare groups, local government and other agencies to promote a holistic approach to land management and serrated tussock control.

The Working Party has been strongly supported by State and local Government in the development of an action program. The program includes:

- Community education and awareness,
- Mapping of infestations,
- Research into improved control measures,
- Landholder education through the facilitator program,
- Coordination of control programs in local areas and along roadsides,
- Together with stronger enforcement of the provisions of the Catchment and Land Protection Act 1994.

Legislation

The Department of Sustainability and Environment (DSE) administers the Catchment and Land Protection Act 1994. This Act provides for the declaration of plants as noxious weeds if they have or have the potential to become a threat to primary production, the environment or community health in Victoria. This legislation confers responsibility on land managers to control and prevent the spread of noxious weeds from their properties.

Current estimates show serrated tussock was affecting 130 000 hectares of public and private land in 1995, the projected figure for potential area under threat is 4.6 million hectares. In response to the 1995 Serrated Tussock Management Strategy, the Government established a Working Party to help advance the program. The 12 members of this Working Party comprise a range of stakeholders including DPI, Port Phillip and Corangamite Catchment Authorities, Landcare and community representatives.

This group reports to the secretary of the Department and has the following terms of reference:

- Oversee the refinement and implementation of the Serrated Tussock Strategy.
- Advise the Secretary, DPI/DSE and Catchment Authorities on the impact and control of serrated tussock.
- Co-ordinate action by local Government, Landcare groups and other groups on serrated tussock.

Department of Primary Industries, (principally Pest Plants and Animals Program) are the service provider to the Working Party. The model developed by DPI/DSE is to provide comprehensive awareness, property inspections and an extension program aimed at encouraging landowners to take all reasonable steps to eradicate serrated tussock.

It aims to increase the effectiveness of existing inputs into its management through the acceptance of currently available opportunities. These opportunities form the basis of the serrated Tussock strategy 2003–2008 and include:

- Containing spread to existing limits and ensure early detection of, and rapid action against, new serrated tussock infestations
- Informing Victorians about the economic, social and environmental impacts of serrated tussock and how to act to minimise this impact;
- Achieving a significant reduction in the impact of existing serrated tussock infestations;
- Establishment of a coordinated, holistic approach to ensure cost-effective serrated tussock management in Victoria;
- Continuous improvement through the evaluation of serrated tussock management in Victoria

Extension

A regional community information and education program is essential to catalyse, support and sustain the management of serrated tussock. The approach taken by DPI/DSE officers is to provide comprehensive awareness, property inspections and an extension program aimed at encouraging landowners to take all reasonable steps to eradicate serrated tussock.

There continues to be a critical need to increase community understanding of the economic and environmental ramifications of serrated tussock. The current extension activities will continue to accelerate behavioural change to achieve faster adoption of the preferred management techniques to combat the serrated tussock spread.

Local Government Programs

While the progress is at different levels depending on the Shire, what is crucial is that there is action. The need to act faster, and in a more cohesive, coordinated and determined process has been an area that was identified in the recent evaluation that must be addressed. Local government involvement in serrated tussock control has been 'well meaning' but still requires a focus on weed management in the rural – urban interface areas where traditional communication networks are limited and the majority of land managers are not using the land for productivity purposes.

Compliance

Enforcement of the Catchment and Land Protection Act 1994 in relation to serrated tussock has the potential to 'ensure' the adoption or cessation of particular activities, which aid or detract from weed management. In the serrated tussock areas, the Working Party and Landcare groups have observed the reversal of traditional attitudes that oppose regulation of the use of rural land. Current community attitudes indicate that land managers are prepared to accept a high degree of regulatory action to involve all the serrated tussock affected properties in a timely and coordinated program.

This process allows each landowner to be treated in a fair and reasonable manner, whilst ensuring the long term control of serrated tussock.

Monitoring

A vital component of the program role is to determine the scale of the problem through an on-going mapping program. The data collected provides benchmarks to base a percentage reduction figure as a performance indicator and to target future control programs. The data is recorded on the DPI/DSE Integrated Pest Management System (IPMS). Local Government and Landcare groups have also been mapping and recording on this system in conjunction with the DPI/DSE program. The best means of determining benchmarks and treatments to determine if we are winning or losing is still IPMS.

A number of techniques have been used in the past, including roadside surveys, parish comparisons and random point assessments. The task is to get everyone inputting to this system (including Landcare groups and local government). Mapping of new infestations in various parts of the state continues.

Program evaluation

The Victorian Serrated Tussock Working Party operates in a complex environment where community behaviours and perceptions surrounding serrated tussock management responsibilities are varied. It was very important that the program looked at what had transpired and the impact of the program on the affected community

This project has clearly quantified the prescribed outcomes of the VST Strategy. It also quantified the effect on the community of the program as a whole. The review has provided recommendations to the Working Party on its promotion efforts in relation to serrated tussock management and its adequacy to influence the attitude of land managers.

Pre-empting the Strategy's expiration the current VSTWP initiated this evaluation project to provide both summative and formative program evaluation data essential for the development of a new strategy 2003–2007, for serrated tussock management in Victoria. Some of the findings from the evaluation process include:

- 27 Landcare groups, 11 councils, 5 Catchment Authorities and DPI now working in partnership along with other community groups and for serrated tussock control and management.
- Landcare groups, other community groups and landholders have taken responsibility for serrated tussock control and management.
- The VSTWP has become a key driver of land management and landuse change in serrated tussock infested areas.
- The serrated tussock management model adopted by Gorse Management Task Force, South West Ragwort Reference Group and interstate programs i.e., Tasmania.
- 75% or more landholders now view serrated tussock control as a high priority, understand the importance of coordinated control and control infestations on an ongoing basis.
- 61% agree to strongly agree that responsibility for serrated tussock control rests with the landholder.
- 85% agree to strongly agree that achieving serrated tussock control is a great personal achievement and 76 % feel they have let the community down if they fail to control serrated tussock.
- Heavily infested properties fell from 13.5% to 3.4% of landholdings 1995–2002 (Landholder survey estimate.)
- 40% of infested properties re-inspected post June 1999 found to be serrated tussock free
- 60% of total infestation has been treated.

Incentives

The VSTWP believe there is scope for greater uses of more innovative incentives to encourage appropriate serrated tussock management. There is a fundamental need to develop a planned strategic approach to serrated tussock management. The group acknowledges that incentives are an adjunct to other strategies used to change behaviour, i.e. awareness and regulation.

Integrating serrated tussock control at a catchment scale through landscape change

The West Port Phillip Catchment contains some of Victoria's worst land degradation including massive infestations of serrated tussock, soil erosion, rabbits, salinity and nutrient discharge. The community has initiated this major program aimed to implement major landscape change over large areas (>5000 hectares) of severely degraded land with a major outcome being the control of serrated tussock at a catchment scale.

This program will plan and implement major landscape rehabilitation to tackle serrated tussock and integrate its control with sustainable land management, enhancement of biodiversity and control of salinity, nutrient discharges, erosion, water quality and pest animals. This will be achieved by having selected landholders involved in revegetation, others involved in long-term agro-forestry enterprises, and encouraging the adoption of best practice land management enterprises.

The resulting massive mosaic of forestry and native trees will be

- A huge barrier to the spread of serrated tussock,
- A reduction in the area of terrain available to serrated tussock,
- Enable improved treatment of the weed on productive soils, and
- Importantly increase the recognition developed in land managers to utilise farm forestry as a productive means of controlling serrated tussock infestations on heavily infested landscapes.

The project has generated ongoing cooperative links between stakeholders and supports further serrated tussock control by demonstrating cost-effective, innovative techniques for landscape change. Using a collaborative approach the project will deliver large-scale, integrated land rehabilitation within 50 km of the Melbourne GPO.

CWM: A simple tool for a complex process

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Summary This paper presents a fairly simple quantitative tool for analyzing the likely costs and benefits of alternative weed management strategies at the regional or State-wide level. The Catchment Weed Management (CWM) model can be used to estimate the financial impact of weeds, using information derived from a pest plant prioritization model (Weiss and McLaren 2002). The basic information required to apply the model includes: (i) the present and maximum potential distribution of the weed; (ii) rate of spread; (iii) types of land use suitable to the weed; (iv) gross margin values for agricultural enterprises; (v) control techniques and their cost; and (vi) strategy's administrative cost. The model's output could form the basis for a rigorous priority-setting process relating to resource allocation decisions when combined with the qualitative assessment of environmental and social impacts of weeds in Victoria.

Keywords benefit-cost analysis tool, coordinated weed management, macro-level evaluation, priority-setting.

Introduction

A regionally coordinated weed management strategy involves a wide-scale application of best management practices (BMPs) in weed control to significantly reduce the potential impact of weeds occurring in the region. Such an integrated strategy may include extension/education programs, prevention and early response to emerging invasive species and the application of chemical, biological, mechanical, cultural and other complementary control techniques.

Usually, the quantitative analysis of weed impact in the presence or absence of a coordinated management strategy is an integral part of a rigorous planning and priority-setting process for managing weeds at the regional or State-wide level. Because of the great number of stakeholders involved in such a process and the 1200 or so naturalized weeds known to exist in Victoria, identifying which strategy to focus investment on is not easy. Also, determining the minimum amount of annual investment that would make communities better off in the long run may be equally or even more difficult.

To ensure that the chosen management strategies provide positive outcomes, we need to have a good understanding of some key issues. Firstly, economic activities that individuals undertake in their pursuit of maximum private benefits which at the same time also results in weeds spreading from one planning unit to another (e.g., one farm property to the next) needs to be well understood. Secondly, we also need to assess the potential impact of such weed spread on the region's agricultural, environmental, human health and other social values. When these assessments are completed, management strategies could then be formulated and prioritized. And thirdly, because of the complexity of the whole process, the use of simple decision support tools to provide information to decision makers in the region when they are actually needed is crucial.

The level of 'guess work' involved in quantifying weed impact in monetary terms could be minimized with the application of benefit-cost analysis tools like the CWM model. The model and the steps followed in applying it are described in this paper.

Materials and methods

Priority-setting approaches

Regional investments in coordinated weed management strategies can be prioritized using alternative approaches. Examples of such approaches are: (i) group consensus; (ii) risk management approach; (iii) combinations of individual approaches; and (iv) no system at all. Obviously, the degree of complexity between these approaches varies. For instance, some groups might decide on their investment priorities based primarily on precedents or historical records. On the other hand, others might employ qualitative and quantitative tools to evaluate and rank priorities as part of a rigorous risk management approach. Qualitative tools generally refer to those where weighted-scores are used in assessing and ranking weed risk. On the other hand, quantitative tools apply benefit-cost analysis approach (e.g., CWM) in measuring the values of weed risk in monetary terms before prioritizing alternative investments.

A quantitative tool

The CWM model follows the classical 'with' and 'without project' scenario approach to benefit-cost analysis. This means the dollar value of the potential impact of the weed associated with its predicted distribution in the absence ('without project scenario') and presence ('with project scenario') of a coordinated strategy over the evaluation period are measured and compared.

Weed invasiveness

The CWM model uses weed invasiveness information derived from the invasiveness assessment model developed at the Department of Primary Industries (DPI), Frankston. In particular, estimates of the maximum potential distribution of a weed in each major type of land use (i.e., cropping, dryland pasture, irrigated dairy, public land) within a Catchment Management Authority (CMA) region in Victoria and the rate of spread of the weed are used as inputs to the model.

Discounting

The model applies the standard discounting procedure to bring streams of future costs and benefits in present day values before these are compared. A discounting factor of four per cent (4%) is used. This rate of discount is the standard rate assumed to apply in the evaluation of government investments in Victoria.

Decision criteria

Users of the CWM model may choose either the net present value (NPV) or benefit-cost ratio (BCR) to evaluate whether or not a weed management strategy is justified. The NPV is the difference in the sums of the discounted benefits less the costs associated with the implementation of a particular strategy while the BCR is simply the ratio of these sums of benefits and costs. Users should use NPV as the decision criterion because NPV is a measure of the absolute amount of potential net savings in dollar terms. The higher the NPV of an investment, the more attractive that investment would be relative to others.

Which benefits and costs?

Weed management, if effective, provides direct and indirect benefits. Indirect benefits may be in the form of production loss saving, conservation of biodiversity value or preservation of soil and water quality. On the other hand, direct benefits of weed control would be in terms of avoided future control costs. One of the things that make the CWM tool simple is that it attempts to measure the benefits of weed control only in terms of (i) future control costs avoided and (ii) agricultural production loss saved. The dollar amount of government investment that is considered in the analysis consists of the (i) annual costs of administering the strategy and (ii) the costs of on-ground control works on public land.

Calculation procedure

Firstly, the model automatically calculates the dollar values of the production loss and control cost associated with the 'without project' and 'with project' scenarios based on the predicted weed distribution over the evaluation period of 30 years. Next, the difference between these values which represents the gross benefit of a particular strategy is calculated (and discounted). Then, the present value of the potential benefit is calculated in the model by factoring in the likely rate of success of the strategy. Finally, the discounted value of the government annual investment in the strategy is subtracted from the value of potential benefit to estimate the net savings (i.e., production loss saved and future control cost avoided) that could be achieved.

Data requirements
To apply the CWM model in the analysis of weed investments, users need to have information on the weeds potential distribution including its rate of spread, dollar value of agricultural enterprises at risk ($ ha^{-1}), and average cost ($ ha^{-1}) for each applicable control technique on every major type of land use. Estimates of the region's annual expenditure associated with administering the coordinated strategy for each species are also required.

Data sources and updates
The users of the model provide the estimate of the total area of current infestation of every weed they nominate for assessment, the average cost of control ($ ha^{-1} per land use type per control technique) and the cost of administering the strategy ($ year^{-1}). These data sets are normally collected and verified through regional workshops involving the model custodians and potential users.

Meanwhile, DPI Frankston provides the predicted maximum potential distribution (ha) of each noxious weed species (i.e. according to major types of land use), the rate of spread of the weed, the alternative weed control technique/s and gross margin (GM) data. These data sets would generally reflect the differences between CMA regions as to their suitability to a particular weed infestation, productivity and profitability of agricultural enterprises. This information is pre-loaded onto each CMA region model with updates reloaded, as new ones become available.

Data uncertainty
The presence of a certain degree of uncertainty in the reliability of data used in most quantitative assessment of weeds may be the rule rather than the exception. This issue is acknowledged as a possible weakness in the current model. However, the CWM model has the added functionality of a 'scenario builder' that allows users to perform sensitivity analysis as a means of examining the likely implications on the over-all outcome of the analysis if key assumptions are allowed to vary.

CWM model
The way data has been organized in the current version (Figure 1) of the model facilitates ease of use. In particular, the incorporation of 'drop down lists' and 'command buttons' in the user interface not only automates the calculation, but also ensures the assessment process to be consistent, repeatable and a bit quicker once all the relevant data are pre-loaded. This also minimizes the frequency by which users have to enter data manually. Table 1 summarizes the steps followed in applying the model.

Results and discussion

Sample output The output summary of the CWM model (Tables 2a and 2b) shows the most important information including the potential net saving to the CMA region that could be derived from the investment or management strategy being analyzed. In this example, the level of infestation of the weed species being assessed is estimated to reach approximately 10 000 hectares of which about 3400 ha is public land. Based on the assessment of the weed's invasiveness, this species is likely to be a serious threat to grazing enterprises (dryland pastures). In other words, this weed is likely to establish and expand on this particular type of agricultural land use.

In the absence of government investment in the coordinated management strategy, the weed is predicted to expand from 10 000 ha to about 92 000 ha in 30 years in the case-study region (Table 2a). The estimated financial loss associated with this potential weed expansion is around $60 million, in today's dollars.

Meanwhile, the 'containment' strategy that aims to reduce the current level of infestation from 10 000 ha to 1000 ha over 20 years is considered feasible. This strategy would require a total of around $1.2 million (in today's dollars) to implement. Assuming a success rate of 50%, this strategy is likely to generate a net savings to the CMA region of about $27 million (the NPV). This means that for every dollar of government investment in this strategy a return of about $23 (the BCR) is likely to

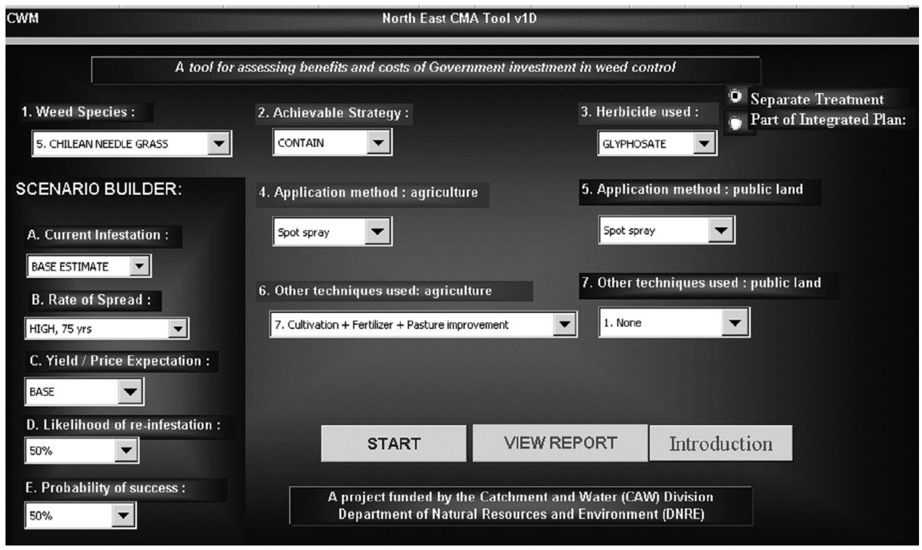


Figure 1. User interface of the CWM model for evaluating government investment in alternative weed management strategies in the North East CMA region

Table 1. Steps followed in using the CWM model

No.	Steps	Notes
1	Select weed species	Considered important in the region
2	Choose 'achievable' strategy[A]	'total suppression' or 'containment'
3	Select applicable control technique/s	Chemical, cultural, mechanical
4	Set the 'base case' scenario	Present distribution, rate of spread, price and yield expectations, rate of re-invasion, rate of success
	Perform sensitivity analysis	Use other values (higher or lower than the 'base case' assumption) to test results

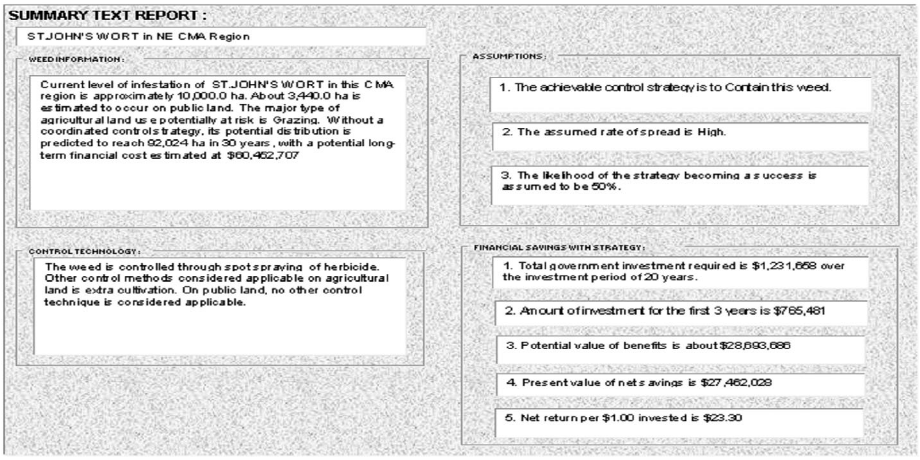
[A] 'Total suppression' is defined as reducing infestation to 1% of current level over 10 years whilst a 'containment' strategy aims to reduce infestation to 10% of current level over 20 years.

Table 2a and 2b. Sample output summaries of a 'base case' scenario analysis for an important weed species in a CMA region in Victoria

(a)

Weed species	St. Johns Wort
Current Infestation Assessed, total	10 000 ha
Infestation on public land	3 440 ha
Land use at risk	Grazing
Without strategy	92 024 ha
With strategy	1000 ha
Likelihood of success	50%
Financial losses no intervention	$60 452 707
Public investment, present value	$1 231 658
Investment period	20 years
Potential benefits, present value	$28 693 686
Net present value	$27 462 028
Benefit cost ratio	$23.30 : $1.00

(b)


SUMMARY TEXT REPORT :

STJOHN'S WORT in NE CMA Region

WEED INFORMATION:

Current level of infestation of ST.JOHN'S WORT in this CMA region is approximately 10,000.0 ha. About 3,440.0 ha is estimated to occur on public land. The major type of agricultural land use potentially at risk is Grazing. Without a coordinated control strategy, its potential distribution is predicted to reach 92,024 ha in 30 years, with a potential long-term financial cost estimated at $60,452,707

CONTROL TECHNOLOGY:

The weed is controlled through spot spraying of herbicide. Other control methods considered applicable on agricultural land is extra cultivation. On public land, no other control technique is considered applicable.

ASSUMPTIONS:

1. The achievable control strategy is to Contain this weed.

2. The assumed rate of spread is High.

3. The likelihood of the strategy becoming a success is assumed to be 50%.

FINANCIAL SAVINGS WITH STRATEGY:

1. Total government investment required is $1,231,658 over the investment period of 20 years.

2. Amount of investment for the first 3 years is $765,481

3. Potential value of benefits is about $28,693,686

4. Present value of net savings is $27,462,028

5. Net return per $1.00 invested is $23.30

be derived. Because the NPV is positive (hence, BCR is greater than one), the result indicates that this particular strategy can be justified based on the NPV or BCR investment decision criterion.

Finally, the development and application of a tool such as the CWM model provides high-level planners or decision makers the opportunity to examine possible financial trade-off between having a weed management strategy now and delaying the investment for some time, or between technically feasible alternative strategies.

Acknowledgments

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The role of the Weeds CRC: its functions and projects

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Summary The Weeds CRC was established in its current form in July 2001 with 19 partners around Australia. Its research, awareness and education programs aim to generate new information on weeds, improve control techniques, and enhance public knowledge and understanding of the extent and seriousness of agricultural and environmental weeds.

Introduction

The Cooperative Research Centre for Australian Weed Management (Weeds CRC) was established in mid 2001 as a second 7-year term of the original CRC for Weed Management Systems. Renamed, its scope was extended from southern Australia to include the whole continent. The main change in research direction was to divert resources from pasture weeds research to new work on weed incursion and risk assessment. Capacity was retained in cropping systems and natural ecosystems research, and increased in the areas of communication and education.

The CRC's official mission is to 'enhance the sustainability of farming systems and natural ecosystems through world-class collaborative research that targets generic control problems using integrated weed management.'

Distributed over 24 sites in all States and Territories, the CRC has seven 'core partners' which contribute funds as well as staff, and 12 'supporting partners' which contribute the time of specified staff. The head office is based at the Waite Campus of the University of Adelaide, and the new CEO (from May 2003), Dr Rachel McFadyen, is located in Brisbane. The five program leaders are located in Adelaide, Wagga Wagga, Brisbane and Townsville.

In determining the direction of the Weeds CRC, a round of stakeholder consultations in 2000 led to the conclusion that the main national weed issues to which the CRC could apply its skills in science and technology were:

- Detecting new arrivals and newly establishing species
  - assessing the risk they pose
  - what should we do?
- The $4 billion per year cost of weeds to agriculture
  - tactics for improved management
- Protecting the natural environment
  - landscape scale and variety
  - weed types
  - tactics, especially biocontrol.

The response to this assessment was the establishment of three research programs, a fourth concerned with delivering results and skills to stakeholders, and a fifth focused on education. Each are divided into several 'tasks', as set out below. A total of 42 research projects were established, most with several collaborating partner agencies. A further 20 projects are underway across the awareness and education programs.

Programs of the Weeds CRC

Research
1. Weed Incursion and Risk Management
2. Sustainable Cropping Systems
3. Landscape Management

Communication
4. Community Empowerment

Training
5. Education

Program 1

Weed Incursion and Risk Management
Leader – Dr. Dane Panetta, Qld Department of Natural Resources and Mines, Brisbane

(1) Detection of weed incursions

The scale of the Australian landscape and frequent difficulty of access suggests that the goal of finding new weeds before they become established is ambitious. However, if a pattern can be shown to exist for arrivals and incursions, then we may be able to more effectively track and eradicate them. These projects test the concept of 'sentinel sites', where such sites might be most strategically located, and how best to monitor them. The work is assisted by the development of a major exotic species database.

(2) Weed risk evaluation

With nearly 3000 foreign plant species currently naturalised in Australia, and 20 more being discovered each year, there is a need to be able to accurately assess which of these could become serious environmental or agricultural weeds. The same issue faces decision makers dealing with applications for plant imports. Climate matching models have been developed and applied, but require further development. Long lag times, often decades, may precede invasive behaviour, and a better understanding of these 'sleeper weeds' and the risk they represent is being sought to help managers decide which species should receive priority attention. The economics of managing weed incursions and the use of cost-benefit analysis is part of weed risk assessment, and the subject of a CRC project at the University of New England (UNE). Another approach being explored is to see whether weed risk can be gauged by classifying weeds into 'plant functional groups'.

(3) Response to weed incursions

Experience in the USA suggests that the eradication of invasive plants becomes especially difficult and costly once the infestation exceeds 100 ha. A series of case studies of successful eradications in Australia is being undertaken, which will assist the development of a decision support tool for incursion response. The CRC has also been reviewing different strategies for responding to weed incursions with a view to developing a set of best practice guidelines suitable for wider use.

Program 2

Sustainable Cropping Systems
Leader – Dr. Deirdre Lemerle, NSW Department of Agriculture, Wagga Wagga

(1) Innovative control tactics

The worsening of herbicide resistance as a cropping problem across southern Australia means that advances in non-chemical ways of weed control are timely. Work in Wagga Wagga and Gatton is underway to develop new equipment for planting which can better handle crop residues and allow planting in narrower rows, which in turn improves crop competitiveness against weeds. Stubble management, row spacing, precision planting and fertiliser placement and planting depth are all issues amenable to improved engineering.

New knowledge of molecular processes controlling reproduction in annual weeds offers an opportunity to chemically disrupt one or more of the key physiological steps leading to final seed set. Supported by GRDC, this research is being undertaken at the University of WA. Breeding for competitive ability in wheat, including root vigour, is being researched through partners at the University of Adelaide.

(2) Best weed management packages

A variety of factors can affect the field performance of herbicides. Examples include weather and soil, as well as plant species, stage of development, competitive ability of the crop and weed density. Research in this area aims to develop guidelines for more efficient herbicide use.

Other 'best weed management' research includes:

- management of summer weeds (a) in cotton, and (b) where they impact on

winter crops
- the low competitiveness of pulses
- managing weeds in the non-crop phase of rotations
- managing seed set in wild radish
- the importance and value of long-term integrated weed management
- eradication of branched broomrape in SA.

(3) Managing existing and emerging weed threats to farm viability
Building on bio-economic models developed in the first Weeds CRC, staff in Orange are quantifying the risks and benefits of various weed management strategies. At the same time, the work takes into account other farm goals and constraints, such as minimising soil erosion and acidity, and seasonal variability.

The emergence of herbicide resistance as a threat to cropping is tackled by two projects. The first sets out to assess whether 'volunteer' populations of crop plants that have been genetically modified to tolerate certain herbicides represent a risk to the environment. The second project is developing guidelines for preserving the susceptibility of weed populations to certain herbicides in the event of resistant individuals beginning to appear. Initial work here is focusing on the susceptibility of annual ryegrass to trifluralin, and later work will look at 2,4-D and wild radish.

Program 3
Landscape Management
Leader – Dr. Tony Grice, CSIRO, Townsville

(1) Management of weed-infested habitats
The variety of weed species that can invade a single habitat may exhibit such a range of growth forms and life cycles that weed control aimed at just one or two species may simply not be appropriate. In response to this situation one CRC project is developing generic principles for weed control in three major habitat types, namely riverine, rainforest and rangelands. Work in riverine environments is currently focusing on herbicide use, while patterns of weed invasion is the primary research topic in the other two.

(2) Management of weed syndromes
It is possible to identify a number of ecological strategies employed by invasive species. These 'syndromes' are being investigated by the CRC using several major weed species as models:
- invasive rangeland shrubs (parkinsonia, bellyache bush)
- bird-dispersed weeds (lantana, bitou bush and boneseed, camphor laurel, bridal creeper, blackberry)
- aquatic weeds (alligator weed)
- unpalatable grasses (stipoid grasses, such as serrated tussock and Chilean needle grass, and weedy *Sporobolus* species).

(3) Biological control
Beyond systems of intensively managed lands, such as high value crops, intensive pastures and a limited area of public lands, biological control (or 'biocontrol') is often the only economically viable technique available to counter invasive plants. Although the average cost of finding and deploying a successful agent is about $1m, and not all attempts succeed, the benefit: cost ratio in the long term can be as high as 100:1 – i.e. highly cost effective.

Research in the CRC on this topic aims to:
- provide more reliable principles for selecting biocontrol agents
- develop better testing protocols to ensure the agent behaves as predicted when released in Australia
- improve strategies for release of agents and their establishment.

Despite recent problems in Queensland with a sap-sucking bug released to attack lantana (which demonstrated a liking for a West Indian tree planted widely in Brisbane and against which the bug had not been tested), biocontrol is a highly regulated practice and normally very secure. It is critical that the improvements now being researched tighten biosecurity further, improve the science, and ensure that it remains available as an essential weapon against invasive plants.

Program 4
Community Empowerment
Leader – Mr. Peter Martin, Weeds CRC, Adelaide

(1) Weed awareness
The communication strategy developed by the CRC operates on several levels:
- general information for the public through the print, radio and TV media, and events such as Weedbuster Week, garden shows and farmer field days
- more technical news and information for community groups and land managers involved in weed control through CRC publications such as the CRC newsletter Weed Watch, brochures, technical documents and an expanding web site (www.weeds.crc.org.au)
- scientific books, papers and other publications for weed professionals and agricultural advisors
- summary information and submissions that seek to brief senior decision makers in business and government on the seriousness of the national weed situation.

The CRC also has a special brief to enhance weed awareness in Aboriginal lands, given the expansion in this class of land tenure in recent years (e.g. now 50% of NT). This is being done through two Aboriginal Liaison Officers based in Darwin and Kununurra.

(2) Adoption of control measures
Surveys show that the majority of farmers list weeds as their number one problem. This level of farmer awareness, however, does not automatically lead to adoption of good weed control practices or the application of research findings. Work in this area by the CRC is aimed at packaging and delivering information about weeds and their control in ways that land managers and community groups find practical and attractive. Examples include:
- benchmarking adoption levels across the southern grain belt, and the preparation and delivery of materials and workshops on integrated weed management
- research into the dynamics and needs of community groups working in weed control
- distribution of biocontrol agents through community groups nationally. Examples of projects include a network of activities with the SA Animal and Plant Control Commission, and the expansion nationally of the successful Victorian Weed Warriors scheme for schools.

Program 5
Education
Leader – Dr. Chris Preston, University of Adelaide

(1) Educating the next generation of weed researchers and managers
The complexity of weed ecology and control strategies requires the application of the best scientific resources our universities and research agencies have to offer. Part of the challenge is to ensure that highly skilled scientists and technicians continue to be available. The CRC and its partners are active in training new weed researchers and managers through Ph.D. and undergraduate scholarships and supervision, and through the development of tertiary course materials. A major challenge for Australian natural resources management as a whole is the creation of a career structure for these graduates, who mostly leave the field due to a lack of permanent jobs. Thus Australia's substantial expertise in weed science is being poorly maintained and is under threat.

(2) Developing the skills of weed professionals
The vocational, education and training (VET) sector is a major mechanism for the delivery of weed information and control skills. This project is developing a range of resources needed by the VET sector for competency-based training, and has begun with the Wagga Wagga-based

Weeds CRC Education Officer working with Tocal College in the Hunter Valley.

(3) Primary and secondary school students
Recognising the importance of educating school children on weed issues, and the influence that this can have at home and in the community, the CRC is developing weed activity kits for schools through a project managed from the University of New England. The plan is to make the material freely available to teachers via the internet. Close links are being maintained with the expanding Weed Warriors program.

Conclusion

The general community is becoming increasingly aware of the cost of invasive plants and the damage they cause to our natural environments, as well as the costs they impose on agriculture. The Weeds CRC is developing new management strategies for weeds in many habitats and environments across Australia, and is committed to delivering new information and control tactics to land managers and community groups over the next five years.

References

www.weeds.crc.org.au

POSTER SUMMARIES

Development of English broom control strategy (post fire) in the Victorian Alps

Michael Dower[1] and **Kate McArthur**[2]
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[2] Department of Primary Industries, PO Box 48, Frankston, Victoria 3199

English broom (*Cytisus scoparius*) was introduced to Australia from Europe and has invaded large tracts of native vegetation in unique and sensitive alpine areas. The success of English broom can be partly attributed to its virulent nature and the lack of indigenous flora and fauna species capable of limiting its reproduction, growth, and spread. Invasion by English broom often results in permanent changes to the composition and structure of native vegetation communities, thus reducing ecological and biodiversity values.

The Bogong Complex fire burnt areas where control programs had previously been implemented to combat English broom. These programs boasted an integrated approach comprising chemical, biological and physical control techniques. The English broom post-fire control program embraces these techniques and also takes advantage of the opportunity to move away from a reactive control program to a pro-active program.

The program aims to control English broom within the burnt area. Different strategies and control measures will be applied to mature and juvenile plants before seed-set. Ongoing monitoring and mapping of broom species distribution will assist in the development of work programs and measure their success in the future. Ultimately, this approach should assist regeneration of indigenous species of once invaded sites.

Parks Victoria, Keith Turnbull Research Institute, Department of Primary Industries, Goulburn-Murray Water, Landcare Groups, Landholders and various community groups will work together across all land tenure to implement this integrated post-fire program. This will reduce English broom infestations in the Victorian Alps.

Control of wheel cactus (*Opuntia robusta*)

Ian Grenda, Nuggetty Landcare Group, PO Box 22, Maldon, Victoria 3463

Wheel cactus (*Opuntia robusta*) is a native of Mexico and is emerging as a weed near Maldon, in Central Victoria. It can grow into very tall, wide, impenetrable clumps. One 'ornamental' clump lived for decades near Maldon until, about 20 years ago, the ravens learned to eat the fruit. The seed and plants have now spread some kilometres from the original site.

The plant is highly adapted to dry conditions. Its skin is tough and waxy and its stomata are tightly closed against water loss in times of low humidity. Killing cactus is not easy. Past methods of killing cactus used strong chemicals, such as 2,4,5-T and 2,4-D. Diesel was added to the mix to cut through the skin. Glyphosate spraying, under the usual fine weather conditions, did not seem to be effective. The cochineal insect, being tested for control of prickly pear, does not eat wheel cactus.

But we're working on it. Members of the Nuggetty Landcare Group have been working on other ways. These include:

- Seedlings and small clumps can be dug out. The rubbish needs to be burned or buried as the cactus will re-shoot from any wheel ('leaf') left lying on the ground.
- A cattle drench gun has been modified to inject 5 mL of undiluted glyphosate into each wheel. This kills the cactus. It will rot away completely over time and not re-shoot.
- Trials are currently being done to test the efficacy of spraying with glyphosate at times of higher humidity and at night. Results are promising so far.

Integrating remote sensing and GIS for strategic management of the native environmental weed, *Acacia longifolia* var. *sophorae*

Jennifer Emeny, School of Ecology and Environment, Deakin University, Warrnambool, Victoria 3280

Knowing the extent and pattern of distribution of a target weed is essential for strategic weed management. However, when an invasion occurs in a remote location or across large spatial scales, field mapping of the weed and factors influencing its distribution can be problematic. A cost effective alternative is mapping weed distribution using remotely sensed data, then integrating results into a Geographic Information System (GIS) for analysis of spatial patterns.

The study presented combines satellite remote sensing with GIS analysis to examine the distribution of the native environmental weed *Acacia longifolia* var. *sophorae* (coast wattle) in south-west Victoria. In this region, coast wattle has spread from its traditional foredune habitat to invade inland vegetation, including sections of the Lower Glenelg National Park. A standard supervised classification procedure was carried out on Landsat TM satellite imagery to map current coast wattle distribution in the national park and surrounding area. The technique was repeated at different times of year to determine whether time of image acquisition affects coast wattle detectability. Distribution data was then integrated into a GIS to investigate factors influencing coast wattle establishment in the park. Results reveal that coast wattle can be detected with overall accuracy greater than 80%. However, successful detection depends on time of image acquisition. Initial observations and GIS analysis indicate that distance from roads, management zonation, surrounding land use, habitat fragmentation and disturbance history may all influence coast wattle distribution. Ongoing investigation into the strength and interactions of these factors is introduced, as well as the extension of methods to other native weed invasions in Victoria.