Weed Society of Victoria Inc.

PROCEEDINGS

THIRD VICTORIAN WEED CONFERENCE

Earth Wind Fire Water and Weeds

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Australian Government

Defeating the Weed Menace

PROCEEDINGS

THIRD VICTORIAN WEED CONFERENCE

Earth Wind Fire Water and Weeds

3–4 October 2007

All Seasons International Hotel, Bendigo

Weed Society of Victoria Inc.

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Australian Government

Department of the Environment and Water Resources

This spring the Defeating the Weed Menace (DWM) Programme, the Australian Government's $44.4 million commitment to national action on Australia's most threatening weeds, will launch a new website - **www.weeds.gov.au** - in mid September to help people identify which plants can be a problem in their local area and to provide advice on how to manage these plants.

A print advertising and editorial campaign targeting gardeners and hobby farmers in peri-urban areas will run from September 2007 to March 2008. Copies of the advertisements and other resource materials will be available on the website.

While the majority of people targeted by the campaign will be directed to the website **www.weeds.gov.au** for further information, enquiries are also likely to be received by state, regional and local governments and nursery retailers for information about weeds issues specific to their local area.

WEED? Check your plants

PROGRAM

DAY 1 WEDNESDAY 3 OCTOBER 2007

07.15 – 08.50	**REGISTRATION**	
08.50 – 09.00	**WELCOME President, Weed Society of Victoria**	
SESSION 1	**KEYNOTE SPEAKERS** Chair: Ken Young	
09.00 – 10.00	Future weed management in a changing environment – socially, politically and physically **Rick Roush**, The University of Melbourne, Parkville	
10.00 – 10.30	Climate change impacts on weeds in southern Australia **Darren Kriticos**, Ensis, Canberra	1
10.30 – 11.00	MORNING TEA	
SESSION 2	**EARTH WIND FIRE WATER AND WEEDS** Chair: Daniel Joubert	
11.00 – 11.30	EARTH The effects of land management on weed seed longevity **Ken Young**, The University of Melbourne, Dookie	6
11.30 – 12.00	WIND How far do weed seeds actually travel? **Roger Cousens**, School of Resource Management, The University of Melbourne, Burnley	9
12.00 – 12.30	FIRE Post-fire weed management: lessons from the Victorian Alps **Charlie Pascoe**, Parks Victoria, Bright	10
12.30 – 13.00	WATER Identifying appropriate aims and management approaches for aquatic weeds **Nigel Ainsworth**, Department of Sustainability and Environment, Melbourne	
13.00 – 14.00	**LUNCH AND POSTER SESSION**	
SESSION 3	**EARTH WIND FIRE WATER AND WEEDS** Chair: Ian Faithfull	
14.00 – 14.20	How can willow sawfly aid our willow management? **Fiona Ede**, Department of Primary Industries, Frankston	19
14.20 – 14.40	Response of Brazilian milfoil (*Myriophyllum aquaticum*) to salinity and water-level fluctuations [#] and its potential to invade wetlands of the Gippsland Lakes, south-east Victoria **Mark Toomey**, Institute for Sustainability and Innovation, Victoria University	22
14.40 – 15.00	Aquatic weeds and their impact in irrigation systems experiencing drought within Victoria [#] **Tim Nitschke**, Goulburn-Murray Water Aquatic Plant Services	28
15.00 – 15.20	Predicting the potential distribution of orange hawkweed on the Bogong High Plains using a dispersal constrained habit suitability model **Nick Williams**, School of Resource Management, The University of Melbourne	30
15.20 – 15.50	AFTERNOON TEA	
SESSION 4	**TACKLING WEEDS ON PRIVATE LAND** Chair: Lisa Minchin	
15.50 – 16.20	Measurement of changes in stakeholder weed management attitudes and actions over the life of the Tackling Weeds on Private Land initiative [#] **Catriona King**, Department of Primary Industries, Seymour	31
16.20 – 16.50	Tackling weeds on private land **Helen Anderson**, Department of Primary Industries, Hamilton	37
16.50 – 17.20	Weed management practice change within organisations **Mark Farrer**, Department of Primary Industries, Stawell	
19.00	**CONFERENCE DINNER**	

DAY 2 THURSDAY 4 OCTOBER 2007

08.00 – 08.30 **REGISTRATION**

SESSION 5 WEED MANAGEMENT Chair: Andrew Clark

08.30 – 09.00	Innovations in spraying techniques, will they enable less herbicide to be used? # **Harry Combellack**, Spray Smart Enterprises	42
09.00 – 09.30	Prioritising roadsides and reserves for weed control in the Shire of Yarra Ranges # **David Blair**, Shire of Yarra Ranges	48
09.30 – 10.00	Grassy weeds as fiery competitors or phantom companions? – Lessons learnt from conservation and land management **Colin Hocking**, Institute for Sustainability and Innovation, Victoria University	55

SESSION 6 WEED ALERT Chair: Daniel Joubert

10.00 – 10.30	The Victoria Weed Alert Program **Stuart Lardner**, Department of Primary Industries, Horsham	
10.30 – 11.00	MORNING TEA	
11.00 – 11.30	Horsetail (*Equisetum* spp.) and knotweeds (*Fallopia* spp.) – progress on eradication of two of Victoria's State Prohibited Weeds **Michael Hansford**, Department of Primary Industries, Box Hill	58

CONCURRENT SESSIONS

SESSION 7	Chair: Sarah Partington		**SESSION 8**	Chair: Chris Knight	
11.35 – 11.55	Early detection for water weeds in Australia **Fiona McPherson**, NSW Department of Primary Industries, Grafton Agricultural Research and Advisory Station	61	11.35 – 11.55	Response of Chilean needle grass (*Nassella neesiana*) and phalaris (*Phalaris aquatica*) seedlings and mature plants to changes in soil phosphorus, nitrogen and soil pH **Charles Grech**, DPI, Attwood	77
11.55 – 12.15	Weed proofing Australia: a way forward on invasive garden plants **Nicola Thomson**, WWF-Australia [for Andreas Glanznig]	64	11.55 – 12.15	Arrowhead in Victoria: current control methods and potential for biological control # **Jean-Louis Sagliocco**, Department of Primary Industries, Frankston	78
12.15 – 12.35	The role of the National Herbarium of Victoria (MEL) in the documentation of new weeds. **Val Stajsic** and **Alison Vaughan**, National Herbarium of Victoria	70	12.15 – 12.35	Weeding out Australia's worst willows **Jackie Steel**, Department of Primary Industries, Frankston	80
12.35 – 12.55	Improving provincial Victoria's bio-security by minimising the risk of new weed introductions **Stephen Young**, Department of Primary Industries, Ballarat	75	12.35 – 12.55	Community based quality assurance scheme **Brian Feldtmann**, Dookie Land Management Group, Dookie	90

13.00 – 14.00 **LUNCH AND POSTER SESSION**

CONCURRENT SESSIONS

SESSION 9 Chair: Michael Hansford

14.00 – 14.20 An investigation of application techniques for the control of various noxious and environmental weeds with picloram gel based herbicides #
Geoffrey Keech, Macspred Australia 92

14.20 – 14.40 Empowering gardeners to make informed choices when buying garden plants #
Nicola Thomson, WWF-Australia 98

14.40 – 15.00 The use of radiation wavelengths to manage weeds #
Ken Young, The University of Melbourne, Dookie 104

15.00 – 15.20 The impact of weeds on our roadside secrets
Karen Jones, Rural City of Wangaratta 107

SESSION 10 Chair: Kate Blood

14.00 – 14.20 Containing orange hawkweed (*Hieracium aurantiacum*) infestations in the Ballarat area
Simon Martin, Department of Primary Industries, Ballarat 109

14.20 – 14.40 Alert and action on *Nassella charruana* and a range of other National Alert List species in Victoria
Sarah Partington, Department of Primary Industries, Bacchus Marsh 112

14.40 – 15.00 The Victorian Weed Spotter network
Catherine McInerney, Department of Primary Industries, Geelong 116

15.00 – 15.20 Water hyacinth illegal trade in Victoria: the trace back and forward of a State Prohibited Weed
Ryan Melville, Department of Primary Industries, Geelong 119

15.20 – 15.40 Seed bank spatial dynamics and plant invasions in Victoria's western basalt plains grasslands
Aaron Dodd, Department of Primary Industries, Bacchus Marsh 121

15.45 **CLOSING REMARKS**

POSTERS

Practice change by Victorian linear reserve managers
Claire Norris, Department of Primary Industries, Geelong 122

Practice change within the Victorian fodder industry
Claire Norris, Department of Primary Industries, Geelong 122

LIST OF ATTENDEES

LIST OF ATTENDEES 123

REFEREED PAPERS

The papers in this proceedings that went through the refereeing process are indicated by # at the end of their title in the program above.

Referees: Ken Young and Kelly Raymond

Climate change impacts on weeds in southern Australia

Darren J. Kriticos, Ensis, PO Box E4008, Kingston, Australian Capital Territory 2604, Australia.

Summary Projected increases in atmospheric carbon dioxide concentrations and concomitant increases in global temperatures are likely to result in significant changes in weed distributions. Tropical and sub-tropical weeds are likely to advance further south. Increases in carbon dioxide could increase growth rates of plants due to the carbon fertilisation effect (CFE), and increase their water use efficiency (WUE). Whether potential gains in crop yield are realised will depend upon the net effects of climate change on the competitiveness of weeds. Climate change is also threatening the effectiveness of herbicides. The greatest uncertainties surround the effects of climate change on the effectiveness of weed biological control systems, which may either be enhanced, or diminished by climate change.

Keywords: Climate change, CLIMEX, species ranges.

Introduction

The Intergovernmental Panel on Climate Change recently reaffirmed and reinforced its earlier messages about the human causes of global warming, concluding that there is now a '…**very high confidence** that the global net effect of human activities since 1750 has been one of warming' and further, that 'Warming of the climate is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average seal level' (IPCC 2007:3-5). The primary driver of this warming has been identified as anthropogenic emissions of so-called long-lived greenhouse gases (carbon dioxide, methane, nitrous oxide and an assortment of halocarbons). The 100-year linear trend in global surface temperatures (1906 to 2005) has been updated to 0.74°C. It is already clear that these observed changes are already having an influence on the distribution and abundance patterns of a range of short generation, mobile species such as Lepidoptera and plant pathogens (Parmesan *et al.* 1999, Parmesan and Yohe 2003, Woods *et al.* 2005, Parmesan 2006).

The observed changes in climate and the concomitant species responses are projected to continue to increase throughout the 21st Century. The IPCC has developed a set of climate change scenarios (IPCC 2000). These scenarios take the form of a set of storylines that describe plausible future socio-economic development paths and consequent greenhouse gas emissions. These scenarios covered a very large range in emissions increases, and when used as the basis for forcing global climate models resulted in a wide range of global warming projections. The model based 'best estimates' range from 1.8°C for the conservative B1 scenario, to 4.0°C for the A1FI scenario (IPCC 2007). Subsequent to the release of the IPCC Fourth Assessment Report, Rahmstorf *et al.* (2007) have published evidence that indicates that whilst global emissions of carbon dioxide are following projections closely, the resulting increases in global temperature and sea level are each tracking on the high end of projections. They conclude that the previous projections by the IPCC may have underestimated the likely changes in temperature, underlining concerns about global climate change.

Global climate change, caused by increased emissions of greenhouse gases, is likely to affect weed management in many ways, but the outcome, for instance, as a shift in weed distributions, depends on the combined effects of climate (temperature, precipitation) and other global change components. The focus of this review is on temperature, soil moisture and the atmospheric concentration of carbon dioxide (CO_2). This paper discusses the projected changes in climate and the mechanisms by which global climate change is likely to affect weeds and their management in southern Australia. The likely impacts of these mechanisms are demonstrated in the context of southern Australia using the CLIMEX modelling package (Sutherst *et al.* 2007).

Direct impacts of increasing atmospheric carbon dioxide

Carbon fertilisation effect

In situations where CO_2 is a limiting growth factor, increased CO_2 can have a fertilising effect. This phenomenon has been termed the carbon fertilisation effect (CFE). Under the CFE, the relative growth rates of plants growing at elevated CO_2 can be enhanced compared with similar plants growing under current (pre-climate change) CO_2 levels. Where other factors are limiting (toward the upper and lower regions of the curve in Figure 1), the carbon fertilisation effect is reduced. Weeds with the C_3 photosynthetic pathway are generally expected to enjoy an increased competitive advantage through enhanced growth rates compared to C_4 crop species (Ziska 2000, 2001, 2003). However, as Williams *et al.* (2007) observed, sometimes C_4 plants could gain a greater competitive advantage from elevated CO_2, and so specific

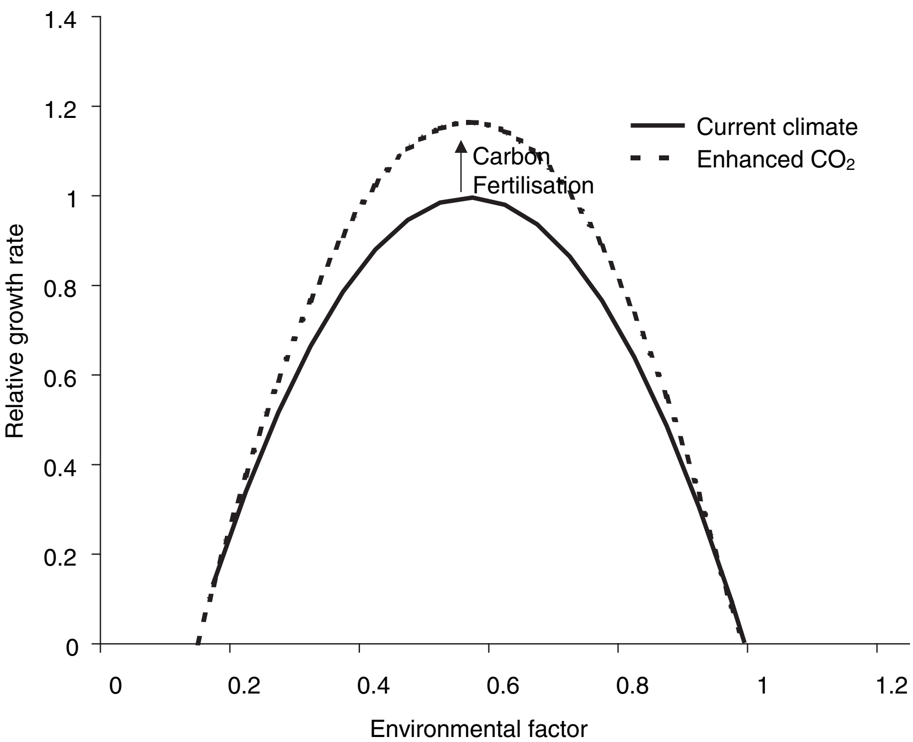

Figure 1. Schematic representation of the carbon fertilisation effect.

situations should be verified. Because of their association with nitrogen-fixing bacteria, legumes may be expected to benefit from the CFE compared with non-legumes in non-agricultural settings where nitrogen is often limiting.

Water use efficiency
Increased CO_2 has the effect of increasing plant water use efficiency (Morison and Gifford 1984a,b). This is because for a given level of stomatal CO_2, a plant can operate with a more restricted stomatal opening, resulting in less loss of leaf moisture. The dashed line in Figure 2 indicates the effect of enhanced CO_2 on the species soil moisture growth response curve. Under elevated CO_2, plants may be able to grow better at moderate (sub-optimal) soil moisture levels. The minimum soil moisture level at which plant growth can occur (permanent wilting point) is unlikely to be altered by changes in CO_2. Increasing CO_2 may therefore allow species to persist in drier regions than they can under reduced CO_2 as they are better able to make use of lower levels of soil moisture.

Emergent effects of climate change on weeds

Length of growing season
In cool to cold climates (e.g. temperate, Mediterranean and alpine), increasing temperatures could increase the length of the growing season for some weeds. This may become apparent through an earlier onset of spring growth as is projected to occur for bridal creeper at Hobart (Figure 3). The pattern of changes in climate suitability however is complicated by the interplay of soil moisture and temperature. As is apparent in Figure 3 during the early part of the year, future conditions could become drier during the late summer and early autumn period. This period of sub-optimal growth could partly offset gains in winter growth. At the trailing edge of the range shifts, where conditions get too hot or dry for a species in the future, the opposite change could be observed, where the growing season contracts (Figure 4).

Shifting species ranges
A common factor limiting the poleward spread of plants appears to be a minimum threshold of growing degree days necessary to complete a generation in the case of annual and ephemeral species, or, in the case of perennial species to complete the reproductive cycle and produce viable mature seeds. It is common to find species growing beyond their ecoclimatic limits for long-term persistence (e.g., *Acacia nilotica* in Sydney botanic gardens, and *Grevillia robusta* in Canberra). It is difficult to imagine however, that a plant growing outside of this range boundary could pose an immediate weed threat problem. The presence of lethal low temperatures can

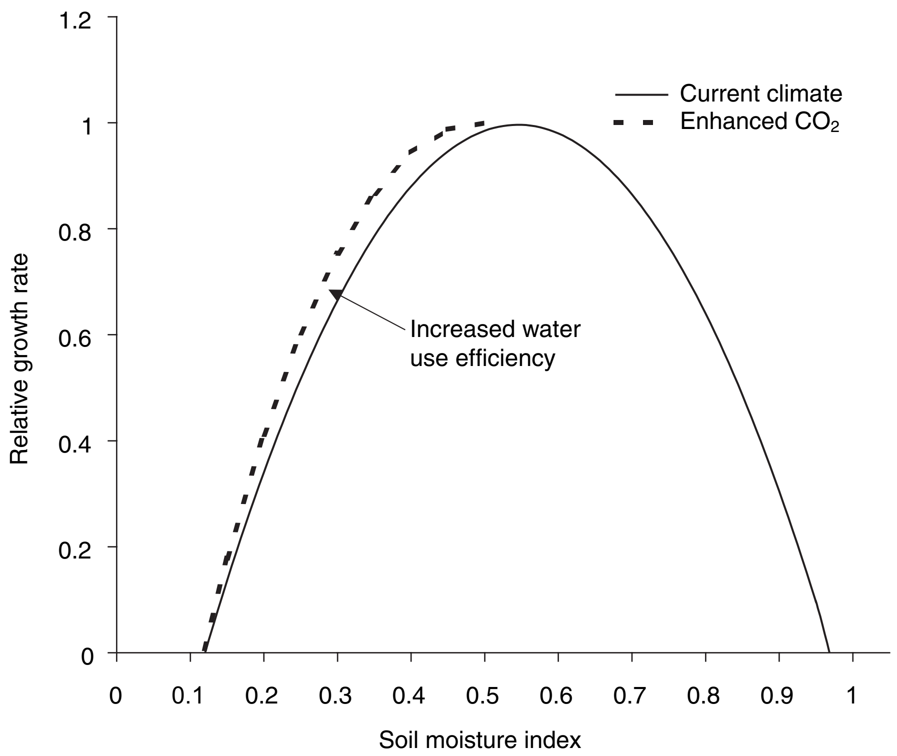

Figure 2. Schematic representation of the effect of elevated CO_2 on plant growth rates and water use efficiency.

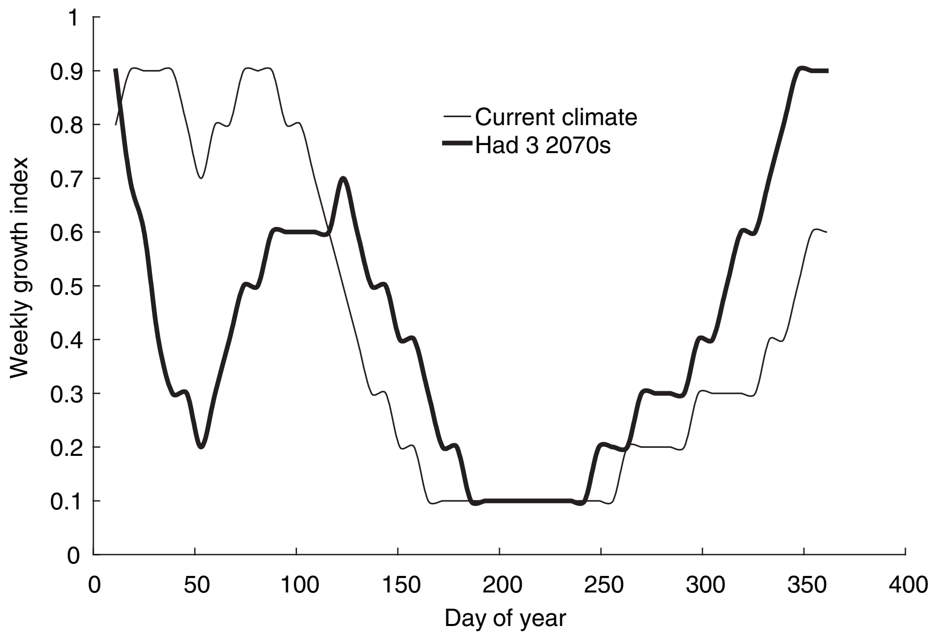

Figure 3. CLIMEX weekly growth index for bridal creeper (*Asparagus asparagoides*) at Hobart (43°00′S, 147°15′E) modelled using the reference climate (1961–1990 average) and the 30 year average around 2075 as simulated using the Hadley mark 2 model with high sensitivity and high emissions scenario. Under the future scenario, growing conditions for bridal creeper are expected to improve slightly at this site. The climate change scenarios were supplied by CSIRO Marine and Atmospheric Research, and adapted using the techniques described in Stephens *et al.* (2007).

also limit a plant species in terms of latitude and/or altitude. Evidence for these mechanisms comes from both mechanistic studies (Woodward 1988), and inferential modelling approaches (Beerling *et al.* 1995, Sykes *et al.* 1996, Holt and Boose 2000, Kriticos and Randall 2001, Kriticos *et al.* 2003a,b, Walden *et al.* 2004, Kriticos *et al.* 2004, Kriticos *et al.* 2005a, Kriticos *et al.* 2005b, Kriticos *et al.* 2006, Kriticos and Potter 2006)

As temperatures increase, we should expect that many species would be able to overcome their current poleward limits. For southern Australia, this means that weeds whose current distribution limits are further north such as rubber vine (*Cryptostegia grandiflora*), and prickly acacia (*Acacia nilotica*) will probably invade further south (Figure 5).

For weeds with a more temperate or Mediterranean climatic preference such as Scotch broom (*Cytisus scoparius*), butterfly bush (*Buddleja davidii*), and bridal creeper (*Asparagus asparagoides*) (Figure 6) climate change is likely to reduce their potential range. The mechanisms by which this occurs are likely to include direct heat stress, as well as competition from plants that are better adapted to the warmer conditions expected in the future. As most weeds have efficient dispersal mechanisms, this displacement of cool-adapted weeds may well come as a result of invasion by other weeds.

Range changes in the context of an active invasion

It is worth bearing in mind that few weeds have reached their Ecoclimatic limits in Australia. Therefore, whilst they are still invading, the effect of climate change will be to shift the geographic limits of that invasion (Figure 7). Therefore in order to understand the effects of climate change on the distributions of weeds it is necessary to consider ecoclimatic models such as CLIMEX (Sutherst *et al.* 2007). Such models provide a means of understanding the synoptic view of the invasion under current climate, as well as exploring the likely effect of climate change scenarios on that invasion.

Decreased herbicide efficacy

Bailey (2004) has shown that increasing temperatures and CO_2 can result in reduced herbicide efficacy through more rapid chemical breakdown, reducing the period during which effective concentrations of the herbicide are maintained. Ziska *et al.* (1999) have shown that elevated CO_2 could lead to increased tolerance of glyphosate by weeds. The mechanism by which this occurs could have to do with decreased stomatal conductance. Archambault *et al.* (2001) found highly variable response of herbicide efficacy to elevated CO_2 and temperature. This variability

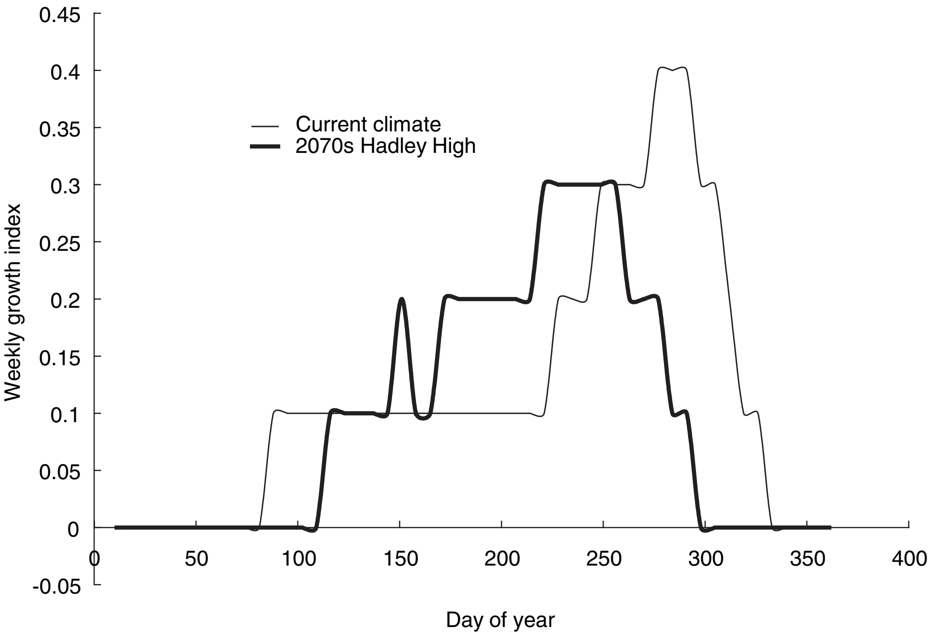

Figure 4. Weekly growth index for Scotch broom (*Cytisus scoparius*) at Bendigo (36°46'S, 144°18'E) modelled using CLIMEX. Under the reference climate (1961–1990) and the 30 year average around 2075 as simulated using the Hadley mark 2 model with high sensitivity and high emissions scenario. Under the warming scenario, growing conditions for Scotch broom are expected to deteriorate at this site. The climate change scenarios were supplied by CSIRO Marine and Atmospheric Research and adapted using the techniques described in Stephens *et al.* (2007).

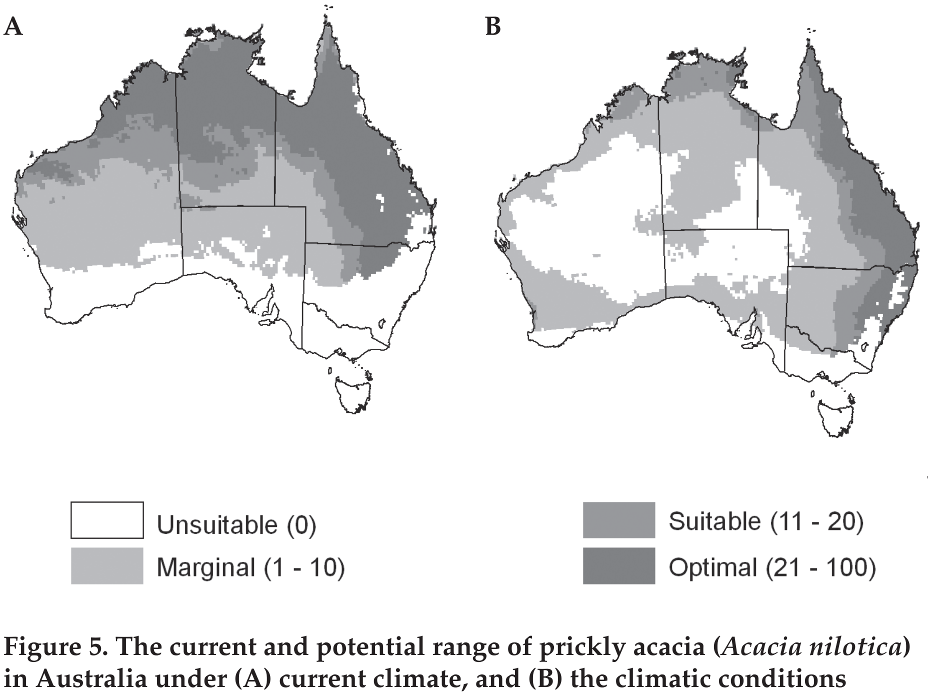

Figure 5. The current and potential range of prickly acacia (*Acacia nilotica*) in Australia under (A) current climate, and (B) the climatic conditions projected for the 2070s using the Hadley mark 2 GCM. Water use efficiency and growth rates due to the carbon fertilisation effect are assumed to remain unchanged. The large unsuitable area in the centre of the 2070s scenario is due to decreased rainfall and increased temperatures reducing soil moisture availability. The climate change scenarios were supplied by CSIRO Marine and Atmospheric Research, and adapted using the techniques described in Stephens *et al.* (2007).

spanned plants with C_3 and C_4 photosynthetic pathways and three herbicide chemicals tested.

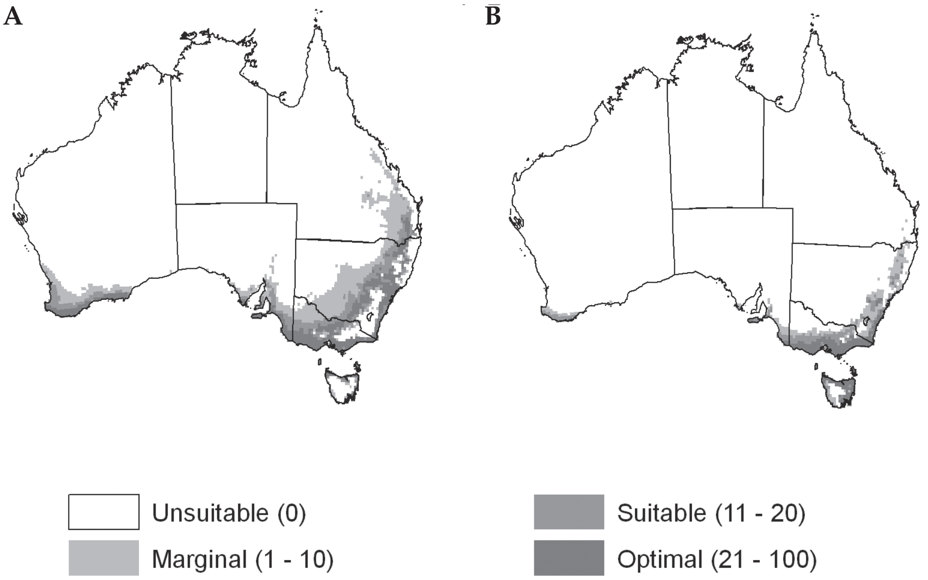

Figure 6. The current and potential range of bridal creeper (*Asparagus asparagoides*) in Australia under (A) current climate, and (B) the climatic conditions projected for the 2070s using the Hadley mark 2 GCM. Water use efficiency and growth rates due to the carbon fertilisation effect are assumed to remain unchanged. The climate change scenarios were supplied by CSIRO Marine and Atmospheric Research and adapted using the techniques described in Stephens *et al.* (2007).

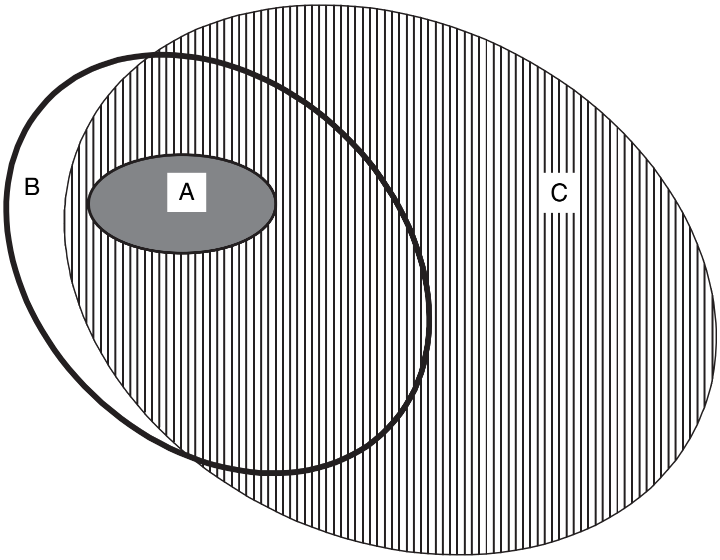

Figure 7. Diagrammatic representation of the relationship between (A) current distribution, (B) potential distribution under current climate, and (C) potential distribution under climate change.

Changing carbon to nitrogen ratios

Increasing CO_2 levels are likely to increase C:N ratios in many plant tissues. This could result in either more or less herbivore damage to plants. Nitrogen is frequently a limiting resource for herbivores. If the herbivores can efficiently and effectively discard excess carbon, as they extract the nitrogen that they need, then they may be able to maintain similar population dynamics to current CO_2 conditions. Under this scenario they may increase the total amount of damage they inflict on a plant population because they increase their *per capita* consumption of tissues in order to maintain a given level of nitrogen intake. If, on the other hand, they are not able to extract the necessary levels of nitrogen, their population dynamics may be negatively affected, leading to less plant damage. The implications of these mechanisms are that biological control efforts against weeds may be either enhanced or retarded under future climate scenarios.

Conclusions

Climate change is likely to pose a series of threats to weed management in southern Australia. Northern weeds will invade further south, and many existing weeds may grow more rapidly, and become more fecund. Many weeds will be able to invade further into arid regions, and grow better under reduced rainfall. Whilst the weeds themselves are growing more vigorously, some herbicides at least will become less effective. Even the positive implication that some temperate weeds will be forced further south is a mixed blessing. They are likely to be forced southward by other weeds, and the temperate crops upon which the valuable southern Australian agriculture depends are likely to suffer similar consequences. Similarly, native flora and fauna are likely to suffer similar southward range shift pressures.

Given the significance of the likely changes in weed management, and the areas of uncertainty, it seems clear that we need to emphasise our ability to adapt rapidly our weed management systems in response to emerging threats and challenges. Modelling and experimental work to date has indicated the likely general ways in which these systems may change, but this work is not sufficiently sophisticated or reliable to be able to predict when these changes might come about, or even what specific outcomes might be expected for given combinations of weeds and valued species (crops and conservation targets). Thus, there will be a need for adaptive or nimble governance of land management enterprises and activities. This approach to land management will need to be aware of the telltale harbingers of the identified (and unidentified) climate change threats, and to be able to rapidly assemble and apply the resources needed to develop adaptations to the emerging challenges.

The projected impacts of climate change on weeds will be paralleled by similar changes for native and production ecosystems. When native plants become stressed as the trailing edge of their range becomes unsuitable, it is quite likely that weeds will invade following a disturbance such as fire, flood or wind throw.

Acknowledgement

Thanks are due to Dr Agathe Leriche for help with some of the graphics.

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The effects of land management on weed seed longevity

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Seed longevity

'One years seeding, seven years weeding'

This old adage bears great witness to weed seeds ability to persist, as most of us who farm, garden or are involved in weed management know! So what causes seed longevity and how do we manage this in the plants that we wish to target. In arable agricultural systems, this will be all of the seedbank as not only do we want low weed seed numbers but also we do not want any carry over of crop seeds from one year to the next as this can cause disease and pest issues and quality issues for the following crop (adventitious presence), a growing issues with the advent of greater product diversity and management of GM crops. In pastoral and natural systems, not all the seed bank is targeted, as we need to maintain a viable seed bank of our pasture and native species to maintain a reservoir of genetic material for replacement recruitment.

There are inherent differences between species in their longevity. Seed size has been put forward as an indicator of seed longevity, with small seeds having longer persistence than larger seed (Thompson *et al.* 1993). The theory behind this is that smaller seeds have a greater ability to be incorporated into the soil, where larger seeds are more likely to be targeted by predator species, and moved to the soil surface through soil movement (Spokas *et al.* 2007). This theory has been challenged by Leishman and Westoby (1998) ,who demonstrate that with Australian native species there is no correlation between seed size and shape and seed persistence. They summarise the difference between the papers are due to the natural history characteristics between British species and Australian species. The later having many species that are more adapted to fire ecology hence having heavier seeds than the herbaceous fruits of British species. However, in our pastoral and arable farming ecosystems, most of our weed species have been derived from overseas and particularly from Europe, so the Thompson *et al.* (1993) theory should hold true for the majority of our arable weeds. But for invaders of Australian native ecosystems, seed size and shape may not be a good indicator of seed persistence.

Before tackling what affects has management practices have on seed longevity, it is important to understand what are the causes of loss of seeds from the seedbank.

Seed losses

The dynamics of the seedbank is due to the influx and efflux of seeds. The influx within a paddock has also been called seed rain. While seed shedding from the mother plant is the main influx, seed importation via wind, crop seeds, machinery and animals can also be major influxes or more particularly the major reasons for new infestations. The effluxes are seed losses due to predation, germination and loss of viability (Cousens and Mortimer 1995). Unfortunately there is little understanding of the relative importance of these three effluxes as most seedbank studies have not recorded differences between the seedbank losses. Many studies have just looked at before and after seedbank numbers (Bekker *et al.* 2000, Felix and Owen 2001, Thorne *et al.* 2007). Others have recorded, initial seedbank numbers, seedling emergence and final seedbank numbers but can not distinguish between fatal germination, decay and predation for the differences between pre management and final seedbank numbers (Young 2001, Davis *et al.* 2005, Brainard *et al.* 2007). Also the studies tend to investigate only one or two of these effluxes at a time. For example, many predation studies are conducted only on seeds on the soil surface. Most persistence studies involve burial of seeds at different depths, utilising mesh bags to contain seeds. Longevity is recorded by recovery of and germination of seeds from within the mesh bag.

However, large seed losses from predation can occur, with losses of 85% being recorded for wild oats (*Avena fatua*) (Cousens and Mortimer 1995), 88% for giant ragweed (*Ambrosia trifada*) (Westerman *et al.* 2006) and modelling predicting up to 65% predation in a range of cropping rotations in the USA (Westerman *et al.* 2006). Under Australian conditions these losses appear to be less , or at least more highly variable (0–100%) with more predation on the paddock edges (Spafford Jacob *et al.* 2006). Predators include ants, voles, earthworms, rodents, birds and carabid beetles (Cousens and Mortimer 1995, Spafford Jacob *et al.* 2006, Westerman *et al.* 2006).

Once seed is buried (e.g. by tillage, falling into soil cracks) predation by animals is dramatically reduced (Hartzler *et al.* 2006, Spafford Jacob *et al.* 2006, Westerman *et al.* 2006) but predation can occur from soil microbes. The effect of soil microbes has been poorly studied with most information coming from treating seeds with fungicides and comparing to untreated seeds with losses estimated to up to 20% (Cousens and Mortimer 1995).

The loss of seed from the seedbank due to germination depends on the seeds dormancy status and its position within the soil profile. After ripening of seeds (either artificially or naturally) can cause a large germination pulse after soil water reaches adequate levels. Seed germination of wild oats increased linearly from 0% to 90% over 18 month of after ripening at 25°C (Adkins and Ross 1981). Different species have different germination rates and pulses as was demonstrated by Young (2001) in comparing wild oats, annual ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*). Both wild oats and annual ryegrass had germination losses from the seedbank primarily in the first year, where wild radish predominately had its germination losses in its second year especially following cultivation (Table 1).

Seed decay or loss of viability has been the least studied phenomena of the three effluxes with estimates of up to 20% loss due to decay (Cousens and Mortimer 1995) but is more likely less than 10% in most situations (Young 2001).

Weed management targeting the seedbank should be aimed at either increasing predation or increasing germination as these two effluxes have the greatest potential to reduce the seedbank.

Table 1. The effect of cultivation on seed longevity and seedling emergence from the seedbank (Young 2001).

	Emergence (%)				
	Year 1	Year 2			
Species		Without cultivation	With cultivation	Dormancy (%) after 21 months	
Wild oats	57.6	5.7	8.0	0.5	0.3
Annual ryegrass	42.8	24.0	6.1	4.4	0.5
Wild radish	11.3	28.3	49.1	32.7	11.3

Management effects on seed longevity

Seed burial

Seed burial has the effect of increasing seed longevity the deeper the burial. In many studies, seed on the soil surface may have a slightly longer longevity initially than seed in shallow depths (1–5 cm) due to germination losses at shallow burial depth. Over time seeds on the surface and at shallow depths (<2 cm) have similar low levels of persistence, but once the depth increases the longevity of seeds increases as depth increase (Figure 1) (Young 2001). So for weed management, it is an option to deep bury seeds to avoid germination of new propagules. However this management can only occur once a decade or longer (based on decay rates) as if these buried seeds are brought back to the surface they will again germinate.

In arable agricultural systems, the effect of cultivation on weed seed movement has been studied (Mohler *et al.* 2006) and is incorporated into models used to predict weed seedling emergence (Sester *et al.* 2007, Spokas *et al.* 2007). Cultivation equipment such as mouldboard plough invert the soil, so initially a large difference in the seed bank can be obtained. Over time however, continual inversion will result in a fairly uniform seedbank throughout the plough depth (Cousens and Mortimer 1995, Sester *et al.* 2007, Spokas *et al.* 2007). Seeds can also work themselves from lower soil profiles into the upper layers over time, negating some of the effects of burial (Mohler *et al.* 2006). Tine implements tend the mix the seeds in a horizontal action with little displacement of seeds at different depths, as do rototillers.

The change in tillage systems from multiple tillage operations to a single pass tillage operation (zero tillage) has also brought with it a change in weed spectra. Reduced tillage systems tend to increase the level of perennial species relatively to annual species (Carter and Ivany 2006, Conn 2006). Under reduced tillage there is less burial of weed seeds causing an increase in the weed seedbank in the top 10 cm of the soil (Conn 2006), which in turn increases the turnover of the seedbank. Though, Carter and Ivany (2006) got greater seedbank build up in the subsoil (>20 cm) than the topsoil (<10 cm), which they explained was due to the soil type being a fine sandy loam. A general observation from the literature suggests that annual grasses respond more to cultivation (less persistence) than either perennial grasses or broadleaves (Cousens and Mortimer 1995).

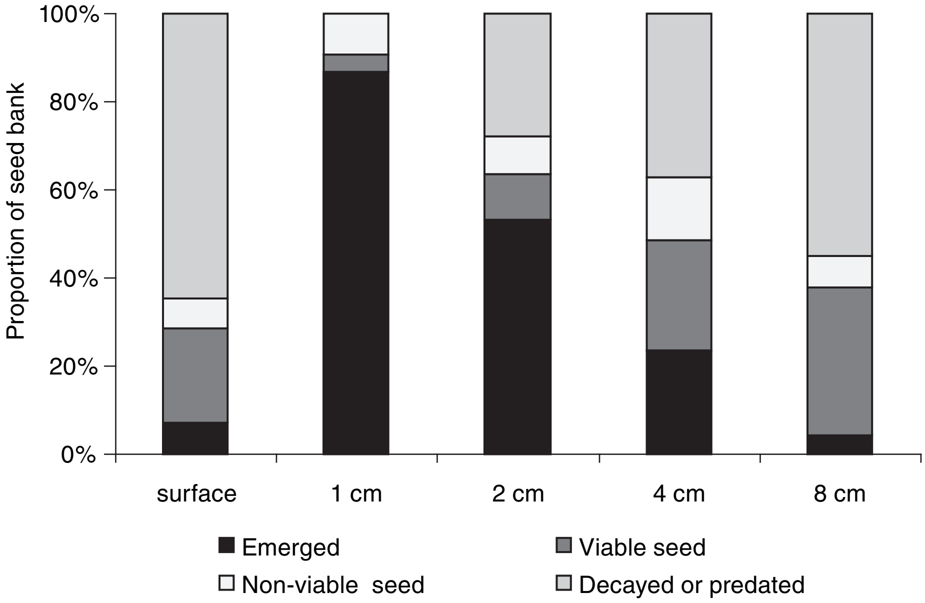

Figure 1. The effect on seed burial of wild radish on seedling emergence, viable seed, non viable seed and decayed or predated seed percentages after 18 months seed burial (Young 2001).

Rotations

Weed seedbanks are altered by crop rotations through different crops having different sowing times, competitive abilities and types of herbicides used. In south-eastern Australian arable dryland ecosystems, the legume and oilseed crops in the rotation are seen to be the most vulnerable to weed outbreaks, through their lower competitive ability (slow growth rate, low sowing densities) and limited herbicide options. In the oilseed canola this has seen the development of herbicide tolerant varieties.

An increase in the intensity of cropping has seen an increase in weed seedbanks (Cousens and Mortimer 1995). This increase in weed seedbanks has been recorded in pastures with increasing disturbance (animal hooves, slashing or cutting hay etc.) (Renne and Tracy 2007, Wellstien *et al.* 2007). These increases in weed seedbanks from more intensified agriculture are of magnitudes of 60–100%.

Crop rotations can have a large impact on seedbank diversity and seed longevity within a species. In a study of Powells amaranth, (Brainard *et al.* 2007), found that seed dormancy was selected for under continuous lucerne (dairy pasture) compared to shorter dormancy under cultivated vegetable cropping.

Heat

Heat can be applied to the soil via various means such as fire, solar radiation, steam, decomposition, and microwaves (Brodie and Young 2007). Heat can be used to either destroy the seeds or promote germination. In natural ecosystems there may be a selectivity between native species and introduced species in their tolerance to heat, with many native species being more ecologically adapted to heat (fire) with fire stimulating germination, where introduced species may be more vulnerable.

In arable situations, heat has been utilised to destroy many weed seeds. Soil solarisation capturing heat through black plastic covers, or heat accumulating through organic matter decomposition in composts has been used to kill weed seeds. Use of steam to control weeds has been developed but has had very limited effect on killing seeds unless implemented in a pressurised device. As soil is a good insulator, seeds even at relative shallow depths are well protected from heat as a control management technique.

Fire has been used to manage weeds after germination in many organic crops, and the effect on seeds has been investigated in managing weeds being returned to the field after crop harvest. Walsh and Newman (2007) found that temperatures in excess of 400°C and 500°C for 10 seconds were required to kill seeds of annual ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*) respectively. Utilisation of conventional and narrow windrows achieved greater than 96% control of both of these species (Walsh and Newman 2007).

Soil quality

Weed suppressive soils based on inputs of carbon through green manure crops, animal manure application, have led to the formation of colonies of deleterious rhizosphere bacteria which in tune has led to a decreased growth of weed seedlings (Kremer and Li 2003). The increased bioactivity within the soil under these 'biological' systems may also decrease the longevity of weed seed banks, though little work has yet been done on this. But biological systems show promise as Davis *et al.* (2005) showed a negative correlation between weed seed persistence and hydrothermal time, indicating that soils with higher moisture retaining properties will decrease the persistence of a seed. This is most probably due to greater activity by fungal and bacterial decay at high soil water levels. Though high C:N ratios can impede soil microbe decay of weed seeds (Shem-Tov *et al.* 2005). Higher organic soils, with greater trash conservation also increases the protection of seed predators, increasing seed predation of the seedbank (Spafford Jacob *et al.* 2006; Westerman *et al.* 2006).

Conclusion

Incorporating a fully integrated weed management techniques into land management by targeting not only the emerged weeds but also the seedbank will lead to better long term management. The two areas to target in reducing weed seedbanks are increasing predation and germination losses. The former fits well into the present paradigm of biological farming and with the advent of new molecular tools, it will be easier to determine which methodologies/technologies are most appropriate for different ecosystems. In pastoral and natural ecosystems where the seedbank not only consists of weed seeds but also desirable seeds, it is still to be determined whether there is sufficient efficacy window for these techniques.

Targeting the germination losses from the seedbank, then requires a follow up to manage the emerged population. This has to then be incorporated within other management tasks such as sowing crops or fertilising pastures, which may cause time delays and hence yield losses. If herbicides are relied on too heavily, there will be weed resistant issue to be managed.

The future to managing weed seedbanks is in the use of computer simulation models in order for land managers to predict possible outcomes under different scenarios that they are faced with annually. These management aids need to incorporate all different management options as well as economic outcomes. A good example of such a model is Ryegrass Integrated Management (RIM).

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How far do weed seeds actually travel?

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Abstract Ecologists invariably focus on long-distance dispersal, since this has a large influence over the rate of spread of invasive species through a landscape. We marvel at the distances that (some) seeds travel and the astonishing array of morphological adaptations by which this is achieved. Theoretical ecologists can now predict the distances dispersed by wind using highly sophisticated models, although our ability to predict distances dispersed by other vectors, such as animals, is crude by comparison. Once they have reached the ground, secondary dispersal can re-distribute seeds by considerable distances. However, short-distance dispersal has a major contribution to patchiness within fields, the level of competition that plants experience, the microsites in which seedlings emerge and the maintenance of species diversity. Whether we look at the number of seeds deposited per unit area at different distances or the frequency distribution of dispersal distance (these two relationships are very different shapes), the vast majority of seeds are deposited within a few metres or centimetres. Thus, we need to measure short-distance dispersal, not just long-distance dispersal.

Examples are given of studies that have measured short distance dispersal by air, water, fire and earth. It is shown that the general characteristics of primary dispersal-density curves are consistent across these vectors: scale of dispersal distance varies, but the general shape does not. However, secondary dispersal can change these relationships considerably. It is also shown how different vectors acting sequentially and/or in parallel can combine to produce distinctive dispersal-density curves.

Post-fire weed management: lessons from the Victorian Alps

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Summary Wildfires can create both threats and opportunities for weed management. An understanding of these can help land managers maximise benefits and minimise risks from post-fire weed control programs. The primary aims of post-fire weed control should be to minimise the impacts of weeds on important natural and other assets, including neighbouring freehold land, and to take advantage of new or enhanced weed control opportunities resulting from the fire.

The management of each weed species following fire should depend on how that weed is likely to respond to the fire, how fire control works may have affected the weed, and how both the fire and fire control may have affected existing weed control programs. With most of the Victorian Alps burnt in wildfires in 2003 and 2006/07, significant resources have, and are being, devoted to post-fire weed control on public land. Lessons learnt following these fires have been formulated into a set of principles for post-fire weed management that are broadly applicable on public land. A number of species case studies illustrate the application of the principles to post-fire weed control programs.

Introduction

The Victorian Alps covers the extensively forested mountainous region straddling the Great Dividing Range in eastern Victoria. For the purposes of this paper, it is loosely defined as the area from Mansfield in the west to Bonang, north of Orbost, in the east. It encompasses the upper and mid-catchments of many of eastern Victoria's major rivers and includes a wide range of geologies, landforms, altitudes, climates and vegetation types, from alpine peaks above the tree line at over 1800 m to deeply-incised, forested valleys at less than 300 m. Much of the Victorian Alps remains as forested public land, although there are many areas of cleared and forested freehold land, particularly in fertile valleys and on flatter uplands, on both sides of the Great Divide.

Within the Victorian Alps, Parks Victoria manages over 800,000 ha of parks, conservation reserves and historic areas, including Alpine National Park (ANP) and Mount Buffalo National Park (MBNP). Most of the remaining public land is State forest managed by the Department of Sustainability and Environment (DSE).

On 7–8 January 2003 and again on 1 December 2006 extensive dry lightning storms started widespread fires in the Victorian Alps. 1.08 million hectares was burnt in the 'Alpine Fires' from January to March 2003, including 489,000 ha of national parks and conservation reserves. The 2003 Alpine Fires burnt most of the Alps east of the Buffalo and Wonnangatta valleys as well as similarly extensive areas in the high country of New South Wales and the Australian Capital Territory.

The 'Great Divide Fires' burnt 1.05 million hectares between December 2006 and February 2007, including most of the western and southern parts of the Victorian Alps. Three other major fires during this period: Tawonga, near Mt Beauty, (33,600 ha); Tatong, north of Mansfield, (31,800 ha); and Hermit Mountain, south of Corryong, (2800 ha) burnt further substantial areas within the Victorian Alps. The combined burnt area included 362,000 ha of national parks and reserves. Approximately 130,000 hectares was burnt in both 2003 and 2006/07, including most of the Tawonga and Hermit Mountain fire areas.

Weed management on public land in the Victorian Alps is a high priority and receives substantial investment, particularly on Parks Victoria's park and reserve estate. Most of Parks Victoria's weed control programs are designed to meet at least one of three broad objectives:

1. Protect important natural, cultural and other values within parks and reserves,
2. Reduce the risks of weeds expanding their distributions to new areas within parks and reserves, and
3. Prevent the spread of weeds onto neighbouring public and private land.

Fire and weeds

Wildfires and fire control efforts can have significant effects on weeds and weed control programs, an understanding of which is important for post-fire weed management.

Impacts of fire on weeds

Fire can directly affect both weeds and native plant species in many ways. Fire can kill plants, both through combustion and radiant heat. Fire can also deplete seed banks, both by killing viable seed stored on plants and in the upper layers of the soil and by breaking seed dormancy and instigating mass germination of seed that survives the fire. The reduction or loss of ground stratum, understorey and canopy vegetation (depending on fire intensity) can also reduce competition for light, moisture, nutrients and physical space for plants that either survive a fire, whether unburnt or only partially burnt above ground or as underground organs (roots, bulbs, etc.), or that are able to germinate quickly on the burnt ground. The creation of vast areas of bare ground can provide ideal germination opportunities that are otherwise rarely available to many colonising species. The availability of light and the flush of nutrients in the ash bed after a fire can promote rapid growth of seedlings.

By their inherent nature, and despite the long period of adaptation of much of Australia's indigenous flora to fires, many weeds of native vegetation can take advantage of post-fire establishment and growth opportunities as well as, or better than, many native species. Some weeds, such as *Cirsium vulgare* (Savi) Ten. (spear thistle), may only proliferate and prosper for a short period post-fire and will be outcompeted once native vegetation re-establishes, while others, such as introduced *Rubus* spp. (blackberries) can maintain their place in the regenerated ecosystem, competing very ably with native species.

While not a direct effect of fire, there is increasing evidence of a strong association between fires and floods (including flash floods) in the Victorian Alps (Lynch 2007, PV and DSE 2007). Steep catchments denuded of vegetation by fire are vulnerable to accelerated erosion, particularly during heavy rain events post-fire. Floods are well known as both disturbance events depositing sediment for seed germination and vectors for dispersal of weed propagules (e.g. Howell and Benson 2000, and references therein). In post-fire floods there is potential for long-distance transport of weed propagules (particularly seeds and easily-broken branches of species such as *Salix* spp. (willows) and *Vinca major* L. (blue periwinkle), although this does not appear to have been studied in Australia.

Significant rain events caused substantial erosion in parts of the Buckland and Mitta Mitta catchments following the 2003 Alpine Fires, and massive erosion in upper parts of the Gippsland Lakes catchments after the 2006/07 Great Divide Fires. Sediment deposited along river banks following such events can be many tens of centimetres deep and could provide a nutrient-rich substrate for the germination and growth of water-dispersed weeds. Again, there appear to have been no studies of this to date and anecdotal observations following the 2003 flood events were inadequate to distinguish between weeds *in situ* pre-fire growing up through the deposited sediment and new incursions taking advantage of the new substrate. Following the extensive post-fire flooding in Gippsland in mid-2007, there will be a heightened need to monitor for, and respond to, the establishment of weeds in riparian areas.

Impacts of fire control on weeds

The Code of Practice for Fire Management on Public Land in Victoria (DSE 2006) recognises the potential for fire control activities to facilitate weed invasion. Mineral earth control lines built to contain fires create extensive areas of, often, severely disturbed, bare ground. In addition, the machinery, vehicles and even personnel used to control fires can carry weed seeds into and around a fire area. Weeds could potentially be transported vast distances in this way, depending on how far away fire fighting equipment and personnel are sourced from. Weeds can also be transported relatively short distances, from weedy to previously 'clean' sections of a fire ground, either as seed or vegetative propagules. The complete absence of established vegetation and the scarcity of native plant propagules on mineral earth control lines means that any weed propagules deposited during fire control face little competition from other plants.

During the 2003 Alpine Fires, over 7500 km of fire control lines were constructed, including over 6000 km on public land (DSE 2005). Many of these were actively rehabilitated in the first three months post-fire by respreading windrowed vegetation and topsoil back across them. The respreading of topsoil, in particular, may help to constrain weed establishment, to some degree, by facilitating the re-establishment of competing native species whose propagules are contained in the soil. The effectiveness of control line rehabilitation, including the distribution and abundance of weeds in relation to disturbance and rehabilitation history, and landscape context, are presently being investigated (S. Cutler personal communication). To date, 27 weed species have been recorded on 2003 fire control lines in ANP and MBNP (S. Cutler, personal communication), including many species not normally found in undisturbed forest environments. These weeds are predominantly pasture grasses and herbaceous weeds commonly found in paddocks, roadsides and other disturbed areas. When completed, this study should provide public land managers with improved knowledge for managing weeds on control lines constructed during future fires.

Impacts of fire on weed control

Fires can provide significant opportunities for improved weed management outcomes, as well as negative impacts on weed control programs. Some of the positive outcomes can include:

- Killing of mature plants,
- Depletion of weed seed banks,
- Easier chemical or physical control of even-aged post-fire regeneration, and
- Improved visibility of, and access to, weed infestations.

These opportunities are discussed further under 'Principles for post-fire weed control on public land', below.

The most immediate effect of fires on weed control is the disruption of weed management programs underway, or programmed to commence, during a major wildfire event. While managers can attempt to keep priority weed programs going, many agency staff are likely to be diverted to assist with the fire control effort. A program manager's duty of care to weed control contractors and field-based staff, and inability to oversee their works and safety, make it almost inevitable that on-ground works will be disrupted, even in areas not directly threatened by fire. This disruption can occur at critical times for some weed control programs, particularly for weeds whose periods of flowering and seed production coincide with peak fire season (e.g. many exotic Asteraceae (daisies and thistles) at higher elevations). Other than attempting to keep vital control programs rolling along with minimal supervision, there is little weed managers can do in these situations. In many cases, it is possible to recommence control works later in the season (e.g. blackberry control programs are often effective during autumn); otherwise works need to be held over until the following year. With the potential for increased fire frequency due to global warming weed managers should consider building contingency plans for fire events into weed control programs.

Other relationships between weed dispersal and fire

There appears to have been little detailed investigation into the specific dispersal vectors and patterns of key weeds in the Victorian Alps, let alone the effects that fires might have on these. The availability of post-fire ash beds, however, is likely to enhance germination success of weed seeds that are able to disperse into burnt areas.

Wind can disperse the seeds of a wide range of weeds (e.g. Asteraceae, *Salix* spp.) over both short and long distances and many species rely on wind as a key dispersal vector (Carr *et al.* 1992). The strong winds and powerful updrafts often associated with wildfires may contribute to the dispersal of certain weeds that set seed during the fire season. An understanding of wind patterns both during and following fires could help weed managers predict potential dispersal patterns of certain wind-dispersed weeds. In the Victorian Alps, strong and gusty north to north-westerly winds predominate during the main fire season (summer to early autumn). Wind-dispersed weeds that occur upwind of recently burnt areas could pose a high risk of invasion into post-fire ash beds.

Investigations of wind dispersal of weeds and inter-relationships with fire would be a valuable area of research. An investigation of this nature, involving *Salix cinerea* L. (grey sallow) on and around the Bogong High Plains, parts of which have been twice burnt in four years, is commencing in 2007/08 (J. Moore personal communication).

Native and introduced animals, which can carry seeds in their fur or gastro-intestinal tracts (Carr *et al.* 1992, Muyt 2001, Eyles 2002), may be forced to forage widely in search of adequate food post-fire, and could help disperse weeds into previously uninfested areas. Weeds can also be introduced into new areas in fodder brought onto fire-affected properties. With losses of fencing during fires and therefore increased levels of stock wandering, as well as licensed grazing in State forests and other crown land, stock could spread both existing and new weeds into burnt areas.

Fire recovery planning

The 'Guidelines and Procedures for Managing the Environmental Impacts of Weeds on Public Land in Victoria' (DSE 2007) summarise the comprehensive State and Federal legislative and policy framework around weed control on public land. With the exception of the Victorian 'Code of practice for fire management on public land' (DSE 2006), which requires that weed management issues be addressed in fire-recovery plans, none of these instruments address weed control in relation to fire. However, all remain as applicable in the post-fire environment as at any other time.

Following each of the major wildfire events in Victoria in recent years, the State government has announced fire recovery programs, which have included significant pest plant and animal control components (e.g. Victorian Government 2007). Parks Victoria and DSE have worked collaboratively in developing integrated public land fire recovery plans (e.g. PV and DSE 2003, 2007), in accordance with the requirements of the 'Code of practice for fire management on public land' (DSE 2006).

The fire recovery plan for the 2006/07 fires (PV and DSE 2007) recognises that:

> *'The post-fire environment provides both opportunities and threats [for weed control]. For example, prompt action can minimise regrowth of weeds, but failure to act can result in even more dense infestations of fire-responsive species, which will choke regeneration of native species and potentially spill over onto neighbouring private land.'*

The '2007 Report from the Ministerial Taskforce on Bushfire Recovery' (Victorian Government 2007) identifies two broad priorities for post-fire weed control: public land close to private land boundaries and sites of vulnerable native vegetation or fauna. The report states that activities are to focus on invasive and fire-sensitive weeds (both new and emerging) to limit regeneration.

Specific post-fire priority weed management actions need to be identified through a combination of systematic risk assessment, collation of other information (including local knowledge) and consideration of basic principles of weed management (e.g. Robinson 1996, DSE 2007), including principles of post-fire weed control (see below).

The risk-management approach involves identifying key values and threats to those values within the fire area. However, risk assessment depends to a high degree on the availability of knowledge on both values and threats. Values vary in their distribution and significance, while threats vary in distribution and severity. Just as importantly, different values are affected to varying extents by different threats. Values that may be affected by weeds include: threatened species and communities, waterways and wetlands, visitor access and amenity, and neighbouring land. While information on values is often mapped and stored systematically, information on threats, usually, is not. Therefore, while a systematic risk assessment can help to identify priority fire recovery tasks, it needs to be augmented by other knowledge and information.

A summary of the broad weed management priorities for public land following the 2006/07 fires is contained in Table 1.

Principles for post-fire weed control on public land

A number of principles can be identified that can assist land managers to minimise the impacts of weeds following wildfires and to maximise the benefits that can be achieved from post-fire weed management.

Prevention

Principle 1: Minimise the availability of weed propagules post-fire by maintaining a high level of pre-fire weed control. For many weeds, there are likely to be fewer opportunities to establish post-fire if their propagules are not present, or reduced, pre-fire. Unfortunately, this requires a high level of continuous weed control, which is often well beyond the resource capacities of most public land managers. However, managers of fire-prone areas should, as a priority, try to maintain a high level of control over weeds which have a high potential to spread during or following fire.

Principle 2: Incorporate weed hygiene principles and practices into fire control plans. While the primary focus of any fire control effort will always be on fighting the fire, many other matters, such as health and safety of fire fighters, public safety, and protection of public and private assets, will also be addressed in fire control plans. Even during the height of a fire, land managers have an opportunity to seek to incorporate into fire control plans measures to prevent or minimise the risks of spread of priority weeds. Such measures could include information for crew briefings, vehicle and machinery washdown requirements, and 'no go' areas). Ideally, hygiene plans for the prevention of spread of critical weeds would be developed in advance and incorporated into pre-fire-season planning, ready for immediate roll-out should a fire occur in, or threaten, any priority weed containment areas.

Principle 3: Facilitate the stabilisation and revegetation of bare ground as quickly as possible post-fire. Bare ground provides enhanced opportunities for weed establishment. Once bare areas have become revegetated, any weed propagules present or newly arriving need to compete with established plants to establish themselves. Stabilisation and prevention of soil erosion assists native vegetation establishment (assuming suitable propagules are present), thereby helping to limit opportunities for weed germination. Conversely, the retention of bare ground can maintain receptive seedbeds for weed invasion and heightened risks of soil instability and erosion (and thus further bare ground for weed establishment).

Table 1. Broad public land weed control priorities following the 2006/07 Great Divide Fires (from PV and DSE 2007).

Key Value	Broad project description
Native vegetation across the fire affected area	Eradicate new and emerging weeds wherever they occur (e.g. Himalayan honeysuckle, black knapweed, Paterson's curse and African lovegrass). (Includes supporting surveillance activities for these and other new and emerging species.)
	Prevent establishment of new invasive species along fire control lines, water filling points, access tracks, etc.
Native vegetation across the fire-affected area with a focus on the highest priority asset areas	Reduce the threat of established, high-risk, fire-responsive weeds, focusing on the highest value areas at risk (e.g. Cape and English broom, willows, gorse and hawkweeds, particularly where threatening alpine bogs, alpine heathlands and *Poa* grasslands).
	Reduce the threat of established weeds with a focus on the highest value areas at risk (e.g. blackberry, willow, blue periwinkle and other riparian weeds in priority river reaches and other priority sites – e.g. those containing threatened species or communities).
Alpine bogs	Remove willows and other pest weeds.
Private land adjoining parks and reserves and forests	On public land adjoining private land, decrease the cover of fire responsive weeds, such as English and Cape broom.
	Decrease the impact of key weeds along the interface, such as blackberry.
	Decrease the impact of gorse by reducing its potential to move into new areas.
	Undertake surveillance and treat new and emerging weeds on public land along interface areas, including ragwort, Paterson's curse, and other weeds.

Principle 4: Undertake surveillance for, and respond to, new and emerging weeds. Following a major disturbance event, such as a wildfire, there is an increased likelihood that new weed infestations will appear. In some cases, these may only be small range extensions of existing infestations (e.g. a weed establishing in the next catchment over from where it was previously known). However, new weeds from much further away could also appear. Weed managers need to implement programs to enable them to be both vigilant for, and able to rapidly respond to, any new incursions as soon as possible. It is important that new infestations be detected before they have an opportunity to set seed (recognising this time frame can vary greatly between species).

Weed managers should use their knowledge of the weed assemblages in and around burnt areas, and local knowledge of weed responses following previous disturbance events in similar locations, to forecast possible new weed incursions that may occur. Particular consideration should be given to possible 'sleeper weeds' that are known to be present but are considered to be relatively benign, but which could rapidly invade burnt areas post-fire. As a precaution, such sleeper weeds, as well as any known, isolated occurrences of invasive species in or near burnt areas, should be eliminated as soon as possible post-fire.

While a general alertness for new and emerging weeds may suffice in many burnt areas, some situations may demand a more proactive level of surveillance. Following the 2003 Alpine Fires, and in recognition of the potentially altered weed risk post-fire, Parks Victoria commissioned a survey and assessment of the weeds and cultivated plants at Clover Arboretum in ANP near Mt Beauty (Ecology Australia 2006). This assessment recommended the control or elimination of 25 cultivated and/or naturalised taxa. Based on local knowledge of the invasiveness of some of the cultivated and naturalised exotic plants in Falls Creek village, Parks Victoria also commissioned a cross-tenure post-fire survey for invasive weeds in the Falls Creek area (Carr *et al.* 2004). This survey also recommended a number of priority actions for land managers.

Opportunism

Principle 5: Take advantage of post-fire reductions in weed biomass. Many large and dense weed infestations can be costly and difficult to control. The sometimes massive reductions in weed biomass following fires can provide opportunities to control infestations with substantially less effort and resources than would otherwise be required.

Principle 6: Remove remaining individual mature plants from infestations. Where fire has killed the majority of mature plants in a weed infestation, the window of opportunity to achieve effective control of the weed can be significantly improved if any surviving mature plants or unburnt patches are also killed. This needs to occur before these survivors have a chance to set seed and replenish post-fire seed stores. For weeds that take two or more years to become reproductively mature, preventing the replenishment of seed stores from surviving individuals can significantly increase the window of opportunity to accomplish their control or eradication.

Principle 7: Capitalise on post-fire depletion of weed seed stores. Weed seed stores can be significantly depleted post-fire, particularly where fire intensity has been high. Like many indigenous Australian plants, which have adapted to fire by storing seed, either on the plant or in the soil, for germination *en masse* post-fire, many weeds have a similar capability (e.g. *Cytisus scoparius* (L.) Link, *Genista monspessulana* (L.) L.A.S.Johnson, *Leycesteria formosa* Wall. and *Ulex europaeus* L.). Post-fire mass germination is an ecological strategy that allows seedlings to take advantage of the nutrient-rich post-fire ash bed and reduced competition from adult plants during establishment and growth. Heat during a fire can also kill weed seed. The greater the fire intensity, the deeper the potential heat penetration into the soil and the greater the potential mortality or germination of the seedbank.

Effective control of post-fire weed seedlings, following mass germination, can prevent re-establishment of infestations in which mature plants have already been eliminated (either through fire-mortality or post-fire control, or a combination of the two). However, post-fire weed seedling density can sometimes be so high that it is difficult to kill all individuals. There can also be subsequent germination from the remnant seedbank following initial seedling control. Follow-up treatment of surviving or newly germinating seedlings may therefore be required in the same season and/or subsequent years. A good understanding of a weed's ecology and regular monitoring of its response to both fire and treatment will help determine the necessary ongoing treatment requirements.

Principle 8: Take advantage of improved post-fire visibility and access to weed infestations. Many weed infestations in the Victorian Alps are in steep and/or thickly vegetated terrain. Weeds such as *Pinus* spp. (pine wildings) growing amongst a dense understorey can be very difficult to both detect and reach. Many riparian weed infestations can also be difficult to access, without the construction of expensive and environmentally damaging access tracks. The economic and environmental costs of access construction can outweigh potential weed control benefits.

However, with the removal of vegetation during a fire there can be significant opportunities to gain relatively easy access to previously inaccessible weed infestations. Post-fire, surviving pines and riparian weeds can be much more visible and accessible to ground crews. Even where new access tracks need to be constructed, this may be accomplishable with less cost and impact than if the site were unburnt. Sometimes fire control lines may even have been constructed in locations that coincide with weed access needs. However, as rehabilitation of new fire control lines often occurs quite early post-fire, weed managers need to identify potentially useful control lines for access to weed infestations as soon as possible and negotiate to keep them open while weed control is undertaken.

Risk management

Principle 9: Protect priority values at risk from weeds post-fire. All environmental weed management programs should, as a priority, aim to protect the highest value natural and other assets in an area that are considered to be at the greatest risk from the impacts of weeds. This is termed an asset-based risk management approach (DSE 2007). DSE (2007) outlines a framework and detailed planning process for identifying priority values at risk from weeds.

Due to the large scales of the 2003 and 2006/07 fires and the need to produce draft recovery plans promptly post-fire, this process was not able to be followed in its entirety. However, the key steps of identifying and prioritising values, identifying threats (weeds being only one of many), assessing the risks of particular weeds to specific values, and selecting priority sites for weed control were undertaken (PV and DSE 2003, 2007).

Table 1 identifies, in general terms, some of the highest priority values threatened by weeds identified in the 2006/07 Great Divide Fires fire recovery plan (PV and DSE 2007). Relatively weed-free examples of vegetation that has an inherent high susceptibility to weed invasion (e.g. moist environments, fertile riparian vegetation communities) are considered to be of high value and therefore are a high priority for attempting to maintain in a low-weediness or weed-free state.

Principle 10: Expect the unexpected. There are often likely to be unknowns when post-fire weed programs are being developed. For example, there could be weeds whose response to fire is not fully known. While the literature may provide indications of likely responses (e.g. time to reach reproductive maturity, based on studied or cultivated populations), what actually occurs locally, at the range of elevations and landscape positions within the fire area and with potential interacting effects of other factors, such as drought, may differ. It is also possible that new infestations of weeds that were previously present, but undetected, could be discovered and may require a significant level of response to contain. Conversely, some existing occurrences of fire-sensitive weeds could be eliminated by fire.

It is important that land managers maintain sufficient flexibility in their post-fire programming to respond to any new or emerging threats or opportunities. In the first summer following the 2003 Alpine Fires, alpine bogs on the Bogong High Plains were quite unexpectedly invaded by *S. cinerea* seedlings (see case study, below). Due to the significance of the threat to these valuable wetlands, substantial additional funding was obtained from the North East Catchment Management Authority and a significant response program initiated.

One of the most important unknowns following the 2006/07 Great Divide Fires is what the cumulative effects of being burnt twice in four years will be for many weeds. Again, the literature will assist, to some degree, but on-ground monitoring will be vital for an accurate understanding of weed responses.

Principle 11: Consider the likely consequences of not controlling fire-responsive weeds post-fire. Many weeds are well adapted to fire and can respond vigorously if left unchecked. Land managers must consider the risks posed if these weeds are not actively controlled post-fire. Whilst effective weed control can be resource-demanding in the initial post-fire period, the potential consequences of not implementing effective weed control are increased risks of vastly greater and more intractable weed management problems in the future. Small or predominantly juvenile infestations are likely to be much easier and more cost-effective to control than large, established, mature infestations.

Continuity

Principle 12: Protect and capitalise on pre-existing weed control investments. One of the priorities for post-fire weed management should be the protection of any pre-fire weed control investments. Resources for weed control on public land are often tight and land managers cannot afford to waste any investment in strategic and effective weed control. If within the potential scope of post-fire weed management budgets, managers should, as a priority, attempt to at least maintain, if not build upon, their pre-fire weed control programs.

Principle 13: Address key post-fire community and political expectations. Following a wildfire local communities, particularly neighbours of public land, can be highly concerned and emotional about the causes, impacts and control of the fire, pre-fire land management, and post-fire recovery (Collins 2006). Politicians can sometimes reflect community angst by being critical of public land management and fire management practices (Collins 2006). It is important that public land managers recognise and accept these reactions and implement post-fire management actions that demonstrate sound land management.

Following a fire, effective control of weeds on the private land interface, particularly where neighbours have reasonable levels of weed control on their own properties, is an important demonstration of sound land management. The identification and control of any new or emerging weeds following fire needs to be a very high priority. There also needs to be effective communication with neighbours to listen to any concerns they may have and to allow them to have input into plans for weed control near the boundaries of their land. Through discussion, opportunities for mutually beneficial cooperative weed control works may be identified.

More broadly, post-fire control of weeds in areas of high visitor activity, such as picnic and camping areas, fishing spots and along major access routes, can help mitigate ongoing community concerns about public land management. Icon sites that attract high visitor numbers, such as the Wonnangatta Valley and Howqua River flats in the Victorian Alps, may require a higher level of weed control than sites with lower visitation. Recognition of, and appropriate measured response to, public expectations can assist land managers to keep focused on implementing priority post-fire works, rather than reacting to community discontent.

Principle 14: Enhance partnerships and integration of programs across boundaries. The significant impacts of fires on weeds and existing weed control activities provide an opportunity for land managers to review the effectiveness of the management and delivery of their existing weed control programs. Except for small and isolated infestations, effective strategic weed control usually requires a tenure-blind, cooperative, collaborative and consistent approach (DSE 2007). Individual land managers can achieve short-term and localised control of certain weeds by working in isolation from their neighbours, but broadscale and/or long-term control requires a holistic, cross-tenure approach, with each land manager doing their bit to achieve a common goal.

In recent years, around the Alps, Parks Victoria has developed a wide range of weed management partnerships, both formal and informal, with other agencies (in particular catchment management authorities, alpine resorts, Department of Primary Industries (DPI) and DSE), researchers and neighbours. These cooperative programs are achieving better and more sustainable results than previously, and are sometimes able to attract additional funding due to their cooperative nature. The development of a cross-tenure post-fire weed control plan, or broader fire recovery plan (e.g. PV and DSE 2003, 2007) is a valuable first step in cooperative management, but it needs to be followed through into implementation and evaluation, so that cooperative management becomes the norm, rather than the exception.

Resourcing

Principle 15: Constrain the ambition of post-fire weed control programs to realistic objectives. Following a fire, and possible associated significant reductions in weed biomass, some widespread, intransigent weed problems may suddenly seem to be containable. While this may be so for certain species in some locations, for many weeds it will not be the case. Some weeds in the Victorian Alps, (e.g. introduced *Rubus* spp. and *Hypericum perforatum* L. – St. Johns wort) are so widespread that it would be logistically impossible to control all, or even most, infestations, even with a very large post-fire weed control budget.

The objectives of post-fire weed control programs therefore need to be constrained by the realities of both short-term fire recovery budgets and realistic expectations of likely future budgets to maintain post-fire gains. There is little value in undertaking massive weed control programs for two to three years post-fire, only to see the weeds recover in subsequent years, due to a lack of resources that should have been foreseeable at the outset.

In relatively undisturbed sites, many post-fire weed control programs should generally be self-maintaining once native vegetation cover reaches sufficient height and density to out-compete invading weeds. In disturbed areas, however, there is likely to be a greater requirement for ongoing weed management, for other weeds are as likely as native species to replace weeds that are killed.

Principle 16: Allocate sufficient resources for post-fire weed management. Fires can provide a unique opportunity to achieve beneficial weed control outcomes, but can also initiate the development or expansion of substantial post-fire weed infestations.

Weed managers need to allocate sufficient resources for increased weed vigilance and survey for at least two to three years post-fire. Increased resources are also likely be needed for at least the same period, or potentially much longer, for intensive on-ground weed control. Due to the specific impacts of fires and fire control activities on weeds, local staff are unlikely to be able to meet legislative obligations (see DSE 2007), community expectations or environmental needs without additional resources.

Monitoring and evaluation

Principle 17: Monitor infestations to reassess control requirements and evaluate effectiveness. All known weed infestations should be assessed following fire to determine both the immediate impacts of the fire and the post-fire responses of the weeds. Repeated monitoring may be required, as different weeds will respond to fire at different rates and the responses of some weeds may change over time. Monitoring is also essential following commencement of control programs to allow evaluation of treatment effectiveness. If treatment results are not satisfactory or off-target impacts significant, the control program may need to be adjusted. An effective monitoring and evaluation program allows such adjustments to be made as early as possible.

Case Studies

The following species case studies help to illustrate application of the above principles for post-fire weed control.

Leycesteria formosa (Himalayan honeysuckle)

Leycesteria formosa, a native of the Himalayas and western China that was imported into Australia as a garden plant, can rapidly colonise undisturbed habitat (Hosking *et al.* 2006). It is spread by mammals, birds and water and is capable of out-competing native plants to the point of completely altering the floristics of a forest understorey if left uncontrolled. Prior to the 2003 Alpine Fires, there were established infestations across a considerable area of the foothill forests of MBNP and in the east Kiewa Valley of ANP, south of Mt Beauty. Pre-fire, efforts to control the species had been carried out for many years in MBNP and to a lesser extent in ANP.

Following the 2003 Alpine Fires, the majority of existing *L. formosa* infestations in both parks were reduced to juvenile plants, germinated from the soil seed bank post-fire. The post-fire control program was focused on MBNP, to build on the long-term pre-fire control work undertaken there and because *L. formosa* was considered to pose a direct threat to several threatened plant and animal species on the slopes of Mount Buffalo.

Broad *L. formosa* control areas were delineated, based on known pre-fire distribution and likelihood of occurrence in areas not previously searched in detail. The highest priority post-fire was to visit, map and control all known infestations. In the first post-fire season, the commencement of the control program was delayed until early February, much later than in pre-fire years, to allow more time for young plants to grow sufficiently to be visible above the rapidly regenerating understorey. Any surviving mature plants were killed. The second priority was to search all gullies and other moist areas considered to have potential to harbour *L. formosa*, within the broadly delineated areas, to ascertain its presence. All such areas were searched in the three years following the 2003 fires.

By 2–3 years post-fire, the vigorous regeneration of native understorey vegetation had significantly increased the difficulty of accessing areas and locating *L. formosa* seedlings. As rangers had observed that it takes 2-3 years for *L. formosa* to produce viable seed (D. Smithyman personal communication), a strategy was adopted of leaving some catchments for two years between searches for new plants. It was felt that this would allow seedlings to grow sufficiently to increase their visibility amongst the heavy undergrowth, without allowing the production of seed. However, there remained a risk that any plants missed would produce seed prior to any subsequent visit. At the time of the 2006/07 fire, many infestations consisted of only small scattered individual plants of 1–2 years of age, hidden under the forest understorey, requiring much careful searching to discover. Very few larger, mature plants remained.

Due to the presence of mature plants in gullies on crown and private land outside MBNP, park staff are working with neighbouring land holders and land managers to encourage and assist them to control *L. formosa* infestations on their land, to help prevent reinfestation of the park.

The combined impacts of the 2003 fire and the intensive post-fire control program have had a significant impact on *L. formosa* in MBNP, with many previously heavily infested areas having only low infestations when burnt again in 2006/07. *L. formosa* is capable of withstanding repeated fuel reduction burning (Robinson 1996), but its response to two wildfires in four years is uncertain. However, it is likely that, given its ability to produce viable seed within 2–3 years, seedbanks are likely to have been at least partially replenished by any mature or regenerating plants missed during the 2003–2006 control programs. However, the 2006/07 fire provides another opportunity to resurvey and retreat all known infestations again, without the hindrance of a dense native understorey.

Introduced Rubus spp. (blackberries)

Introduced *Rubus* spp. are extremely widespread in the Victorian Alps, particularly in gullies and riparian areas, but also in disturbed areas and moist environments away from waterways. *Rubus* spp. are so ubiquitous and readily dispersed by native and introduced birds and mammals that in most areas eradication is not possible. Broadscale control over wide areas, while technically feasible, would be too costly, even for a well-funded fire-recovery program. Control programs therefore need to be strategic and targeted at protection or maintenance of specific values, e.g.:

- threatened species (and their habitats) or communities;
- areas of predominantly blackberry-free vegetation;
- access along roads and tracks for recreational users and along rivers and streams for anglers;
- the natural visual landscapes that visitors enjoy, particularly around lookouts and picnic and camping areas; and
- the boundaries of freehold land, where the adjacent land is either blackberry-free, or has an effective control program.

Rubus spp. recover very well following fire and are capable of redeveloping a dense canopy from roots protected from excessive heat in the soil, within two to three years. In addition, except in very intense fires, at least some above-ground parts of some *Rubus* plants often survive the passage of fire, due to their preference for growing in moist habitats, thereby further enhancing the recovery of *Rubus* post-fire. The re-establishment of Introduced *Rubus spp.* is often quicker than the recovery of many native plants, particularly woody species.

Parks Victoria's approach to post-fire control of introduced *Rubus* spp. in the Alps has been to build on pre-existing strategic control programs and generally only to tackle new sites where improved access or other changed circumstances provide an opportunity, that was not previously apparent or available, to achieve a level of control that is likely to be able to be maintained in the medium- to long-term. The temptation to undertake large-scale *Rubus* control programs, for which follow-up funding is unlikely to be available, is generally avoided.

Cytisus scoparius (English broom)

Cytisus scoparius has probably been present in the Victorian Alps for over 100 years, with infestations now present in many areas, including the Mitta Mitta, Kiewa, Ovens, Buckland, King, Howqua and Delatite Valleys and Bogong High Plains. It is a highly invasive woody weed that can form both a dense canopy and deep litter that is able to out compete most native species. The high density and flammability of mature *C. scoparius* stands makes surrounding vegetation more susceptible to the effects of fire, due to the intensity with which *C. scoparius* burns (Parsons and Cuthbertson 1992).

Cytisus scoparius can flower and set seed in the second season post-fire (Allan *et al.* 2004), although at high elevations reproductive maturity may take four years (Robertson *et al.* 1999). Soil-stored seed viability remains high for many years, up to 80 years if stored dry (DNRE 1998). Broom stands can therefore form massive soil seed banks of up to 65,000 seeds per square metre (DNRE 1998). Seed is readily spread by water and in mud attached to vehicles, machinery, animals and footwear. It can spread rapidly down waterways and along roads and tracks (DNRE 1998). In some areas of the ANP, there is a very strong association between the occurrence of *C. scoparius* and the movement pathways of cattle up into summer grazing areas (Robertson *et al.* 1999).

Effective management of *C. scoparius* relies on depletion of soil seed banks (Robertson *et al.* 1999, McArthur 2003). Fire of sufficient intensity can contribute substantially to this outcome by heat-killing seed in the upper part of the soil profile and by stimulating mass germination of much of the seed bank that remains (Robertson *et al.* 1999, Muyt 2001). Seed bank depletion of up to 90% can be achieved post-fire (DNRE 1998).

The 2003 and 2006/07 fires burnt the majority of *C. scoparius* infestations in the Victorian Alps, killing most mature plants. The 2003 Alpine Fires, however also destroyed all of the *C. scoparius* biocontrol research and nursery sites, which had been established and nurtured over many years (Allan *et al.* 2005). Following the 2003 fires, Parks Victoria and DPI developed a post-fire plan for the management of *C. scoparius*, which proposed a multi-pronged strategy to achieve progressive control of the weed (McArthur 2003). The overall aim was to take advantage of post-fire seedbank depletion and prevent replenishment by killing any surviving plants in spring 2003, then controlling post-fire regeneration from autumn 2004 onwards.

Unfortunately, the size and complexity of the overall post-fire recovery program meant that resources were not allocated soon enough and chemical control, even of most of the surviving patches of mature plants, did not commence until autumn and spring 2004. By that time, but particularly the second spring post-fire (2004), the density and height of seedling regeneration in many areas restricted chemical penetration, thus allowing many plants to survive and produce flowers and seed (Allan *et al.* 2005, 2006). The application of multiple chemical treatments prior to first seeding in late spring 2004 could only be applied at a limited number of sites. Thus, a level of control sufficient to prevent post-fire flowering and seeding was only achieved in a few areas.

Other priority actions following the 2003 Alpine Fires included a comprehensive post-fire broom mapping program (Wells 2004), re-establishment and further expansion of the biological control program by DPI, establishment of an adaptive experimental management program to trial the effectiveness and impacts of different post-fire chemical control techniques and timing, including off-target impacts on native species (Allan *et al.* 2004, 2005, 2006), and establishment or enhancement of partnerships with a wide range of agencies and organisations to improve cross-boundary collaboration and effective landscape-scale management of *C. scoparius*. Following the failure to prevent post-fire seedbank replenishment over wide areas, the post-fire strategy for *C. scoparius* has also been further updated to guide ongoing control.

Following the 2006/07 fires, PV and DSE will be targeting the mostly isolated *C. scoparius* infestations within the fire area, particularly those previously treated pre-fire. Surviving plants will be sprayed to prevent seed set in spring 2007. Spraying of seedlings will commence at the same time and, based on monitoring of effectiveness and ongoing recruitment, continue as frequently as required each year to control survivors and new germinants. Considerable effort will be made to prevent any further seed set in controlled infestations.

A trial of the strategic use of prescribed fire to re-deplete seedbanks that have recharged following the 2003 Alpine Fires is planned for 2007/08. Again, chemical control of any surviving plants and all regenerating seedlings will be undertaken repeatedly, as required, following the burn. If successful, and subject to assessment of cumulative impacts on native vegetation, further strategic use of prescribed fire may be employed in the control of *C. scoparius* infestations in the Victorian Alps.

Hieracium aurantiacum L. (orange hawkweed) and H. praealtum Vill. ex Gochnat (king devil hawkweed)

All *Hieracium* species are State Prohibited weeds. *Hieracium aurantiacum* is thought to have been present in Falls Creek village for over 20 years, although it was only recorded at naturalised there in 1999 (Williams and Holland 2007). From Falls Creek, it has invaded nearby areas of the Bogong High Plains in ANP, apparently dispersing on north-westerly winds (Carr *et al.* 2004, Williams *et al.* 2006), although human and animal vectors may also have contributed to its expanding range (Williams and Holland 2007). *Hieracium praealtum* was only discovered in late 2003, growing in a disturbed area on the edge of the Falls Creek alpine resort. Isolated infestations of it, too, have since been found in a south easterly direction from Falls Creek, on the Bogong High Plains.

The 2003 Alpine Fires burnt substantial areas on the Bogong High Plains and some areas within the Falls Creek Alpine Resort, although very few of the sites where *H. aurantiacum* had previously been recorded were burnt (refer maps in Williams *et al.* 2006). Nevertheless, following the 2003 Alpine Fires, Parks Victoria was concerned that *H. aurantiacum* could disperse into post-fire ash beds. A targeted survey for *H. aurantiacum* was therefore commissioned in late 2003, although this was subsequently expanded to incorporate other invasive weeds known to occur in the Falls Creek area, including *H. praealtum* (Carr *et al.* 2004). Fortunately, despite extensive searching, only one new occurrence of *H. aurantiacum* and two of *H. praealtum* were located (Carr *et al.* 2004). However, further occurrences of both species have since been recorded, although there is no clear link between these new sites and fire history.

To better refine search effort for *H. aurantiacum*, Williams *et al.* (2006) developed a constrained habitat suitability model for the species (including fire history as a disturbance factor), which they combined with a dispersal model, based on wind direction and frequency during the flowering season. This model was to be used to guide survey effort in the Falls Creek/Bogong High Plains area during summer and autumn 2007, but survey plans were thwarted by the Tawonga Gap fire in December 2006, which again burnt parts of the Bogong High Plains, although not any known Hawkweed sites. An intensive Hawkweed survey effort is now planned for summer 2007/08, to attempt to locate any unidentified infestations.

At Mt Buller, *H. aurantiacum* was discovered in 2002/03, growing on a little-used track (Williams and Holland 2007). Despite control efforts, it subsequently expanded onto the adjacent batter and downslope into adjacent dense sub-alpine vegetation, beneath which it was very difficult to detect. Again, intensive surveys planned for 2006/07 were frustrated by fires. The Great Divide Fires burnt all of the vegetation on both sides of the track, but left the track itself unscathed (L. Perrin personal communication). Surveys for potentially undetected infestations will now be easier over the 2007/08 summer, while native vegetation remains relatively sparse in burnt areas.

During the 2006/07 fires at both the Bogong High Plains and Mt Buller, procedures were incorporated into daily fire control plans to minimise the risks of spread of Hawkweeds. Fire crews working in areas in which Hawkweeds may have been present were briefed on the species and risks by local staff and vehicles and machinery were excluded from areas of known infestations. As a precaution, a washdown point was established in a suitable location in Falls Creek village to clean down potential soil and seed carrying areas of all vehicles and machinery that operated off formed vehicle tracks on the Bogong High Plains.

Salix cinerea L. (grey sallow)

Salix cinerea is a highly invasive willow of waterways and wetlands. It seeds prolifically and seed can be wind dispersed over tens of kilometres (National Willows Taskforce 2006). Many alpine bogs burnt intensively during the 2003 Alpine Fires. These bogs are a threatened vegetation community listed under the Victorian Flora and Fauna Guarantee Act (1988) and provide habitat for a range of threatened flora and fauna species. With the burning of bog vegetation, extensive areas of exposed bare peat remained.

In the summer of 2004, a year after the fires, park rangers and alpine botanists alike were surprised to discover *S. cinerea* seedlings appearing in vast numbers in alpine bogs on the Bogong High Plains. Such a significant incursion was not expected, as willows had not invaded alpine bogs following previous major fires in the Alps, such as Black Friday in 1939 and the Caledonia fire on the Gippsland high plains in 1998. However, searches in gullies and other moist areas on the Bogong High Plains, nearby Mount Hotham, and the surrounding valleys showed that mature *S. cinerea* were widespread and very much alive, despite the recent fires. Smaller *S. cinerea* seedling infestations in Mount Buffalo bogs were also recorded. These searches, and subsequent more systematic aerial surveys during autumn, benefited from the sparseness of native vegetation post-fire.

Following the discovery of *S. cinerea* invasion into bogs Parks Victoria developed a two-pronged strategy for control: hand pulling of seedlings in bogs and other areas as they appeared; and survey and control (mainly cutting and painting) of potential source populations. A systematic approach was adopted for the survey of source populations, with waterways and other moist areas closest to, and situated to the north of, the Bogong High Plains and Mount Hotham being targeted first. Considerable funding was provided by the North East Catchment Management Authority to assist with this work and Mount Hotham and Falls Creek Alpine Resorts also enthusiastically cooperated. Large numbers of volunteers, as well as staff and contractors, pulled out many tens of thousands of *S. cinerea* seedlings between 2004 and 2007.

It seems likely that across the Victorian Alps in 1939, and at Caledonia in 1998, source populations of mature *S. cinerea* were not present to invade bogs post-fire. With hindsight, a more proactive approach to willow control prior to 2003 may have prevented, or at least restricted, the severity of *S. cinerea* invasion of bogs post-fire. However, it is possible that at least some of the *S. cinerea* source populations were located well beyond Parks Victoria's area of management within ANP. Importantly, due to the slow recovery time of alpine bogs after fire, many bogs can retain exposed, moist, bare peat for several years post-fire. These areas, if moist at the time of seed dispersal, provide ideal seedbeds for invading *S. cinerea*. Fire-affected bogs may therefore need inspection and follow-up willow control annually, until bare areas are fully revegetated.

Parks Victoria will be actively monitoring bogs across the 2006/07 fire areas over coming years to assess, and respond to, post-fire weed invasion. It is hoped that the extensive control of both mature and juvenile *S. cinerea* between 2004 and 2006 on and around the Bogong High Plains and Mount Hotham (and, to a lesser degree, Mount Buffalo) will have lessened the seed source for further invasion there. However, given the potential for long distance wind dispersal of *S. cinerea*, it is likely that many substantial potential source populations have not yet been treated.

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How can willow sawfly aid our willow management?

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Summary Willows are serious weeds of waterways, impacting on physical and biotic processes. The discovery of willow sawfly (*Nematus oligospilus*) in Australia potentially has implications for willow management activities. Willow sawfly larvae eat willow leaves and when populations increase to high levels, entire willow trees can be defoliated. Experience with willow sawfly incursions in other Southern Hemisphere countries has shown that ongoing, severe defoliation of trees can result in tree deaths. It is possible that sustained high populations of willow sawfly in Victoria will result in a change of investment focus in willow management programs and may aid the transition from willow dominated riparian communities to those dominated by healthy native riparian vegetation.

Introduction

In Victoria and other parts of south eastern Australia, willows (*Salix* spp.) are serious weeds of waterways and wetlands, due to their highly invasive nature and detrimental impacts on river health. These impacts include modification of stream channels and hence river flows, exacerbation of riverbank erosion, exclusion of native species from riparian vegetation communities, alteration of in-stream food webs and reduction of access for recreational pursuits. For these reasons, several *Salix* species are declared noxious in Victoria and are listed as Weeds of National Significance (WoNS). Significant resources are currently invested in willow management, with control costs in Victoria alone totalling about $10m per annum.

The recent arrival of willow sawfly (*Nematus oligospilus*) in Australia has the potential to affect some willow management programs. High populations of this insect can result in tree defoliation and eventually tree death, and willow sawfly has caused significant damage to willow populations in other countries in the Southern Hemisphere, particularly New Zealand (Disbury *et al*. 2004).

Willow sawfly biology

Willow sawfly, *Nematus oligospilus* (Förster (Hymenoptera: Tenthredinidae)), is native to the Northern Hemisphere. It is widespread in the Holarctic (northern) Region of Europe and is also found in Eurasia and North America (Koch and Smith 2000). Populations of willow sawfly in the Northern Hemisphere include both males and females whereas populations in the Southern Hemisphere appear to consist entirely of females (Koch and Smith 2000).

The adults lay eggs on fully expanded willow leaves, generally on the upper leaf surface. The eggs hatch after about a week and larvae initially feed on the leaf material adjacent to the eggs. There are five to seven larval instars before pupation (Charles and Allan 2000). Pupation occurs in a cocoon attached to an intact leaf, branch or stem, or other available surface (Ede *et al.* 2007). Adults emerge after four to fourteen days, depending on conditions, and commence oviposition immediately (Ovruski 1994). The duration of the life cycle from oviposition to adult emergence can be as short as 22 days under ideal conditions (Charles and Allan 2000). Six generations per season have been reported from sites in New Zealand (Charles *et al.* 2004), but in Chile, only two generations per season were observed (Gonzalez *et al*. 1986).

As willows are deciduous, willow sawfly overwinter in a dormant state. In order to do this, the larvae which develop late in the season spin dark brown cocoons in the soil or leaf litter under willow trees (Ede *et al*. 2007). The larvae remain in these cocoons in the larval form throughout winter and pupate into adults at the beginning of spring. The emergence of adults commences in October in New Zealand (Charles and Allan 2000) and Chile (Gonzalez *et al*. 1986), which also appears to be the case in Victoria (Ede *et al*. 2007). Emergence is asynchronous resulting in a range of age cohorts in the population at any time through the season. In Victoria in 2007, willow sawfly larvae entered the overwintering phase in early May (Ede *et al*. 2007).

Impact of willow sawfly on willows

Willow sawfly larvae eat willow leaves. They consume about two leaves in total during their development, and can eat an entire leaf in their last day as a larva prior to pupating (Ede 2006). New leaves develop to replace those eaten by the larvae, but if larval numbers are high, these new leaves are rapidly consumed.

Defoliation of entire trees occurs when willow sawfly population levels are high. In the 2006/07 season, willow trees at a site in north east Victoria were initially defoliated in late November, and although several flushes of new leaves were produced through the season, high willow sawfly numbers meant that the trees were moderately to severely defoliated for the remainder of the season (Ede *et al.* 2007).

Tree deaths as a result of willow sawfly activity have been reported from South America (Dapoto and Giganti 1994, Alderete and Fidalgo 2004), southern Africa (Urban and Eardley 1997) and New Zealand (Charles *et al*. 2004). The experience of catchment managers in the North Island of New Zealand suggests that tree deaths can occur in the second season of severe willow sawfly infestations (I. McIvor personal communication). There have yet to be any deaths of willow trees in Australia that can be categorically blamed on severe defoliation as a result of willow sawfly activity, but it is possible that some trees badly affected in the last two or three seasons will fail to produce new foliage in the coming spring.

However, it has been reported that in some Southern Hemisphere populations, willow sawfly does not maintain high population levels in the long term. For example, in several regions in the North Island of New Zealand, willow sawfly activity initially resulted in tree defoliation and death, but sustained activity over more than two or three seasons was not evident (Cowie 2006). The only region where willow sawfly populations have maintained high numbers and caused ongoing defoliation and tree death is Hawkes Bay on the east coast of the lower North Island (Ede 2006). It is not known whether physical or biotic factors such as predation, parasitism or disease result in declining willow sawfly populations.

Willow sawfly in Australia

The first reported observations of willow sawfly in Australia were made in March 2004, when infestations were observed defoliating crack and weeping willows in the Canberra area, with further infestations of willow sawfly recorded 150 km south of Canberra in 2004 (Bruzzese and McFadyen 2006).

In the 2004/05 season, willow sawfly was confirmed at additional sites in the ACT and southern NSW, in the Adelaide Hills and in a suburban garden in north west Melbourne (Bruzzese and McFadyen 2006). The known distribution of the insect increased in the 2005/06 season, with willow sawfly reported at several sites across south eastern Australia (Finlay and Adair 2006). Tree defoliation occurred at several sites in north east Victoria and in central NSW, in addition to those sites previously affected (Ede 2006).

It is not known how willow sawfly arrived in Australia. It is possible that cocoons may have been inadvertently imported in packaging material or containers, or that adults blew across the Tasman Sea from New Zealand in easterly wind systems (Bruzzese and McFadyen 2006), as has occurred for other insects.

Willow sawfly in Victoria

Willow sawfly was first observed in Victoria in April 2005 in north west Melbourne (Bruzzese and McFadyen 2006), with a number of further sightings occurring in the past two seasons (Finlay and Adair 2006, Ede *et al*. 2007). The most extensive outbreak is in the Kiewa Valley in north east Victoria, where defoliation of *S*. × *rubens* trees was first noticed in December 2005. Willow sawfly populations in this area have caused severe defoliation of large numbers of willow trees along at least 15 km of the valley for the past two seasons.

Defoliation of willow trees has now been recorded at several other sites in Victoria, including the Murray River in the north east; the Broken River and tributaries, Goulburn River, and Campaspe River in central Victoria; the Tarago River, Pheasant Creek, and Fosters Creek in southern Victoria; and at Boneo on the Mornington Peninsula (Ede *et al*. 2007).

Willow taxa affected by willow sawfly

Field experience in New Zealand indicates that willow sawfly is more likely to defoliate tree willows than shrub willows, although the shrub willow *S. purpurea* (purple osier) is susceptible to willow sawfly (Cowie 2006, Ede 2006). Charles *et al*. (1998) found in laboratory trials that adults selected shoots of tree willows or purple osier for oviposition, but not shoots from other shrub willows.

In Victoria to date, willow sawfly has defoliated crack willow (*S. fragilis*), golden upright willow (*S. alba* var. *vitellina*), crack × golden willow (*S*. × *rubens*), black willow (*S. nigra*), Chilean pencil willow (*S. humboldtiana*), tortured willow (*S. matsudana* 'Tortuosa'), weeping willow (*S. babylonica*), and golden weeping willow (*S. sepulcralis* var. *chrysocoma*).

In addition, willow sawfly has been found on New Zealand hybrid willow (*S. matsudana* hybrids), purple osier (*S. purpurea*) and grey sallow (*S. cinerea*) (Ede *et al*. 2007).

Implications for willow management in Victoria

At sites in Victoria where willow sawfly populations establish high densities, it is likely that defoliation of susceptible willow taxa will occur, and tree deaths are possible. However, it is unclear whether large willow sawfly populations will persist over time and whether they will be widespread through the state.

Two scenarios are possible. In the first scenario, willow sawfly populations build up to damaging levels for a few years only, or at a limited number of sites, and over the long term, willow sawfly has very little impact on willow populations, and on their management. The second scenario involves wide scale and longer term impacts, with high willow sawfly populations continuing to cause tree defoliation and death for several years, and/or in many locations across the state. This outcome would have a significant impact on willow management.

It is not yet possible to predict which of these scenarios is the most likely. However, the results from the 2006/07 season indicate that high willow sawfly populations have developed simultaneously at disparate locations (north east Victoria, central Victoria and southern Victoria) causing tree defoliation in willows of several different taxa.

There are a number of implications for willow management under the second scenario. At sites frequented by the public, or where downstream infrastructure such as bridges is a concern, death of whole trees or of large branches may result in the need to remove dangerous material, which will require resource investment, and may shift investment priorities in the short term. Tree deaths along rivers where willows currently form part of the river bank stabilisation infrastructure will also require additional investment to ensure that the loss of willows in those areas does not result in significant bank erosion.

However, in many cases the death of willow trees will be viewed as a beneficial outcome by catchment managers. If willow sawfly is effective at killing willows of particular taxa, then it may be possible to shift resources from these species to those less affected by willow sawfly. Currently, it appears that willow sawfly is more likely to adversely affect tree willows such as crack willow, golden willow, black willow and various hybrids, with shrub willows such as grey sallow less affected. If willow sawfly is able to significantly impact on populations of tree willows, then resources could be reallocated to addressing the threats posed by grey sallow and other taxa.

In situations where willow sawfly causes occasional tree defoliation but does not lead to tree death, it is likely that current willow control techniques will be affected to some level. Most obvious is foliar application of herbicides, which requires foliage, but the efficacy of frill and fill and stem injection techniques would also be affected by partial or total defoliation as a consequence of diminished sap flows through the trees.

Many willow management activities currently seek not only to remove willows from riparian areas, but to restore native vegetation communities in these areas. Defoliation of willow trees as a result of willow sawfly activity will result in an increase in understorey light levels. This change in light environment may facilitate invasion by other riparian weeds or promote the establishment of native species, depending on the surrounding vegetation and land use. At sites with limited connections to native vegetation communities, it may be desirable to undertake planting or seed bank augmentation with native species in the early stages of a willow sawfly infestation. By minimising disturbance under the existing willow canopy, and through appropriate species selection, this process would favour the rapid establishment of a native riparian community which is able to flourish once the willows are no longer live. This management technique would be best suited to sites where willows can be left *in situ* once dead, and is less likely to result in severe infestations of other riparian weeds.

Further research is required to understand these interactions between willow sawfly impacts and willow management and restoration of native riparian communities. As well, the impact of willow sawfly on reproductive potential of seeding willows is a topic of interest to willow managers. If willow sawfly decreases tree fitness, does this in turn decrease seed production to such an extent that seeding willows are no longer a significant problem in the environment? The relationship between tree defoliation (both extent and frequency) and declines in tree root biomass is another potential avenue for research. Preliminary findings from New Zealand suggest that root biomass declines dramatically with defoliation (Ede 2006) and a better understanding of this relationship would aid willow management. For example, at sites where high willow sawfly populations initially cause tree defoliation but do not persist for a sufficient length of time to kill trees, it may be desirable to kill affected trees using chemical or physical methods while they are in a weakened state.

Although it is highly unlikely that willow sawfly will adversely affect all willows across all of Victoria, it is possible that this insect will have sufficient impact to allow a redirection of current investment in willow control and to maximise opportunities for the replacement of willow dominated riparian zones with those dominated by healthy native vegetation communities.

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Response of Brazilian milfoil (*Myriophyllum aquaticum*) to salinity and water-level fluctuations and its potential to invade wetlands of the Gippsland Lakes, south-east Victoria

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Summary Brazilian milfoil (*Myriophyllum aquaticum*: Haloragaceae) is an introduced freshwater aquatic macrophyte that has been found in some freshwater wetlands of the Gippsland Lakes in south-eastern Victoria and has the potential to spread to other fresh and brackish-water wetlands in the region. This paper reports on the effects on *M. aquaticum* of salinity and water-level fluctuations, in order to improve understanding of the invasive potential of this species and to determine the effectiveness of water-level and salinity manipulations as potential control strategies. Laboratory experiments showed that plant biomass was reduced by exposure to salinities as low as 2 g L^{-1} (= approx. 3300 µS cm^{-1} at 25°C) for instantaneous exposures and 4 g L^{-1} (= approx. 6600 µS cm^{-1} at 25°C) for gradually increasing salinities. A complete draw down of water levels in Sale Common, a wetland in the Gippsland Lakes complex, over three months in summer 2006–2007 caused significant reductions in the biomass and surface extent of *M. aquaticum*. Laboratory incubations with dried sediments, however, demonstrated that plants could recover quickly from dried sediments, so partially desiccated plants may re-establish when the wetland floods again. Because if its sensitivity to salinity, we conclude that *M. aquaticum* has limited ability to permanently invade brackish-water or salinised wetlands of the Gippsland Lakes: invasions may occur during periods of inundation with fresh water but plants are likely to be killed or inhibited by subsequent periods of higher salinity.

Introduction

Myriophyllum aquaticum (Vell.) Verdc.; syn *Myriophyllum brasiliense* Cambess. is an introduced freshwater macrophyte in the Family Haloragaceae, native to South America and commonly sold as an aquarium plant because of its aesthetic appeal and ease of cultivation (Sutton 1985). As with many exotic plants, *M. aquaticum* has a propensity to escape cultivation and it is now naturalised in many wetlands and slow-moving aquatic systems outside of its native range. It was first recorded in Australia in 1908 and has since spread throughout wetlands, ponds and slow-moving streams in south-east Queensland, near-coastal areas of New South Wales, much of Victoria, Tasmania and parts of south-western Western Australia (Parsons and Cuthbertson 2001).

Myriophyllum aquaticum is a rhizomatous perennial which is distinguished from other species in the genus by its feathery, glaucous green emergent stems with pinnate leaves arranged in whorls (Aston 1973). By taking root at the margins of shallow lakes and slow flowing rivers, *M. aquaticum* extends into wetlands from the water's edge up to a depth of about 1.5 m as a dense mass of tangled rhizomes with many emergent shoots (Sytsma and Anderson 1989). It can persist also on moist mudflats and on gravel (Aston 1973; Orchard 1979). Growth of *M. aquaticum* can be problematic under certain conditions and, although it is a perennial, *M. aquaticum* commonly exhibits the growth characteristics of an annual; when water temperature rises in spring shoots rapidly grow from rhizomes (Sutton 1985).

All *M. aquaticum* plants in Australia are female, and Sainty and Jacobs (1981) warned specifically of the danger of accidentally introducing male plants through the aquarium trade. As only female plants are present in Australia, reproduction is entirely vegetative, by way of stem and rhizome fragmentation resulting from the action of wind and waves or animal disturbance. Where conditions and substrata are suitable, fragments of *M. aquaticum* can readily establish via adventitious roots, which form at the node and form new individuals (Jacot-Guillarmod 1979). The clonal growth habit facilitates long distance dispersal where there is flowing water to distribute vegetative components to new areas (Evans *et al.* 2003).

Myriophyllum aquaticum was first reported in Sale Common, a freshwater wetland in the Lake Wellington wetlands complex of the Gippsland Lakes Ramsar site, in 1992 (Parks Victoria), although Aston (1973) reported that it was already present on farm dams around the township of Lakes Entrance in 1969. Sale Common is a 300 ha, shallow freshwater marsh located 3 km south of Sale in south-eastern Victoria (38°30'S, 147°51'E). It is the most westerly wetland in the Gippsland Lakes Ramsar site and is probably the freshest: wetlands to the east become progressively more saline as they approach Lake Wellington and the entrance to the Southern Ocean at Lakes Entrance (e.g., see Roache *et al*. 2006: Raulings *et al*. 2007). *Myriophyllum aquaticum* was mentioned specifically as one of five pest plant species in the Strategic Management Plan for the Gippsland Lakes Ramsar Site (Department of Sustainability and Environment 2003) and as the highest priority pest plant, before even blackberries and willows, in the Lake Wellington Wetlands Draft Management Plan (Parks Victoria 1997). The basis of this concern is that excessive growths of *M. aquaticum* have manifold impacts on aquatic ecosystems. Dense stands restrict stream flow, increase the deposition of sediment and organic matter (Evans *et al.* 2003), deplete oxygen concentrations in the water column (Sytsma and Anderson 1989) and increase rates of water loss from water bodies via transpiration (Cilliers 1999). Dense accumulations of shoots and leaves in the water column provide habitat for mosquito larvae, since predation by fish is much decreased among the tangled plant material (Orr and Resh 1991). The ability of *M. aquaticum* rhizomes to completely colonise moist or fully submerged sediments also affects colonisation by native taxa (Washington State Department of Ecology 2003).

Chemical control of isolated outbreaks and manipulations of water regimes for larger infestations were proposed by Parks Victoria (1997) as the two most viable control options for *M. aquaticum* in wetlands of the Gippsland Lakes. Certainly, a number of studies have reported on water-level draw down as a weed control strategy for problematic aquatic species, including *Cambomba caroliniana* (Goldsby and Saunders 1977), *Hydrilla verticillata* (Poovey and Kay 1998) and *Egeria densa* (Thomaz *et al.* 2006). Where infrastructure is present to allow hydrological manipulations, a draw down of water levels can be a cheap and effective weed management technique that has long-lasting effects on problematic aquatic vegetation. Previous research has reported on the accumulation of *M. aquaticum* biomass under favourable environmental conditions (Monteiro and Moreira 1990, Sytsma and Anderson 1993a), but we are unaware of any report on the response of *M. aquaticum* to draw downs of water level over the critical summer period, when desiccation effects are likely to be most severe under Australian conditions. Accordingly, the effect of water-level changes on the growth of *M. aquaticum* was the first objective of the research reported in this paper.

To date there has been little or no consideration given to the role played by salinity in the potential for spread of

M. aquaticum in Australia, nor as a possible control mechanism that could be implemented by wetland managers under suitable conditions. Salinity may play a major role in limiting the spread of *M. aquaticum* in the more brackish-water wetlands of the Gippsland Lakes, because the Lakes complex has become increasingly salinised as a result of the artificial opening of the lakes to the sea at Lakes Entrance in 1889 (Bird 1962, 1966). It is noteworthy that *M. aquaticum* has been reported in Sale Common, the freshest of the wetlands in the Lake Wellington complex and there is little or no information on its spread to other, more salty, wetlands to the east. The limited amount of research undertaken on the species in the past has suggested that *M. aquaticum* can colonise saline habitats: Haller *et al.* (1974) reported that, over a four week period, *M. aquaticum* in the USA grew in salinities up to 10 g L^{-1}. This result, however, is in stark contrast to what is known of the salinity tolerance of most species of freshwater macrophytes in Australia. There are a range of thresholds below which Australian freshwater macrophytes can tolerate salinity and still remain viable, but most do not tolerate salinities greater than about 1–2 g L^{-1} (Hart *et al.* 1991) and 4 g L^{-1} appears to be an upper limit of nominally freshwater species (Brock 1981).

Salinity impacts on plants are not simple, and there is some evidence that aquatic plants are more tolerant of gradual increases in salinity ('presses') than to sudden increases or 'pulses' (e.g., see McKee and Mendelssohn 1989). Thus a second aim of our research was to determine the effects of increased salinity on *M. aquaticum* and whether the adverse effects of salinity were reduced by gradual, rather than sudden, increases in salt concentrations.

Method

A suite of laboratory incubations were used to determine the effects of salinity and re-flooding on *M. aquaticum*, whereas the effects of water-level draw down were inferred from a set of field-based observations over the summer of 2006–2007.

Responses to increases in salinity

Two laboratory experiments were undertaken: 1) a trial in which plants were exposed to a sudden increase in salinity; and 2) a trial in which salinities were increased gradually up to a maximum of 16 g L^{-1}. Mats of *M. aquaticum* were separated into single rhizomes of similar size and condition and placed in individual 2 L containers filled with tap water. Each rhizome consisted of emergent shoot and leaf material, submerged rhizome, aquatic adventitious roots and some submerged leaves. Plants were acclimated for two days before the experiment commenced, during which time dead plants were discarded and replaced with healthy specimens to ensure a healthy cohort at T_0. Plants were exposed to one of five saline solutions: 1, 2, 4, 8 and 16 g L^{-1} and were grown with a 12 h light to 12 h dark cycle with light provided by an array of hydroponic fluorescent lamps (Gro-lux®, Sylvania Lighting Co., Germany). The temperature was maintained at a constant 20°C for the duration of both experiments.

Experiment 1: Sudden salinity increases Ten plants each were randomly assigned to one of five treatments and another set of ten plants set aside as controls. Plants were exposed to one of the five saline solutions and any water lost via evapotranspiration was replaced with deionised water up to the 1.8 L mark every second day; this method maintained stable saline solutions for the duration of the experiment. The experimental exposure ran for nine weeks, after which plants were removed and necrotic plant tissue was discarded. Roots were discarded also because epiphytic algae sometimes grew so profusely that they confounded an accurate assessment of root biomass. The remaining living rhizomes and leaves were washed and oven dried at 90°C for a minimum of 24 h until constant weight was attained.

Experiment 2: Gradual salinity increases Fifty individual plants were chosen for exposure to gradually increasing salinities. The experimental design aimed to generate, after five weeks, a suite of plants that had been exposed to gradually increasing salinities ranging from 1 to 16 g L^{-1}, with ten replicate plants at each of the five salinities. Plants would then be kept at their designated salinities for a further four weeks, until the experiment was stopped.

At the beginning of the first week, all 50 plants were exposed to the 1 g L^{-1} treatment and then were conceptually divided into five groups (each of ten plants) to be allocated to the various final salinities of 1, 2, 4, 8 or 16 g L^{-1}. Plants were incubated as described above and, after one week, 40 of the initial 50 plants moved to the 2 g L^{-1} treatment; the remaining 10 plants were kept at a salinity of 1 g L^{-1}. These 10 plants remained at this salinity for the duration of the experiment. After a second week, 30 of the 40 plants in the 2 g L^{-1} treatment were moved to the 4 g L^{-1} treatment and the remaining 10 plant left in the 2 g L^{-1} treatment for the duration of the experiment. Similarly, 20 of these 30 plants were moved at Week 4 to the 8 g L^{-1} treatment and 10 left at 4 g L^{-1}; a final 10 plants were moved to the 16 g L^{-1} treatment at Week 5. All plants then remained exposed to their designated salinities for a further four weeks until the conclusion of the experiment at Week 9. At Week 9 all plants were washed, sorted, dried and weighed as described previously.

Statistical analysis Plant biomass data were not distributed normally and, since attempts to transform them to conform to the assumption of normality were unsuccessful, the non-parametric Kruskal-Wallis Single Factor Analysis of Variance by Ranks was used to analyse the effects of salinity on plant performance. Comparisons of biomass to control groups within each treatment were made with Nemenyi non-parametric Multiple Comparisons. Mann-Whitney U tests were used to compare responses following the sudden exposure to salt with those of a gradual salinity increase, always comparing responses at equivalent final salinities. Data were analysed using SPSS v. 15.0., with the exception of Nemenyi non-parametric multiple comparisons, which were completed longhand as per Zar (1999).

Responses to water-level fluctuations

Observations at Sale Common Observations of *M. aquaticum* in Sale Common were made on four occasions during the summer of 2006–2007: 9 November 2006, 14 December 2006, 15 January 2007 and 12 February 2007. Water levels were drawn down by natural evaporation over the hot dry summer of 2006–2007; levels had fallen markedly after the November 2006 sampling and, upon the visit in December 2006, the wetland was completely dry.

Fifteen permanent transects were laid out randomly, in groups of three at five locations in Sale Common that had substantial accumulations of *M. aquaticum*. Each transect started 3 m to the landward side of the shoreline or the nearest vegetation and all transects extended 15 m into the wetland, with start/end points permanently marked by GPS and stakes. Biomass was sampled using a 20 × 20 cm quadrat placed at the mid point of the largest patch of *M. aquaticum* along each transect. This approach was used to determine the maximum biomass of *M. aquaticum* present at each transect. In November 2006, biomass samples were collected by cutting the floating rhizomes and emergent shoots with shears around the inside perimeter of the quadrat from the top to bottom of the water column. In subsequent months, after the water-level draw down, surface vegetation was collected by hand from within a quadrat placed on the ground. In December 2006 the quadrat sampling position was offset 20 cm to the right by of the November 2006 sampling position sampling position, so as to avoid the previous sampling area. In January 2007 the quadrat was offset 20 cm to the left and in February 2007 it was offset again a further 20 cm to the left. Cleaned samples were oven dried at 90°C until a constant weight was attained then dry-weight biomass was recorded.

The lateral spread of *M. aquaticum* was quantified each month by measuring the start and end points of vegetation that came into contact with the transect line. Where *M. aquaticum* surface coverage was patchy or disjointed, it was necessary to record several vegetation start and end points. The sum of the differences of the vegetation start and end points was used to calculate total lateral spread along each transect.

Effects of experimental re-inundation of dry sediment Upon the final visit to Sale Common in February 2007, 16 soil sods (15 cm × 10 cm) containing *M. aquaticum* rhizomes were dug from the dry wetland. A sub-sample was taken from the soil sods to measure moisture content and the remainder of the samples inundated with fresh water to a depth of 10 cm for 29 days. The experiment took place outdoors and water lost via evaporation was constantly replaced. After 29 days the number of new shoots that emerged from *M. aquaticum* rhizomes within and above the surface of the sediment samples was recorded.

Statistical analysis Biomass and surface coverage data were analysed by a Repeated Measures ANOVA. The assumption of normality was verified (Kolmogorov-Smirnov test) but Mauchly's test for sphericity violated the assumption of equality of variances. Therefore, the Repeated Measures ANOVA *F* statistic we used was the more conservative Lower-Bound test statistic. Bonferroni post-hoc analysis was used to compare differences across months. Data from one transect were not analysed due to substantial insect grazing.

Results

Responses to increases in salinity

Plant biomass was lost from shoots that developed necrotic regions along the length of the rhizome and following death of the emergent tips of plants. In both the sudden and the gradual experimental trials, there was a trend of declining biomass of live rhizomes in response to increasing salinity (Figure 1). In the sudden exposure trial, salinity significantly affected live rhizome biomass after nine weeks of treatment ($P < 0.005$). The development of necrotic regions among plants exposed suddenly to a salinity of as low as 2 g L^{-1} caused a significant reduction of viable, live rhizome biomass compared with the control group kept under freshwater conditions (Q statistic = 5.65, q critical = 2.64). Although there was a steady loss of biomass with increasing salinity at all treatment levels, the harmful effects of salinity were most pronounced at the upper range of the salinity treatments (i.e. in excess of 8 g L^{-1}), with the stems of plants exposed to salinity of 16 g L^{-1} having become completely necrotic by the end of the experiment.

There were also significant adverse effects on living biomass in the exposure trial where salinities were increased gradually ($P = 0.021$). The harmful effects of salinity, however, were less severe when salinities were increased gradually in a 'press' disturbance than when increased suddenly in a 'pulse' disturbance. At the end of the experiment, plants that had been exposed to gradual increases in salinity had more viable rhizome biomass than plants exposed suddenly to an increase in salinity to the same final salt concentration (Figure 1). Although stem necrosis in the sudden exposure trial was substantially greater, there was no significant difference in mean biomass between the two treatments with the exception of the 16 g L^{-1} treatment level ($U = 25$, $P = 0.013$), which had no living biomass remaining at the end of the sudden exposure trial.

Responses to water-level fluctuations

Myriophyllum aquaticum underwent an initial growth phase between November 2006 and December 2006, with both biomass and surface coverage reaching a peak in December 2006. The mean maximum dry-weight biomass of *M. aquaticum* was 269 g m^{-2} and 701 g m^{-2} in November and December, respectively. Following the draw down of water levels in Sale Common over the summer of 2006–2007, both plant biomass and surface extent of *M. aquaticum* fell significantly each month (Figure 2 and 3) and the mean maximum biomass across all 14 transects had fallen to 221 g m^{-2} in February 2007.

Patterns in surface cover and lateral extent mimicked that of the biomass: there was an initial expansion during the

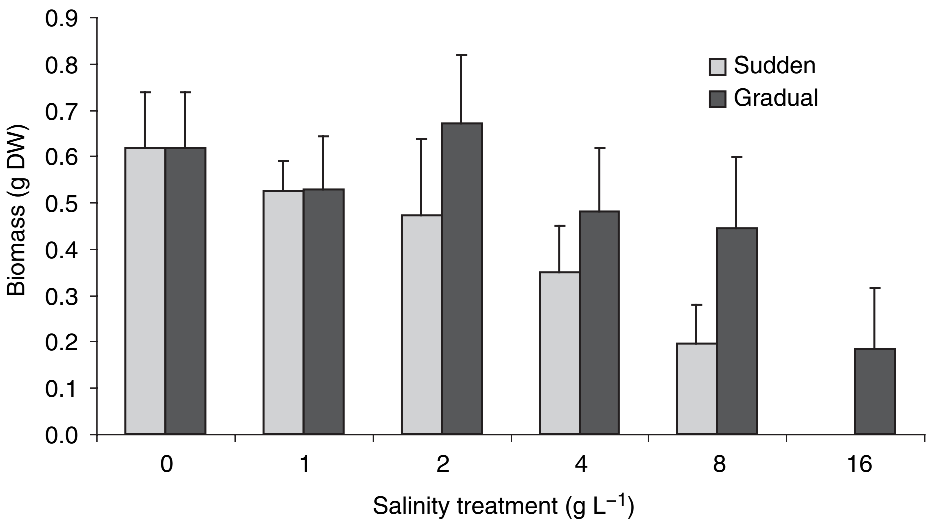

Figure 1. Changes in mean dry-weight biomass of *M. aquaticum* under sudden and gradual increases in salinity. Means and standard errors are shown, n= 10.

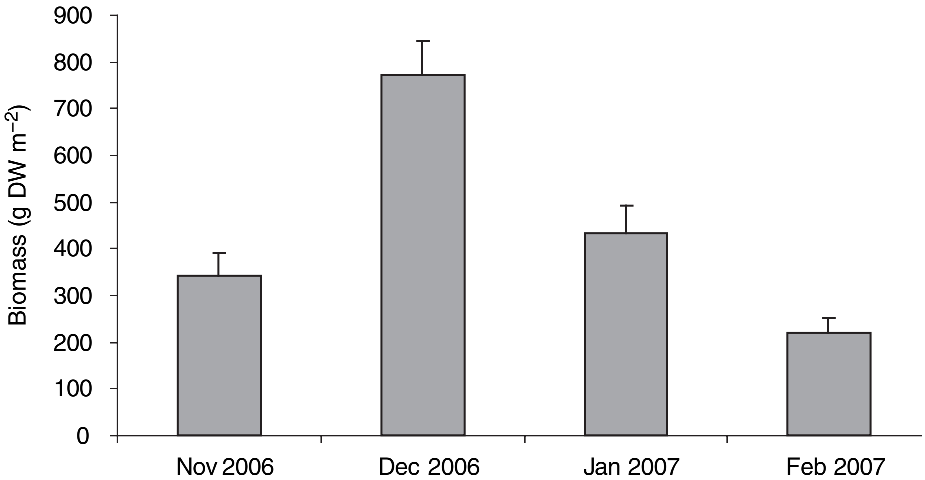

Figure 2. Temporal changes in dry-weight biomass of *M. aquaticum* from transects at Sale Common from November 2006 to February 2007. Means ± standard errors are shown, n=14.

early summer and a subsequent reduction in cover and extent as a consequence of the water-level draw down in December. During the initial growth phase, the mean extent of *M. aquaticum* cover expanded by 2.4 m along the transects, reflecting a significant increase from a mean extent of 5.1 m in November 2006 to one of 7.5 m in December 2006 ($P = 0.001$). In response to water-level draw down, however, *M. aquaticum* beds began to contract after December 2006. The reduction in surface cover was statistically significant between December 2006 and January 2007 ($P = 0.036$) and again between January 2007 and February 2007 ($P = 0.004$). By February 2007 the extent of *M. aquaticum* cover was very disjointed and patchy, and it extended merely an average of 2.7 m along the 14 transects.

The experiment in which dried wetland sediment was experimentally re-flooded indicated that re-shooting from desiccated rhizomes occurred within one week of inundation. By the end of the experiment at 29 days, the mean number of emergent shoots per sediment clod was 14.1, equivalent to a plant density of 970 shoots per m^2. The mean soil moisture from the sediment samples taken when the wetland was dry in February 2007 was 49% on a gravimetric basis.

Discussion

Effect of salinity

The few published reports of the salinity tolerance of *Myriophyllum* species suggest they are more tolerant of saline water than many other submerged nominally freshwater macrophytes. For example, the lethal salinity for *Myriophyllum spicatum* in the USA was reported to be greater than 13 g L^{-1} (Haller *et al.* 1974) and 52% of an Australian native milfoil, *Myriophyllum crispatum*, withstood 72 days of exposure to salinities of 7 g L^{-1} (James and Hart 1993). As noted earlier, the salt concentration reported by Haller *et al*. (1974) to be toxic to *M. aquaticum* was between 10 and 13 g L^{-1}.

In the present study it was not possible to quantify mortality in the way used by Haller *et al.* (1974), who measured growth rates. The extent of stem necrosis, however, did provide a good indication of the harmful effects of salt; we found the loss of biomass was most pronounced at high salinities (i.e., 8–16 g L^{-1}). The harmful effects of salt on non-halophytes occur as much from duration of exposure as from salt concentration (James and Hart 1993, Howard and Mendelssohn 1999) and it was apparent that the duration of sudden exposure to salinity increases was sufficient to cause a severe reduction in *M. aquaticum* vegetative vigour. Although the results obtained by Haller *et al.* (1974), for plants in North America, indicate an ability of *M. aquaticum* to invade environments with salinities of up to about 8 g L^{-1}, our results suggest that *M. aquaticum* in south-eastern Australia would be unlikely to permanently colonise wetlands with a salinity of greater than about 4 to 8 g L^{-1}. Although we found significant adverse effects of salinities of as low as 2 g L^{-1} when salinities were increased suddenly, it is likely that *M. aquaticum* could invade wetlands during periods of very low salinity (e.g., after overbank flooding of wetlands from adjacent rivers, such as the Latrobe or Avon Rivers in the Gippsland Lakes complex) but then retreat again as salinities increased in the wetlands as water levels fell due to evaporation, or following intrusions of saline water from the adjacent Lake Wellington. In view of these findings, we consider that the more saline wetlands of the Lake Wellington complex are probably not at high risk of permanent invasion by *M. aquaticum* dispersed from Sale Common. The nearest large wetland in the Lake Wellington complex is Dowds Morass State Game Reserve, and measurements of salinity in that wetland indicate a salinity regime of from 0.5 to 11 g L^{-1} between 1992 and 2003 (Boon *et al*. 2007). Future experiments may, however, address the salinity tolerance of *M. aquaticum* obtained from sites with a higher background salinity than Sale Common, such as the Heart Morass to the north of Dowd Morass, and in these cases we might find more salt-tolerant strains.

Our results indicate that salt effects may be delayed or decreased when salinities are increased gradually in a 'press' disturbance rather than suddenly in a 'pulse' disturbance. Viable biomass was reduced significantly by a sudden exposure to salt at only 2 g L^{-1}, whereas the first sign of an impact following gradual increases in salinity occurred 4 g L^{-1}. Moreover, plants in the gradual exposure group had higher final live biomass than did those at the equivalent salinity when salinity was increased suddenly. Under natural conditions, both gradual and sudden increases in salinity may occur in wetlands: the former during, for example, evaporative concentration and the latter during sudden, wind-and tidal-mediated intrusions of seawater from the adjacent Gippsland Lakes.

Responses to water-level fluctuations

The dramatic increase in *M. aquaticum* biomass at Sale Common between November 2007 and December 2007 was a function of the synergistic effects of wetland inundation and late spring climatic conditions, including high temperatures and a long photoperiod, which favoured rapid growth. This explanation for seasonal growth patterns is consistent with what is known of the life cycle of *M. aquaticum*; in temperate climates, warm spring conditions augment rapid growth and expansion (Sutton 1985, Parsons and Cuthbertson 2001) until maximum biomass is achieved, which then remains constant throughout summer (Monteiro and Moreira 1990, Sytsma and Anderson 1993b). The maximum mean biomass recorded in December 2007 in Sale Common (>700 g m^{-2}) was lower than that recorded by Sytsma and Anderson (1993b) for a Californian Lake during summer (>1000 g m^{-2}). It is plausible, however, that biomass accumulation and surface coverage had not peaked prior to the drought-related draw down of Sale Common in early December 2007 and, had the summer been more mild, biomass may have continued to increase until autumn to reach values similar to those reported for the Northern Hemisphere.

When rooted in shallow water, *M. aquaticum* typically spreads from lake margins into deeper water as a floating mat of emergent and submerged foliage (Orchard 1979, Sytsma and Anderson 1989). The

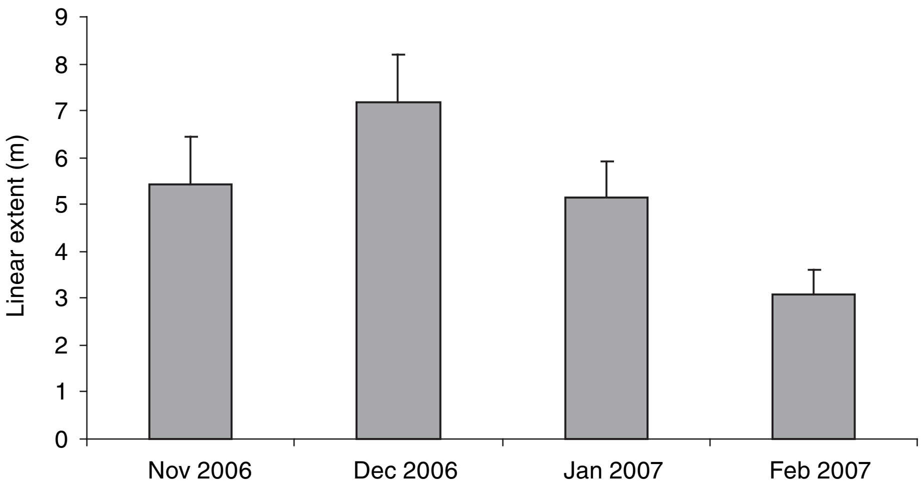

Figure 3. Temporal changes in extent of *M. aquaticum* along transects at Sale Common from November 2006 to February 2007. Means ± standard errors are shown, n=14.

lateral spread of *M. aquaticum* observed in December (mean increase 2.4 m) occurred at both the ends of several transect lines – at the lakeward and landward limits of the vegetation. Wetland inundation in November 2007 was beyond the innermost margin of the *M. aquaticum* beds, which allowed the plant to spread laterally in two directions along some transects (i.e. into the wetland and simultaneously toward the shore), thereby facilitating surface spread and biomass increase. Had water remained at this level throughout summer, it would be possible for *M. aquaticum* to permanently establish a larger surface coverage by spreading up the shoreline gradient as well as out into the wetland.

The significant reduction of both biomass and surface cover from December 2006 through to February 2007 is a clear indication of the deleterious effects that prolonged summer water-level draw down has on *M. aquaticum*. Owing to the chronic drought experienced in south-eastern Australia over the study period, water levels were completely drawn down in Sale Common over the summer of 2006– 2007. Despite these severe conditions, *M. aquaticum* recovered strongly when dry soil clods were inundated with fresh water, indicating that this species is tolerant of at least short-term desiccation. The persistence of subterranean rhizomes of *M. aquaticum* in otherwise dry sediments may be an effective mechanism for surviving water-level draw down and sediment desiccation, as it has been shown with other species of aquatic plant that moisture loss through plant surface material severely reduces plant survival rates (e.g. *Alternanthera philoxeroides*: Julien 1995, Kruger 2004).

Water-level draw down can successfully limit the growth and colonisation of aquatic plants providing that it is aimed at vulnerable aspects of the target species' life cycle. Notoriously problematic aquatic plant species, such as *Hydrilla verticillata*, possess underground storage organs (tubers) that retain nutrients within the plant (Sculthorpe 1967) and facilitate rapid regrowth at the onset of more favourable conditions (Van and Steward 1990). In the case of *H. verticillata*, a late summer draw down is most effective as it kills summer re-growth and prevents the formation of new tubers that could be activated in subsequent years (Haller *et al.* 1976). As *M. aquaticum* lacks comparable storage organs, its ability to withstand sediment desiccation is dependent upon the perennial rhizomes that facilitate re-growth once favourable conditions return. This aspect of *M. aquaticum* biology indicates that the exact timing of a draw down may not be critical other than in terms of the extent of sediment drying. The desiccation tolerance exhibited by rhizomes, however, suggests that the duration of draw down is likely to be critical.

Summer draw downs lasting longer than three months would probably be required to sufficiently dry vegetation and soils to control *M. aquaticum*. Whilst our experimental results indicated that *M. aquaticum* recovered rapidly when recently dried sediments were re-flooded, colonisation of exposed sediments at Sale Common by tall emergent terrestrial species (e.g. *Persicaria decipens*) during draw downs have the potential to create strong competition for light, space and nutrients when reflooding does occur. In any case, the timing of re-inundation is important because re-flooding may augment nutrient release from decaying vegetation and re-flooded soil, thereby facilitating rapid plant recovery. If re-inundation occurs in late summer, it is possible that any benefits gained from the draw down may be quickly lost as *M. aquaticum* grows back rapidly under the favourable, warm and nutrient-rich conditions. Further field-based research is needed to determine whether draw downs of water level over summer can be used as a control measure for *M. aquaticum*.

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Aquatic weeds and their impact in irrigation systems experiencing drought within Victoria

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Summary Aquatic weeds greatly reduce the effectiveness of water distribution systems. Aquatic weeds have a negative impact on native flora and fauna species and on the integrity of natural waterways. Drought is a key factor in the prevention of further spread of most aquatic weed species. The results of lower channel levels and reduced flows due to drought, however can lead to an increase in abundance of aquatic weed infestations within the irrigation system.

Keywords: Aquatic, irrigation, infestations, drought, biodiversity.

Introduction

Aquatic weeds have been a 'thorn in the backside' to irrigation managers since the early inception of irrigation systems in Victoria. Aquatic weeds are managed because they block channels and drains, causing increased water levels that lead to inefficiencies in water delivery and damage to infrastructure. One such aquatic weed example, sagittaria (*Sagittaria graminea* Michx.), was not initially treated as a major threat, until the early 1980s, when the distribution of the plant increased rapidly. The reasons for this dramatic increase are unclear, though one theory may be that the number of propagules produced constantly since the 1960s by smaller populations reached a critical level by the 1980s that allowed the plant to spread beyond established populations. This is in accordance with established principles of aquatic weed infestation (Arthington and Mitchell 1986) that invasion by aquatic species is followed by a period of establishment before dispersal.

Sagittaria now infests drains and channels across four of the six of Goulburn-Murray Water's Irrigation Areas in Victoria, the Murray and Murrumbidgee Irrigation Areas in southern New South Wales, and many natural systems in Northern Victoria and Southern New South Wales. These include the Edwards River, Goulburn River, Broken Creek and associated Nine-Mile and Boosey Creeks, the Ovens River, particularly at its confluence with the River Murray and the River Murray itself. By the end of 2005 it was the most widespread introduced emergent aquatic plant between Echuca and Torrumbarry Weir. There are several other aquatic plant species that have the potential to create similar impacts as sagittaria, both within irrigation systems and in natural waterways.

The problem

Annual expenditure on the control of aquatic weeds by Goulburn-Murray Water (G-MW) alone is estimated at over $3,000,000 depending on seasonal variables that govern the growth of aquatic weeds. Aquatic weeds are managed by G-MW because they impact on service delivery to customers. They block channels and drains, causing increased water levels that lead to inefficiencies in water delivery and damage to infrastructure. They may also cause flooding where water flows in drains are retarded during rain and periods of high drain flow (Gunasekera and Krake 2001). They also have a negative impact on native species and on the integrity of natural waterways. They may also contribute to the reduction in volume of available water within a system due to uptake and loss from the system through evapo-transpiration.

Methodology review

History has shown that aquatic weeds cannot be effectively controlled through one method alone, but rely on several aspects of control which can determine the success or failure of a program. Early detection and prevention has proven to be the most cost-effective method of aquatic weed control, where small infestations can be managed efficiently and effectively. Where aquatic weeds have established and continue to disperse an Integrated Weed Management (IWM) approach needs to be implemented. IWM can be defined as the integration of effective, environmentally safe and socially acceptable control tactics that reduce weed interference below the economic injury level (Elmore, 1996). In practical terms, this means the development of a management plan that includes aspects of the target species' biology, along with targeted or specific herbicide use and other management techniques, such as minimising the spread of weed propagules or drying out a waterway where practical. It may also include aspects of biological control, if available. With a sound knowledge of other possible approaches to aquatic weed management, a good IWM program may be able to be implemented. Currently the principal method of control is through the use of herbicides.

Herbicides

A number of herbicides are currently used for aquatic weed management. Given the restrictions of the environments such as natural carriers and Ramsar Wetlands in which infestations may grow, options are very regulated and restricted. However in irrigation channels and drains herbicides are likely to continue having an ongoing role in aquatic weed management. Regulatory bodies on irrigation systems continue to expand over time and continually constrain operations.

Physical/environmental control

The management of aquatic weed infestations by removal of silt by excavation continues to be undertaken. Problematic issues in channels due to this method are time to implement, access, cost, and loss of clay lining on channel beds. Mechanical control can be very effective through the removal of silt and hence the absence of a suitable environment for aquatic weed growth, however stem fragments through mechanical control pose a threat for further spread. Therefore this method is not suitable for many species.

Cutting of *Typha* spp. is an accepted method of control, particularly when the plant is cut below water level, allowing the plant to 'drown' (Apfelbaum 2001). This process may not be effective against all species, as some species can respond to cutting by actively putting on new growth.

Shading is another method of mechanical control that is gaining in popularity. Anecdotal evidence that aquatic weed growth in small, on-farm channels is reduced by the presence of large shade trees, is backed up by the more intense shade provided by the use of plastic sheeting (Carter *et al*. 1994). This sort of control has its disadvantages, however, being prohibitively expensive for large areas, such as Goulburn-Murray Water's 7000 km of open channels, and being more appropriate for submersed vegetation, over which the sheeting can sit. As well as this, re-colonisation is rapid after removal of matting (Eichler *et al*. 1995), and matting can get covered with sediment in a dynamic system, providing a fresh substrate for weeds to colonise. Draw-down and drying of the irrigation system allowing over-wintering to naturally control aquatic weeds is an operational practice employed by G-MW. In periods of drought where all water is precious, outfalling irrigation water at the end of an irrigation season into the natural carriers has been significantly reduced. Channels have been left at their supply level for stock and domestic purposes and this has resulted in increased aquatic weed growth within the irrigation system.

Biological control

This method can be defined as 'the use of living organisms to suppress a pest population, making it less abundant and thus less damaging than it would otherwise be' (Crump *et al*. 1999). It can be broadly divided into two categories, classical biological control, where an organism is released into the environment to reproduce and proliferate and, from there, to infect, compete with or consume the target organism, and inundative biological control, where the controlling organism is cultured and applied directly to the pest organism.

Classical biological control is hampered by the large amount of money required to implement it (Chokder 1967) and sometimes variable success rates. An example of the successful implementation of classical biological control is the introduction of the *Cactoblastis* moth into Australia to control prickly pear. Such unbridled success stories are somewhat rare, however.

As well as examples, like prickly pear, of biological control using an organism that eats or infects the pest species, introduced species may compete with the pest plant for resources (allelospoly), or interfere with the pest species by releasing compounds into the environment that act upon the pest species, a process known as allelopathy (Szczepanski 1977). Literature on allelopathy in aquatic plants is very limited, however, and effects are often mistakenly attributed to this process.

The most successful method of inundative biological control for alismataceous species has been the mycoherbicide approach, where a mycoherbicide is defined as 'a fungal pathogen which, when applied inundatively, kills plants by causing a disease' (Crump *et al*. 1999). In the Australian rice industry, most work has been done using the fungus, *Rhynchosporium alismatis* (Cother 1999), but other pathogens have been investigated overseas (Chung *et al*. 1998).

Issues

Drought has led to higher water values and lower returns for irrigation water suppliers due to the lack of sales water. Protection of irrigation assets, including the water reserves themselves, is a vital factor in effective management of an irrigation system. Knowing and recognising which aquatic plant species pose the most risk to our waterways, early identification and treatment, and constant surveillance of our waterways is required to prevent further infestations of new aquatic weed species. Control based on plant biology and ecology morphology, seed dormancy and germination, physiology of growth, competitive ability and reproductive biology are all aspects that need to be used for management of aquatic weeds. Information on seed banks, root reserves, dormancy and longevity of propagules may be used to better predict infestations. Weed seed bank densities and root reserves can be greatly reduced by eliminating seed production for a few years (Buhler *et al*. 1997) or through interference with dormancy or germination requirements (Bhowmik 1997), or can increase rapidly if plants are allowed to produce seed. Being able to accurately identify establishment thresholds for aquatic weed species and implementing a method of control prior to experiencing dispersal, is a key management tool.

Conclusion

Drought has a pronounced effect in altering aquatic plant abundance and diversity. It has a positive effect in reducing the spread of weed species, as most species rely on spread by water as the main vector for the spread of propagules and seed. Drought has a negative effect in increasing the abundance of certain weed species due to changes in management practices.

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Predicting the potential distribution of orange hawkweed on the Bogong High Plains using a dispersal constrained habit suitability model

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Abstract

Developing tools to predict the location of new biological invasions is essential if exotic species are to be controlled before they become widespread. Currently, alpine areas in Australia are largely free of exotic plant species but face increasing pressure from invasive species due to global warming and intensified human use. To predict the potential spread of highly invasive orange hawkweed (*Hieracium aurantiacum*) from existing founder populations on the Bogong High Plains in southern Australia, we have developed a spatially-explicit dispersal-constrained habitat suitability model. The model combines a habitat suitability index, developed from disturbance, site wetness and vegetation community parameters, with a phenomenological dispersal kernel that uses wind direction and observed dispersal distances. After generating risk maps that defined the probability of invasion across the study area, we intensively searched several locations to validate the model. The highest probability of *H. aurantiacum* establishment was southeast from the initial infestations. Native tussock grasslands and disturbed areas had high probabilities of *H. aurantiacum* establishment. Extensive field searches failed to detect new populations however time-step validation, using 1998–2000 locations, accurately predicted the occurrence of all post-2003 populations in areas identified as having a high probability of occurrence. No *H. aurantiacum* was found in areas outside the predicted dispersal plume. This suggests our model has good predictive power and will improve the ability to detect populations and prioritise areas for on-going surveillance.

This research (Williams *et al.* in press) has been accepted for publication in Ecological Applications and should be published in late 2007 or early 2008.

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Williams, N.S.G., Hahs, A.K. and Morgan, J.W. (in press). A dispersal-constrained habitat suitability model for predicting invasion of alpine vegetation by *Hieracium aurantiacum. Ecological Applications*.

Measurement of changes in stakeholder weed management attitudes and actions over the life of the Tackling Weeds on Private Land initiative

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Abstract The Tackling Weeds on Private Land initiative focused on developing effective partnerships with, and building the capacity of key stakeholders whose actions directly impact on or influence the management of weeds on private land. An adoption model was used by the project both to develop engagement strategies and to measure the impact and effectiveness of these strategies over the life of the project. The model is based on stakeholders progressing along a continuum of 'awareness' and 'acceptance' to 'action'. Both quantitative and qualitative methods were used to analyse shifts over time for five different stakeholder groups (CMAs, Municipal Council, Linear Reserve managers, the Garden industry and the Fodder industry). Data was collected and analysed at the beginning (to provide a baseline), mid and end of project. Municipal Councils and the Garden industry showed the greatest level of progression along the continuum from the baseline to the end of the three year project.

Introduction

Tackling Weeds on Private Land (TWoPL) was a three year, $9 million state-wide initiative, delivered by the Department of Primary Industries (DPI) on behalf of the Department of Sustainability and Environment (DSE), Victoria. It was aimed at ensuring that government and the community share responsibility for weed management and private land managers, agencies and industries are capable and empowered to act to decrease the impact of weeds on the State's social, economic and environmental values. The focus of the initiative over these three years has been on developing and maintaining effective partnerships with key stakeholders whose actions and activities impact on or influence the management of weeds on private land. The initiative recognised that if we are to be successful in tackling weeds, a coordinated approach is required to engage the many land custodians including State Government, Municipal Councils, private landowners, industry and the community.

The project worked with five key stakeholder groups: Municipal Councils, Catchment Management Authorities (CMAs), Linear Managers (VicRoads and railway authorities), the Garden industry and the Fodder industry. It was felt that it was a more effective approach to work with these groups and encourage them to influence the communities or businesses within their sphere of operations, rather than spread the project's resources thinly by trying to work at the community level. Some project activities, such as media campaigns and compliance operations, were however directed at the community level.

The project delivered a variety of strategies aimed at raising awareness of the stakeholders' weed management responsibilities and encouraging them to take action. These strategies ranged from extension, through to incentives and the development of partnerships between government and stakeholders, and amongst the stakeholders themselves. These partnerships jointly developed innovative approaches to weed management which were focused on sustainability beyond the life of the three year initiative. Project activities were designed to be strategic with a long term focus to complement the stakeholders' on-ground weed control programs (in the case of Municipal Councils, CMAs and Linear Managers). DPI had not previously worked with the Garden and Fodder industries in great depth in relation to weed management and so this project worked at building relationships, raising awareness about the problem of spread of both declared weeds and non declared, invasive plants through their business activities, and on the co-development of strategies to reduce this risk. The aim of this research was to determine the effectiveness of the project by measuring changes in stakeholder awareness and actions in terms of their weed management responsibilities over the life of the project.

Methods

Adoption model

The project team developed a model of adoption which recognised that adoption of new or different practices is a staged process. The model used by the initiative (Figure 1), describes a progression along a cycle of 'awareness', and 'acceptance' to 'action'. The model also maps some of the elements of a Bennett's hierarchy (Bennett 1977); Knowledge, Attitudes, Skills, Aspirations and Practice Change, in relation to the Aware, Accept and Act segments of the adoption cycle.

Domains of change – what does success look like?

In order to measure the effectiveness of the project, it was necessary to define what success looked like, or what changes we wanted the stakeholders to make, in order to act on their weed management

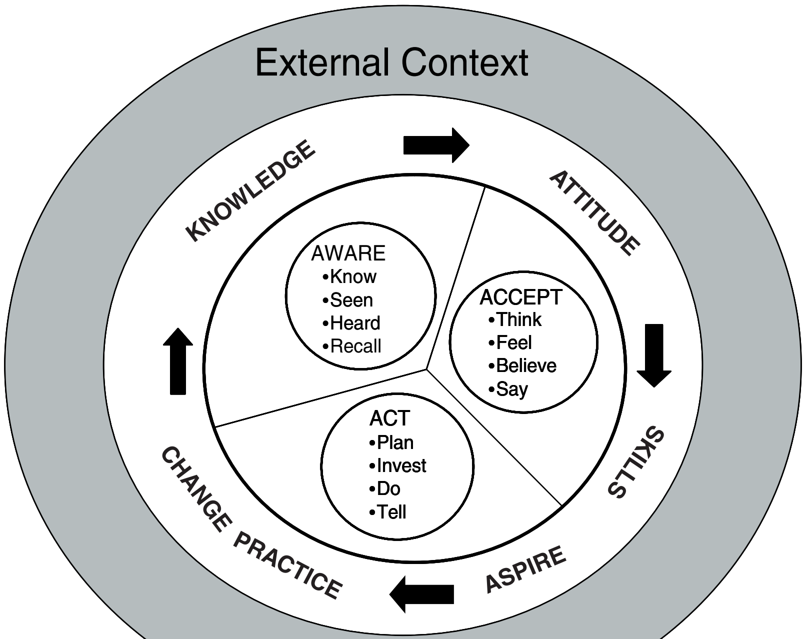

Figure 1. Aware, Accept, Act Adoption model.

responsibilities. Research questions were then formulated to measure the degree of change for each stakeholder in each domain, over the life of the project. The domains of change were defined to be as generic as possible for each stakeholder group, but some differences were necessary for the agency groups and industry groups (Table 1).

Data collection
Data was collected at the beginning of the project to provide a baseline from which to measure shifts in each of the domains; at the mid point and at the end of the project. Surveys were designed to collect both quantitative and qualitative information and were administered by telephone. The same survey instrument was used for each of the agencies (CMAs, Municipal Councils and Linear Managers) and modified ones were designed for the Garden and Fodder industry representatives. Survey samples were kept as uniform as possible for the three surveys, however there was some variation due to staff turnover. In the case of the agencies, surveys were conducted with a senior management and an operational representative (e.g. Environment/NRM Officer) of each organisation. Samples for the end of project survey are shown in Table 2.

Data analysis
A research methodology was designed which would enable objective and quantifiable measurement of change over time, of the stakeholders' awareness, acceptance and actions in relation to their weed management responsibilities.

A range of dichotomous (Yes/No) survey questions were designed and grouped according to the Domain of Change and whether they belonged to the Aware, Accept or Act segment of the adoption model. This is described in Table 3 for the agency group of stakeholders.

For each of the cells in Table 3, the results were expressed as the proportion of respondents answering 'Yes' out of the total number of respondents who answered those questions. Statistical significance of the changes between the baseline and end of project results was tested using Chi^2 tests and P values of <0.05 or lower were considered significant.

Additional quantitative and qualitative survey questions were designed to provide information about the stakeholders' attitudes, motivators and barriers towards their weed management responsibilities and the information from these responses was used in conjunction with the dichotomous ones to provide a richer picture. The focus of this paper is on the quantification of the stakeholders' changes in the Aware, Accept and Act segments of the adoption model.

Table 1. Domains of change.

Agencies - CMAs, Councils, Linear Managers	Industries – Garden and Fodder
1. Manage priority weeds on land they are responsible for	1. Not selling or promoting declared weed species, or products containing weeds
2. Prevent the spread of weeds resulting from their business operations	2. Prevent the spread of weeds resulting from their business operations
3. Report new weed species	3. Report new weed species
4. Work with other land managers in a coordinated approach to weed management	4. Work with other industry members in a coordinated approach to weed management
5. Show leadership in weed management[A]	

[A] CMAs and Councils only.

Results
The following series of tables show the results for each stakeholder at the beginning of the project (baseline) and at the end of the project. For simplicity, the results collected at the mid point of the project are not shown. These mid project results, together with the qualitative information were used to inform the delivery of the remainder of the project activities and modify strategies accordingly.

Catchment Management Authorities
Overall, CMAs showed an increase in awareness for the five domains for change combined, but no significant increases in the Accept and Act segments of the adoption model. The improvements in awareness were mainly attributable to improvements in the Managing priority weeds, Prevention of spread and Working with other land managers domains. Results for each individual domain which contribute to this finding are as follows:

Manage priority weeds on their land
CMAs showed a significant increase (P <0.01) in awareness of their responsibilities of managing weeds, the priority species and their locations within their catchments. There was a slight decrease in the Accept segment which relates to the organisation setting goals for weed management improvement, and there was no significant change in the Act segment which

Table 2. Survey samples.

Stakeholder group	Number of respondents
CMAs	16
Municipal Councils	38
Linear Managers[A]	4
Garden industry	250
Fodder industry	150

[A] Eight Linear managers were interviewed in the baseline survey but numbers were not able to be sustained at the end of project survey. As the sample size is so small, results for this group are not included in this paper.

Table 3. Survey design.

Domain of change	Aware	Accept	Act
1. Manage priority weeds on land they are responsible for (agencies).	3 questions	2 questions	4 questions
2. Prevent the spread of weeds resulting from their business operations	2 questions	2 questions	3 questions
3. Report new weed species	2 questions	2 questions	1 question
4. Work with other land managers in a coordinated approach to weed management	1 questions	3 questions	1 question
5. Show leadership in weed management	No questions	No questions	2 questions
Total all Domains	8 questions	9 questions	11 questions

incorporates issues such as allocating specific staff and funds to weed management, having scheduled works and staff training programs in place.

Prevent the spread of weeds There was a significant increase (P <0.01) in awareness of the ways in which CMAs could spread weeds during their works programmes and how they could reduce this risk (for example through vehicle hygiene). There was also a significant increase (P <0.05) in the CMA respondents whose organisations had Codes of Practice in place with procedures and systems to support them. These were indicators used for the Accept segment. In terms of the Act segment, there was no significant change in the proportion of CMAs which inserted weed hygiene clauses in their contracts (e.g. with works contractors) and provided facilities and equipment, and time for staff to implement vehicle wash-down procedures.

Report new weed species There were no significant changes in awareness of new high risk weed species, risk areas and potential pathways of introduction and spread; in acceptance as measured by the number of CMAs actively distributing information to staff about these new species, and also implementing a reporting procedure; and in actions in terms of actual reports of new weed species.

Work with other land managers Significantly more CMAs were aware (P <0.001) of other land managers and agencies and their responsibilities for weed management. However, there was a decrease in those who were actively working with others and with resources committed to these collaborative activities (Accept indicators). Similarly, fewer CMAs had actually initiated collaborations since the baseline survey (Act indictor).

Leadership in weed management There was no significant increase in the proportion of CMAs saying that their organisation was the lead agency for a collaborative project or an active advocate for weed management (Table 4).

Municipal Councils
Overall, Councils showed significant increases in awareness, acceptance and actions for the five domains of change combined. These were mainly attributable to improvements in the Prevention of spread, Reporting new weeds and Working with other land managers domains, as described below.

Manage priority weeds on their land There was no significant increase in the proportions of Councils demonstrating awareness of their responsibilities of managing weeds, the priority species and their locations within their shires. There was however, a significant decrease (P <0.01) in the Accept segment, and no change in the Act segment. Indicators for these segments were the same as previously described for CMAs.

Prevent the spread of weeds There were significant increases in awareness (P <0.01) of the ways in which Councils could spread weeds during their works programmes and how they could reduce this risk. There were no significant increases in the Accept and Act indicators (as previously described for CMAs).

Report new weed species There were significant increases in awareness (P <0.01), acceptance (P <0.001) and actions (P <0.001) of Councils in terms of understanding the risk of new weed species, implementing procedures to minimise this risk, and reporting incidences of these species.

Work with other land managers Significantly more Councils were aware (P <0.001) of other land managers and agencies and their responsibilities for weed management and had also initiated collaborations (Act, P <0.05).

Table 4. Catchment Management Authorities.

	% of responses					
	Aware		Accept		Act	
	Baseline	End	Baseline	End	Baseline	End
Manage priority weeds on their land	67	90	61	56	40	42
P value	<0.01		n.s		n.s.	
Prevent the spread of weeds	61	94	19	53	19	23
P value	<0.01		<0.01		n.s.	
Report new weed species	75	84	31	50	61	75
P value	n.s.		n.s		n.s	
Work with other land managers	44	100	87	85	83	69
P value	<0.001		n.s		n.s	
Show leadership in weed management	–	–	–	–	78	81
P value	–		–		n.s	
Total – All Domains	65	91	54	64	47	49
P value	<0.001		n.s		n.s	

Table 5. Municipal Councils.

	% of Responses					
	Aware		Accept		Act	
	Baseline	End	Baseline	End	Baseline	End
Manage priority weeds on their land	79	81	54	34	58	55
P value	n.s		<0.01		n.s	
Prevent the spread of weeds	90	100	41	53	43	54
P value	<0.01		n.s		n.s	
Report new weed species	56	79	24	62	40	87
P value	<0.01		<0.001		<0.001	
Work with other land managers	38	100	70	76	55	79
P value	<0.001		n.s		<0.05	
Show leadership in weed management	–	–	–	–	53	67
P value	–	–	–	–	n.s	
Total – All Domains	71	88	50	58	51	62
P value	<0.001		<0.05		<0.01	

Leadership in weed management There was no significant increase in the proportion of Councils saying that their organisation was the lead agency for a collaborative project or an active advocate for weed management (Table 5).

Garden industry
Garden industry respondents showed significant increases in the Awareness, Acceptance and Action segments of the adoption model for all four domains of change combined. Significant improvements in awareness were attributable to all domains except for Working with other industry members; significant improvements in acceptance were seen only in the Reporting new weeds domain and significant improvements in actions were seen only in the Prevention of spread of weeds domain.

Not selling or promoting weeds There was a significant increase (P <0.001) in garden industry respondents being aware of the declared noxious weed list, having access to the list and in their knowledge of which species are on the list (Aware indicators). There was no significant change in the Accept indicator which was that businesses provided training to their staff on declared weed identification. Indicators of Action for this domain were that the businesses had experience with selling (or using, for landscapers) plants, which they subsequently found out to be weeds and if they had taken steps to prevent this happening again. There was no significant increase in this indicator.

Prevent the spread of weeds For this domain, indicators were developed which described the spread of weeds in terms of selling or using invasive plants (other than declared weeds), and using garden supplies (such as soils, mulches, rocks etc.) which might be a source of weeds.

There was a significant increase in awareness (P <0.05) of the risks from invasive garden plants, garden supplies and landscaping works. Acceptance was measured by indicators about educating customers about invasive plants, implementing procedures to ensure that supplies were weed free, and implementing weed hygiene procedures for landscapers. This indicator had not increased significantly since the baseline. There was a significant increase in the Act segment (P <0.01) which was measured by indicators about suggesting alternative, non invasive plants to customers, requiring weed free guarantees on garden supplies and inserting machinery hygiene clauses into contracts for landscapers.

Report new weeds There was a significant increase (P <0.001) in awareness of the species of invasive garden plants of concern, the ways in which they might become naturalised, and appropriate reporting procedures. There was also a significant increase (P <0.05) in acceptance which was measured by respondents' perceived responsibility for identifying and reporting these new weed species and in ensuring that their staff are also trained to be able to do this. There was no change in the proportion of respondents who had actually reported these weeds (non declared weeds); the Act indicator.

Work with other industry members There were no significant differences in awareness, acceptance or actions for this domain. The Aware indicator was knowledge of other members of the garden industry that the respondents could work with to minimise the sale or spread of weeds. Accept was measured by the respondents' beliefs that it was both beneficial and practical to collaborate in this way, and the Acting indicators were whether the respondents were currently participating in such collaboration and contributing to industry discussions about current and future problem species (Table 6).

Table 6. Garden industry.

	% of Responses					
	Aware		Accept		Act	
	Baseline	End	Baseline	End	Baseline	End
Not selling or promoting weeds	74	83	42	35	69	73
P value	<0.001		n.s		n.s	
Prevent the spread of weeds	91	94	59	64	52	60
P value	<0.05		n.s		<0.01	
Report new weed species	57	68	60	67	8	7
P value	<0.001		<0.05		n.s	
Work with other industry members	49	56	84	89	21	26
P value	n.s		n.s		n.s	
Total – All Domains	70	77	64	68	40	46
P value	<0.001		<0.05		<0.001	

Fodder industry
Fodder industry respondents reported a significant increase in awareness, but not acceptance or action for all domains combined. The significant awareness increase is attributable only to the Preventing the spread of weeds domain.

Not selling or promoting weeds There was a slight but not significant increase in the indicators contributing to the Aware rating; knowledge of the provision of the *CaLP Act 1994* that it is illegal to sell declared weeds, or offer them for sale as part of another product (i.e. weed contaminated fodder), understanding the difference between declared and non declared weeds and having access to a declared weed list. There was a slight decrease in both the Accept and Act ratings. Accept indicators were related to use of Codes of Practice which specifically address the presence of weeds in the fodder, and the Act indicators which concerned respondents who had experience with selling fodder which they subsequently found out to be contaminated with declared weeds and if they had taken steps to prevent this happening again.

Prevent the spread of weeds There were significant increases both in awareness (P <0.001) and in acceptance (P <0.05) but no significant increase in acting for this domain. Awareness was measured by the respondents' rating of their knowledge of the ways in which weeds could be spread during fodder production and /or transport, and acceptance related to using a Code of Practice which addressed machinery and vehicle hygiene. The Act indicators were whether hygiene systems and processes were actually implemented and complied with by respondents' staff and contractors.

Report new weed species There were no significant changes in this domain. Awareness was measured by knowledge of new high risk weeds not yet known in Victoria; acceptance measured by respondents' rating of their responsibility for identifying and reporting these new weeds, and acting was whether they had actually reported any of these species.

Work with other industry members As for the garden industry, this domain concerned collaborative activities to minimise the spread of weeds. The Accept rating was significantly higher (P <0.05) due to an increase in respondents believing that it was both beneficial and feasible to collaborate with other industry members, however this was not carried through into action, with a significant decrease (P <0.05) in respondents who were currently participating in collaborative activities (Table 7).

Discussion

The following table (Table 8) compares significant improvements in different domains of change for each stakeholder. Municipal Councils have progressed to the Act stage of the adoption model in the domains of Reporting new weed species and Working with other

Agencies and the Garden industry are at the Act stage for preventing the spread of weeds. The least amount of progression across all stakeholder groups is evident for the first domain (Managing priority weeds/ not selling or promoting weeds). The Fodder industry shows the least degree of progression.

The Aware, Accept, Act adoption model proved to be an effective basis for designing a quantifiable method of measuring behavioural and attitudinal shifts over time. Caution however, must be exercised in relying solely on these measures to determine the effectiveness of an initiative such as Tackling Weeds on Private Land. For the stakeholders with smaller sample sizes, such as CMAs and Municipal Councils, the qualitative findings (not presented in this paper) created a far richer picture of changes and impacts and provided greater insights into causalities than the quantitative results alone. For the Garden and Fodder industries, where the sample sizes were larger, the quantitative results were more reliable, but the qualitative information was also invaluable in providing insights into causalities and reasons behind the numerical results. A risk of relying solely on the quantitative data presented in this paper is that it does not take into consideration contextual factors operating during the period of the research. These factors are critical in order to determine whether changes (improvements or otherwise) to the Aware, Accept and Act ratings can be attributed to the project interventions alone or whether external factors are having an impact. For example, the serious state-wide drought and bushfires in some regions negatively impacted on most stakeholders' abilities to implement as much weed management activity as they might otherwise have done.

When the qualitative information, as well as additional evaluation data collected throughout the life of the initiative is brought to bear on interpreting these results, greater insights can be gained for each stakeholder and are summarised below:

Catchment Management Authorities

While significant gains have been seen in several areas of weed management, the CMAs' statutory position of leadership for natural resource management within Victoria might have been expected to lead to even greater progression along the adoption cycle. This result however, might be explained by the feedback that CMAs did not perceive themselves to be land managers with direct weed management responsibilities per se, but rather to hold a more strategic, policy setting role. Engagement strategies delivered by the project were designed mainly towards building awareness, particularly of CMAs' roles and responsibilities with regard to weed management. There were also some engagement strategies designed at gaining acceptance and action, particularly in relation to minimising weed spread during CMAs works programmes (such as vehicle hygiene practices), however the project had limited success engaging CMAs on these issues.

Municipal Councils

Significant improvements were seen in nearly all areas measured for Municipal Councils. A large portion of the TWoPL initiative's resources was allocated to this stakeholder group, with an incentive program, educational resources and a series of information and networking forums amongst the key engagement strategies. Additional data was collected which showed the degree of impact of each of the strategies on Municipal Councils' attitudes and actions towards their weed management responsibilities. This data supported a causal link between the TWoPL engagement and the significant improvements in the Aware, Accept and Act ratings over the life of the project. In terms of understanding the external factors, the qualitative information showed a consistent

Table 7. Fodder industry.

	% of Responses					
	Aware		Accept		Act	
	Baseline	End	Baseline	End	Baseline	End
Not selling or promoting weeds	77	81	51	48	91	86
P value	n.s		n.s		n.s	
Prevent the spread of weeds	38	61	48	70	70	73
P value	<0.001		<0.05		n.s	
Report new weed species	52	55	91	88	9	11
P value	n.s		n.s		n.s	
Work with other industry members	50	67	89	91	46	37
P value	n.s		<0.05		<0.05	
Total – All Domains	61	69	78	79	56	53
P value	<0.001		n.s		n.s	

Table 8. Comparison of significant improvements in domains of change by stakeholder groups.

	CMAs	Municipal Councils	Garden industry	Fodder industry
Manage priority weeds on their land / Not selling or promoting weeds	Aware	–	Aware	–
Prevent the spread of weeds	Aware Accept	Aware	Aware Act	Aware Accept
Report new weed species	–	Aware Accept Act	Aware Accept	–
Work with other agencies /industry members	Aware	Aware Act	–	Accept
All domains combined	Aware	Aware Accept Act	Aware Accept Act	Aware

concern about an issue of confusion over the legal responsibility for managing weeds on council managed roadsides. Municipal Councils expressed high levels of frustration over the length of time that it was taking State government to resolve the issue and many perceived the likely outcome to be another example of cost shifting from State to Local Government. It can only be hypothesised that even greater gains may have been made in the absence of this cause of tension between the project sponsors and this stakeholder group.

Garden industry
As for Municipal Councils, the significant improvements seen in the Garden industry can also be attributed, at least in part to the TWoPL initiative through analysis of respondents' ratings of the impacts of specific engagement strategies. In addition, however, understanding the social context is important for interpretation of these findings. Qualitative information showed that Garden industry members have very high ratings for their industry's responsibility for not contributing to weed spread through their business activities and a high personal motivation for caring for the environment. The change required of this industry, if managed carefully, need not have an impact on their profitability. For example, a key project with this stakeholder was the development of a brochure entitled 'Grow me Instead' which provided safe alternative species to corresponding invasive garden plants. This substitution, given sufficient lead time was perceived not to negatively affect profitability. Indeed, competitive advantage could be conferred on businesses portraying the 'sustainability' message. Research at the beginning of the project indicated that a barrier for practice change adoption with this industry was a lack of trust of State government and a concern that significant numbers of new species would be declared under the *CaLP Act 1994* very quickly with no consultation or lead time to allow businesses to prepare. Some representatives of the Garden industry also expressed concern that Government and other organisations appeared to focus mainly on the introduction of weeds through their industry compared with other vectors of weed introduction and spread (e.g. for agricultural weeds). Understanding this context allowed the TWoPL project to design engagement strategies targeted at building relationships with the industry peak bodies to increase trust, and then to jointly develop strategies to address the weed spread risk. One anecdote alone indicates the success of this approach. Compliance staff conducted audits for declared and state prohibited weeds at three annual Melbourne International Flower and Garden shows. Before the first year's compliance activity, the Garden industry peak body expressed strong concern about the possibility of negative publicity for the industry if any exhibitors were seen to be prosecuted at such a showcase event. This led to the compliance activity being undertaken in a very discreet manner, with officers conducting inspections out of opening hours and in plain clothes. By the third year, the relationship between this peak body and the TWoPL team had improved to the extent that the peak body requested the compliance officers to attend during public open hours, and in uniform. In this way, the industry was seen to be actively supporting the message to the public about the threat of introductions of invasive plants.

Fodder industry
Active engagement with the Fodder industry by the TWoPL project only began approximately 12 months prior to the final survey. In addition, engagement was mainly with two key industry peak bodies so additional time is required for the messages to reach the 13,000 Fodder industry players in Victoria. Understanding this context helps to interpret the Aware, Accept, Act ratings and the fact that there was limited progression along the adoption cycle for this stakeholder during the life of this project. An innovation or practice change in the agricultural sector is more likely to be adopted when it has a high 'relative advantage' over the product or practice it supersedes (Pannell *et al*. 2006). In addition, a research study indicated that time lags exceeding one year existed between the time when the first farmer discovered an innovation and the time when 50% of farmers in the study area had discovered it (Gibbs *et al*. 1987). This is only the time it takes to be aware of the innovation, not to adopt it. A further study indicated that the adoption time from delivery of an extension package to reaching the adoption ceiling (when the rate of adoption plateaus) was seven to eight years (Marsh *et al*. 2000). These studies relate to the adoption of a new farming production system, such as a new crop variety, with an improvement in production and/or profitability being the main driver for adoption. In the case of adoption of natural resource management practice change, it is also known that the rate of adoption is slow and non-adoption is relatively high (Pannell *et al*. 2006). Environmental attitudes generally show a limited relationship with natural resource management practice change, with financial risk and management skills being far more powerful influencers of adoption (National Land and Water Resources Audit (2002)). It is not surprising therefore, that we have not yet seen greater adoption of weed spread minimisation practices by the Fodder industry. The qualitative findings of this study do indicate that some industry representatives recognise the competitive advantage of ensuring weed free products and implementing hygiene practices to reduce weed spread during their operations. However, they also provide strong evidence that implementing stringent weed hygiene practices is frequently not cost effective or practical, particularly for the smaller industry players. In addition, these findings clearly confirm that market forces dictate a far higher tolerance amongst consumers for weed contaminated fodder during times of product scarcity, such as the recent drought.

Limitations
The results presented in this paper represent the stakeholders' self reporting. In the full evaluation of the TWoPL initiative, other metrics of project success such as numbers and types of projects initiated, partnerships developed etc., have been used to 'ground truth' this self reporting data.

It was difficult to design survey questions to represent Accept indicators. As a result, there was often a non linear relationship from Aware to Accept to Act, as one might expect from the adoption model. Greater importance is therefore placed on the Aware and Act indicators

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Tackling weeds on private land

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Summary The Victorian Government initiative 'Tackling Weeds on Private Land' was a three-year initiative that sought to encourage landowners to work collaboratively to manage weeds.

The $9 million initiative accelerated implementation of the Government's Victorian Pest Management Framework – A Framework for Action.

The project worked with five key stakeholders whose activities significantly influence how weeds impact upon and are managed on private land; Local Government, Catchment Management Authorities, Linear Reserve Managers, the Garden Industry and the Fodder Industry.

TWoPL built on the momentum of a range of existing programs by building the profile of weed management as a core component of business operations. Through partnerships with key stakeholders, a range of new initiatives promote weed management responsibilities, share knowledge, build capacity and ensure integrated and cooperative approaches to preventing new weeds and managing existing problems. Significant practice change in weed management responsibilities was achieved by all five stakeholders over the life of the project.

Introduction

The cost of weeds to Victorian agriculture is estimated at more than $900 million per year (Sinden *et al.* 2004). This is a conservative estimate as it does not include costs and losses associated with weed management in natural environments or with loss of amenity. Weed invasion is ranked second only to habitat loss as the major cause of biodiversity decline (Sattler *et al*. 2002). Changing environmental conditions, increased knowledge and a rising number of new weed incursions, demand the development of new and improved approaches to managing weeds.

Sixty percent of Victoria's land is privately owned and all of it requires coordinated weed management. There are many examples of successful community partnerships tackling weeds and successful key stakeholder policies and programs for weed management. The Government recognises however, that more can be done to coordinate the range of stakeholders involved in weed management. Coordinated approaches to weed control will encourage all land managers and organisations to play their part in reducing the impact of weeds on social, environmental and economic assets.

The Tackling Weeds on Private Land (TWoPL) initiative was launched in October 2004 as a policy initiative under the Victorian Government's Victorian Pest Management – A Framework for Action (VPMF). The $9 million, three-year initiative sought to expand and promote innovative and collaborative approaches to reducing the impacts of weeds on private land. Victoria's Department of Primary Industries (DPI) delivered key components of the initiative on behalf of the Department of Sustainability and Environment (DSE).

Between July 2004 and June 2007 TWoPL worked with five key stakeholders whose activities significantly influence how weeds impact upon and are managed on private land; Local Government (MC), Catchment Management Authorities (CMAs), Linear Reserve Managers, the Garden Industry and the Fodder Industry. 'Weeds are everyone's property' was the slogan for TWoPL. It recognises that all land managers and Victorians have a role or responsibility in weed management, not only for the management of our existing weed problem, but also for the prevention of new and emerging weeds.

Materials and methods

The five key stakeholders comprised Local Government (62 Municipal Councils), Catchment Management Authorities (ten CMAs), Linear Reserve Managers (VicRoads and four rail companies), the Garden Industry, and the Fodder Industry. Stakeholder analysis was undertaken for each of the five stakeholders to gain an understanding of organisation/industry structure; operational systems and networks; decision-making processes and key personnel; inter and intra-organisational dependencies; size of organisation/industry and major organisations/industry influences (Mantelli 2005).

Eight project objectives linked to the project goal of 'key stakeholders accepting and acting on their weed management responsibilities in a collaborative manner'. Implementation of the project objectives was achieved through four subprojects; Partnerships; Prevention and early intervention; Enhanced enforcement; and Engagement. The Partnerships subproject supported key stakeholders to: gain a better understanding of their roles and responsibilities; actively integrate weed management into their programs; and increase collaborative action on weeds. The Prevention and early intervention subproject established a process to prioritise new high-risk weed species in Victoria for improved surveillance, and aimed to improve stakeholder adoption of prevention of spread principles (with particular emphasis on pathways) and hygiene systems and practices. The Enhanced enforcement subproject provided increased support to stakeholders and community priority weed control programs through targeted compliance programs. The Engagement subproject supported delivery of the other subprojects through expertise in communication, social research and evaluation.

Changes in stakeholder awareness, acceptance and action

Adoption of new or different practices is a staged process. The model used by the initiative, is a progression along a continuum of 'awareness' to 'acceptance' to 'action' (AAA continuum). Baseline positioning of key stakeholders along the AAA continuum was established through initial attitudinal research in 2005. Shifts along the continuum were assessed mid 2006 and at end of project, mid 2007 (King 2007a,b,c). Comparison of results with baseline data and with qualitative data was used to determine the effectiveness of the initiative in bringing about practice change. Evaluation took into account the potential differences in positioning on the AAA continuum between individuals within stakeholder organisations and the organisations themselves.

Four key areas of weed management responsibility were defined. These were used to design relevant engagement strategies and to evaluate their effectiveness in increasing stakeholders' awareness and action in each area. These were:

1. Managing priority weeds on land the .stakeholder is responsible for (agencies – CMAS, MCs, Linear Reserve Managers) OR Not selling, promoting or transporting declared weeds or products containing declared weeds (garden and fodder industries).
2. Preventing the spread of weeds resulting from the stakeholders' business operations.
3. Reporting new potential weed species.
4. Partnerships and collaborative weed management activities with other agencies or industry members.

Social research, stakeholder analysis and partnership discussions were used to identify appropriate approaches. Engagement activities included development of printed and website extension material, media releases, regional forums, presentations, interviews with senior executives, partnerships project grants, technical advice and stakeholder participation in shaping policy.

TWoPL tailored engagement tools and materials to the needs of the individual organisations to ensure that the project built on previous work undertaken. Opportunities for networking and information sharing have led to collaborative action resulting in a more coordinated approach to weed management.

Prioritising high risk weeds to Victoria

There are some 1300 weed species already in Victoria, with an estimated 40,000 potential weeds that could still enter Australia. A preliminary investigation was undertaken to identify the most likely candidate species posing a weed risk to Victoria. A rapid assessment methodology was developed (Blood 2005) to enable the candidate weeds to be prioritised to identify the highest risk species to Victoria. Criteria included weed history, current recorded distribution and potential threat.

Improvements in surveillance

Preventing the introduction and establishment of serious new weeds to Victoria is dependant on early detection and eradication. Weed Spotters are a network of people who keep an eye open for and report potential new and emerging weeds. Resource materials and training programs were developed to build the capacity of Weed Spotters to detect, identify and report Victorian Alert Weeds.

Surveillance for Victorian Alert Weeds can be streamlined by focusing on the most likely 'pathways' these weeds might travel to enter Victoria. The methods by which weeds enter or spread (or pathways of distribution) throughout the country, state or region need to be prioritised, so resources can be directed appropriately toward prevention strategies. A risk assessment framework was developed to establish a quantifiable risk assessment of weed spread pathways in Victoria to inform current weed management projects and enable objective prioritisation and strategic development of future weed management projects and initiatives.

The risk assessment framework identified 10 potential activities or vectors implicated in potential weed introduction and spread in Victoria (Australia). A matrix was developed referencing the activities with 28 industries and organisations which may introduce and spread weeds by one or more of these activities. A set of 15 criteria, each with five associated intensity ratings was developed to assess 98 organisation/activity combinations for their risk of introducing and distributing 86 high priority weeds into Victoria. Confidence scores, indicating the level of certainty and availability of data were also provided. A decision support system, Analytic Hierarchy Process (AHP), was then used to assist decision making on the relative weightings of each of the criteria.

The risk assessment framework can be readily adapted to other regions and pests.

Support for community led action

Demand from the community for action on weeds is high. The community weed model employed by groups in Victoria such as the Victorian Serrated Tussock Working Party and Gorse Task Force, has allowed key stakeholders to pool resources and knowledge, and work cooperatively and strategically toward controlling weeds. This collaborative approach has proved very effective in encouraging the majority of landowners to participate in weed management. Stakeholders are aware that all land owners must participate for projects to be effective, as land managers that refuse to control weeds threaten the efforts and investment of the community and impact on the natural or agricultural environment. This generates significant demand for government to provide compliance support to ensure the small percentage of land owners that refuse to meet their obligations, does not jeopardise the success of these projects.

The Enhanced enforcement component used a targeted mobile compliance approach as an efficient means to support stakeholders tackling weed problems. The approach, utilising a team of specialist compliance staff (approximately 4.5 full time equivalents), has been piloted across Victoria over the last three years to provide compliance support to community groups that are actively working toward control of established weeds. The project also utilised specialist compliance skills to provide support to regional staff involved in supporting community groups and building the capacity of DPI to carry out compliance under the *Catchment and Land Protection Act 1994.*

Use of social research, evaluation and coordinated communication

Social research was conducted to inform the development of the project's engagement strategies and communication messages and to evaluate their effectiveness. Research was conducted in two stages. At the commencement of the project, studies were conducted to gain a better understanding of the size and complexity of the stakeholders to assist in project scoping and the development of a broad engagement and communication strategy. More detailed research was then conducted to collect both qualitative and quantitative information on knowledge, attitudes, current practices, motivators and barriers to change relating to weed management. This information built on the scoping studies and together formed a detailed picture of each stakeholder which was used to identify and target specific engagement strategies. This research was particularly valuable for understanding stakeholder groups with whom DPI had not previously worked in depth (such as the garden and fodder industries), and enabled relevant and targeted engagement and communication strategies to be designed to achieve the necessary change for each stakeholder group.

Key messages were developed and delivered through targeted communication materials as well as the mass media. Effective project communications were designed with distinctive branding, identifying the different stakeholders. All communication strategies used consistent project quality assurance and approval processes.

Evaluation was conducted throughout the project, enabling continuous improvement to the delivery of the project's activities as well as at the end of the project to measure achievement of the project objectives.

Results

The TWoPL initiative was a major contributor to implementation of the Weed Management Strategy of the Victorian Pest Management Framework – A Framework for Action. The initiative contributed to 16 of the 18 objectives of the Weed Management Strategy, and 31 of the 50 strategic actions identified to meet these objectives (Victorian Government 2002).

The three project annual reports (Anderson *et al.* 2005, 2006, 2007) provide detailed information on TWoPL achievements including stakeholder advocacy of benefits of weed management partnerships in the media, industry and weed management forums. A brief summary of TWoPL achievements is provided below.

Changes in stakeholder awareness acceptance and action

Increases in awareness and acceptance, of the four weed management responsibilities noted above, were seen for all five stakeholders (Table 1), with statistically significant increases in awareness achieved by CMAs (26%), Municipal Councils (17%), the Fodder Industry (8%) and Garden Industry (7%) and in acceptance by Municipal Councils (8%) and the Garden Industry (4%). Sample sizes for Linear Reserve Managers were too small for statistical analysis.

Increases in action on weed management responsibilities were achieved by CMAs, Municipal Councils, Linear Reserve Managers, and the Garden Industry. Municipal Councils and the Garden Industry showed the greatest level of improvement with statistically significant increases of 11% and 6% respectively.

The Fodder Industry was the only stakeholder where a decline in action on responsibilities occurred although this was not statistically significant. This may have been a consequence of the significant pressure on the fodder industry imposed by the drought in combination with the fact that active engagement with this group did not occur until the final 12 months of the project.

Table 1. Practice change in awareness, acceptance and action on weed management by stakeholders by project end.

	CMAs	Municipal Councils	Linear Managers	Garden	Fodder
Aware at end project	91%	88%	84%	77%	69%
% change	26% ***	17% ***	4%	7%***	8% ***
Accept at end project	64%	58%	50%	68%	79%
% change	10%	8% *	6%	4% *	1%
Act at end project	49%	62%	57%	46%	53%
% change	2%	11% **	5%	6% ***	(3%)

Statistically significant change from beginning to end of project *P<0.05, **P<0.01, ***P<0.001
Sample sizes for the Linear reserve managers were too small for significance testing.

Partnerships

To aid partnership development, innovation and capacity building in weed management a three year grants program was established to provide opportunities for the key stakeholders to manage weeds into the future. Fifty six organisations, representing municipal councils, linear reserve managers, fodder and nursery industry associations, implemented a total of 107 projects with $1.9 million funding assistance and co-investment of $3.7 million. Projects implemented incorporated one or more of the following areas; community education and awareness, weed spread prevention training, weed mapping and marker systems, codes of practice development, implementation of weed hygiene protocols, local law development, planning guideline creation and project evaluation. A case studies booklet (Roche *et al.* 2007) highlights progress in weed management achieved through 24 projects implemented by Municipal Councils, Linear Reserve Managers, the Garden and Fodder Industries.

Engagement was also achieved through; high level meetings with Municipal Councils to gain executive support for TWoPL objectives, feedback to key stakeholders on the performance of their weed management programs and key stakeholder participation in planning and running forums. The forums were designed to showcase achievements, share information, enhance networking and partnership development, distribute extension material and allow the sharing of weed management stories. Ten forums were held during the project with approximately 600 people from nearly 270 organisations attending these events.

Through engagement activities and collaborative development, 20 significant new weed management partnerships have been established. These partnerships take the form of joint projects where resources, risks and decision-making are shared. Other activities include; agreed participation in decision making committees, strategic planning, sharing information, business partnerships and commitment to regular ongoing dialogue and collaboration.

Communication

A scoping report on development of weed management extension material (Snell and Norris 2005) identified the needs of key stakeholders and priorities for further development. Materials developed included 47 fact sheets incorporating key messages, industry specific subjects and technical information. Over the life of the project, 25,344 fact sheet kits each containing up to seven fact sheets were sent to organisation/industry executives and staff members.

Media was utilised to raise awareness and communicate TWoPL achievements. Sixty seven media articles were released by the project over the three years, resulting in 237 published media articles. Analysis of the extent to which the seven key messages were reported in the media found that 67% reproduced all or more than half of the related media release content. Towards the end of the project there was an increase in the number of articles on weeds produced by stakeholders themselves and in the number of unsolicited media enquiries. The overall tone achieved in media coverage was 89% positive, 8% neutral and 3% negative. (King 2007d).

Prioritising high risk weeds to Victoria

Some 1268 candidate species were identified through initial assessment as a potential risk to Victoria. Application of rapid assessment criteria to the candidate weeds (Blood 2005) identified 410 weeds with high potential threat to Victoria. These species are known as Victorian Alert Weeds and included;

- 212 taxa not currently known in Victoria (priority for prevention of introduction),
- 141 taxa with less than 10 known distribution records (priority for eradication) and
- 57 taxa with 11–20 known/unknown distribution records.

The Victorian Weed Alert Plan describes Victoria's approach to prevention and eradication of new weed incursions. The Weed Alert Plan has been updated to include approaches for surveillance and response to Victorian Alert Weeds.

Improvements in surveillance

Thirty of the 410 Victorian Alert Weeds were selected to provide focus to the Victorian Weed Spotters Network. These weeds were promoted to the Weed Spotters to encourage reporting of these new and emerging species to improve surveillance measures. A Weed Spotters website has been developed (www.dpi.vic.gov.au/weedspotters) as a one-stop information and resources site for current Weed Spotters and those inquiring about the network. The website includes a photo library of the 30 priority taxa to assist identification and enable improved surveillance. Weed Spotters are provided with a Reference Manual and have the opportunity to attend training workshops. Six training modules were developed including; an introduction to Weed Spotters, plant biology, recognising weed alert species, hygiene health and safety, reporting weed alert species, and collecting and submitting plant specimens.

The results of the weed spread pathways risk assessment are shown in Table 2. The analysis produced a list of potential weed spread pathways ranked by relative risk score. A number of industries, (seed, aquarium, landscaping and nursery) and specific pathways (deliberate introduction via business, deliberate introduction via community and contaminated equipment, produce and vehicles) were amongst the highest risk for introducing these high priority weeds into Victoria (Thomas *et al.* 2007).

Table 2. Top 10 Weed spread risk industries and pathways.

Industry/Organisation	Pathway	Risk Rating	Rank
Seed	Deliberate introduction via business	0.894	1
Aquarium/pet shop	Deliberate introduction via business	0.893	2
Landscaping	Deliberate introduction via business	0.827	3
Public	Deliberate introduction via community	0.819	4
Nursery	Deliberate introduction via business	0.808	5
Landscaping	Contaminated vehicles	0.801	6
Aquarium/pet shop	Contaminated goods/produce	0.788	7
Earth moving	Contaminated equipment	0.787	8
Earth moving	Contaminated vehicles	0.770	9
Forestry	Contaminated vehicles	0.766	10

Source: Thomas *et al.* 2007.

Support for community led action

Seven compliance projects were carried out over three years on a range of established weeds in areas including the south west, north east, north central, central and eastern areas of Victoria. Species targeted were gorse, blackberry, serrated tussock and ragwort. The project also provided compliance support to regional projects targeting other species on a smaller scale.

The seven projects targeted areas where a relatively high percentage of land owners had failed to meet their obligations for weed control in the past. Inspections were carried out on 370 priority properties covering 19,797 hectares. Notices under the Catchment and Land Protection (CaLP) Act were issued to 314 land owners requiring them to take action on weeds. The first Priority Area Notice under the CaLP Act, covering approximately 100 properties, was also implemented under the project following Ministerial approval. Of the 27 land owners prosecuted in the Magistrate's Court, 18 were issued infringement notices (fines) and a further 14 land owners were issued official warning letters for lesser breaches of the CaLP Act.

The compliance projects generated significant media interest for the groups involved, allowing promotion of their efforts and key messages. Positive feedback was received from all groups supported, along with requests to be involved in any similar projects in the future.

Discussion

The five key stakeholders involved in TWoPL have a significant influence on successful weed management in Victoria. They have all contributed to weed management to varying degrees in the past and believe weeds to be a major problem that requires collaboration and additional resourcing. While key stakeholders were already aware, accepting or acting on their weed management responsibilities at the start of the project, participation in TWoPL has enhanced and built their capacity further.

Project learnings identified throughout the project are described in detail in the three project annual reports (Anderson *et al.* 2005, 2006, 2007). Learnings were used to inform continuous improvement of the project throughout its life with recommendations incorporated into the following year's program. Key learnings from TWoPL are outlined in the following discussion.

The analysis underpinning TWoPL practice change programs has been critical to success of project delivery. Analysis of industry and organisation structure, networks, size and influence as well as attitudinal information on barriers and drivers of change has been critical for understanding the current context and the type and scale of change required through stakeholder engagement. Sufficient time allocated to this type of analysis can provide a greater level of confidence both to the project investor and project manager that successful practice change activities can be delivered within the project management framework.

TWoPL experience in engaging with industry bodies and government agencies has found that initial meetings and dialogue at the executive level of organisations and industry to elicit support for intended engagement with their organisation is critical to the success of practice change projects.

The TWoPL partnership approach has confirmed that collaboration and partnerships between government, community and industry are essential to the success of weed management programs. The experience of the TWoPL project has shown it is possible to develop partnerships and collaborative activities with organisations. Critical to the success of TWoPL partnerships has been establishing trust, respect and dialogue with partners as well as agreeing on mutual benefit and allowing partners to participate in the shaping of policy.

For initiative projects with a focus on stakeholder engagement where productive partnerships have been developed and there is mutual benefit to maintain those partnerships, there is merit in considering planning to strategically exit from such projects. Relationships between DPI and TWoPL key stakeholders are benefiting from the production and implementation of the project Exit Plan. Project staff underestimated the complexity of developing an Exit Plan. During the project development phase, sufficient time should be allocated in the project work breakdown structure if it is intended to include a project Exit Plan.

Stakeholder groups were selected based on the best available knowledge at the time, of each group's relative risk for weed spread and their ability to minimise the impact of weeds through successful partnerships and increased weed management activities. It was recognised that there are a number of other key organisations and industries, which are likely to have significant potential for weed spread and therefore might be important stakeholders for future weed management projects.

The weed spread pathways risk assessment process was developed to provide a quantifiable assessment of the relative risk of weed spread through the activities of different industries and organisations. The results of the risk assessment have been used to inform the focus of subsequent Victorian Government initiatives including the $6.2 million 'Improving Provincial Victoria's Biosecurity' and $30.1 million 'Weeds and Pests' Initiative announced in May 2007.

The identification of new, high risk weed species to Victoria (Victorian Alert Weeds) required consideration of how to respond to the introduction of these weeds. There is no legislative requirement to control Victorian Alert Weeds; therefore, any management action is entirely voluntary. This situation requires the development of a 'Voluntary Removal Concept' for responding to Victorian Alert Weed introductions and incursions. The development of this concept has been included as a project deliverable in a new DPI initiative called Improving Provincial Victoria's Biosecurity.

Setting of targets for stakeholders' progression along the 'Triple A' continuum of Aware – Accept – Act was based on the assumption that the stakeholder surveys conducted at the beginning, mid point and end of the project would provide objective, quantifiable data with which to inform target setting (Baseline survey results) and to measure progress against these targets (mid and end of project surveys). The project team set targets based on their estimate of the increase in the Aware, Accept and Act ratings as measured at the Baseline survey which might be expected after delivery of the project activities. It is likely that these targets were set too high.

The Enhanced enforcement component of the TWoPL project, which effectively funded approximately 4.5 full time staff, was responsible for producing almost 23% of all DPI compliance actions on pests (briefs of evidence/ warning letters/ prosecutions/ infringements) over the three year period. More importantly, the subproject provided significant support to active community groups showing leadership in managing weed issues and assisted in protecting the investment of government and the much larger number of landowners meeting their responsibilities for pest control. The targeted mobile compliance approach has been shown to be an effective tool for supporting stakeholders that are actively working toward control of established weeds and also assisted in building the capacity of DPI to carry out compliance under the CaLP Act.

TWoPL communications activity played a role in raising the Department's reputation with industry groups, local governments and, to some extent, with regional communities. Communication materials and activities were seen as professional, high quality and well organised. Landscape Protection senior management and the DSE investor were generally very satisfied with the way in which they were kept informed about TWoPL and found it useful for advocating the project to external stakeholders.

Overall, TWoPL has progressed weed management in Victoria by building the capacity of key stakeholders to manage weeds and encouraging and fostering partnerships and collaboration that will last well beyond the life of the initiative.

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Innovations in spraying techniques, will they enable less herbicide to be used?

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Abstract This review considers innovations in the delivery, retention and uptake of herbicide sprays. The complexity of each, current knowledge limitations as well as future requirements needed to increase overall efficacy are considered. The lack of understanding of plant structure and how it affects form of deposit is poorly recognised but is a key determinant of outcome. Overall, satisfactory progress will not be made until appropriate models are developed for each process and integrated into a comprehensive agrichemical management system. It is surmised that implementation of such models will enable less herbicide to be used and a lowering of adverse environmental contamination.

Keywords: Spray application; formulation; efficacy; deposition; retention; uptake; translocation.

Introduction

The challenges facing users of herbicides today have increased in complexity over recent years. On the one hand consumers require the highest quality of produce whilst regulators insist on minimal product residues and risks to the operator and environment. Herbicide efficacy can be defined as the interactions of: delivery: interception: retention: uptake: translocation and active ingredient activity (Zabkiewicz 2003). Risk can be reduced by not using specific herbicides or reducing the amount used (Combellack 1989, Haas 1989). Such options can be implemented as demonstrated by the use of integrated weed control (Combellack 1989); the use of less persistent herbicides and lower frequency of herbicide use in cropping systems (Haas 1989) and through the introduction of genetically modified crops. However these are neither without cost nor controversy.

Regulatory requirements for herbicide use have increased but have been mainly aimed at reducing off-target effects. The requirement to increase biological efficacy and reduce detrimental environmental effects within the sprayed area can only be met by improved spray application and formulation technologies. They must be considered together because together they vary the proportion of product intercepted by and subsequently retained on the target plants. There are recognised challenges when selecting nozzles and spraying systems for specific applications. This has led to an awareness that these have to be considered in relation to the spray formulation, as droplet size can vary significantly with formulation when used with different nozzles or operating conditions (Butler Ellis *et al.* 2001, Combellack 2004). However, although some generalisations can be made, we are still a long way from being able to predict appropriate combinations accurately. In particular, the influence of plant surface characteristics on retention and uptake of herbicides is still poorly understood and may still be the dominant variable in some of the spray application/formulation/efficacy processes.

An illustration of possible overall herbicide efficiency for early and late spraying of a crop is given in Table 1. These estimates confirm what was emphasised previously (Combellack 1981) that the proportion of herbicide misplaced within the sprayed area is far higher than that lost outside. The estimates also show that spraying later results in reduced misplacement within the sprayed area. This is an important consideration if contamination of ground water is important, but as crop yields benefit from the early removal of weeds, optimal timing is contentious. Such estimates are also crucial in demonstrating where spraying efficiencies can be made. For example in the estimates presented, the amount of spray intercepted to that retained, varies with crop age due to changes in leaf area, phenology and surface structure when the same nozzle and spray is used. These figures would change if different nozzles were used. If droplet drift had to minimised then a coarser higher velocity spray would be an option. This can be achieved by either using a narrower angle flat fan nozzle, 65° to 80° rather than 110°, or higher flow rate nozzle 03 (12.5 m sec^{-1}) rather than an 01 (5.5 m sec^{-1}). The narrower spray angle increases droplet size as well as droplet velocity as do higher flow rate nozzles (see Table 4). Further droplet velocity can be increased by using selected adjuvants (Butler-Ellis *et al*. 1997, Holloway *et al*. 2000, Combellack 2004). Typically oil based adjuvants increase droplet size and velocity while non ionic surfactants reduce droplet size and velocity (Butler-Ellis *et al*. 1997, Miller personal communication, Table 4). A further option is to use a twin fluid or venturi nozzle as both can generate low velocity coarse spray. This is illustrated by the mean velocity for a twin fluid nozzle which was around 1.9 m sec^{-1} (Miller *et al*. 1990) compared to the 14.3 m sec $^{-1}$ for coarse spray using a 11008 flat fan (Miller personal communication, Table 4). The addition of a non-ionic surfactant will increase the droplet size of twin fluid nozzles but lower their velocity due to the induction of bubbles of air into the droplets (Miller *et al.* 1990). Slower moving droplets from such nozzles, particularly if generated with additional non ionic surfactant, are better retained on target surfaces covered in crystalline wax (Miller *et al.* 1990). These examples show that manipulation of droplet velocity and the physical characteristics of the spray can significantly change the percentage of the spray retained. However, to date, little or no consideration has been given to this aspect and its influence on the percentage of spray misplaced.

Studies on the efficiency of the spraying process have evolved from empirical tests and field trials to more detailed fundamental studies. Most attention has been focused on herbicides as they account for over half of all pesticides used (Underwood *et al.* 2001). The behaviour

Table 1. Estimates of herbicide destination at two growth stages of wheat if sprayed at 50 L ha^{-1}.

	% of applied	
Parameter	GS 13	GS 39
Intercepted [% which hits the target]	10	40
Retained [% intercepted less % reflected plus % retained by non target plants]	5	25
Taken up [%which passes through cuticle of target]	2	10
Effective [% of total applied that affects efficacy]	0.5	3
Misplaced within sprayed area	80	50
Lost outside sprayed area [mostly as droplets or vapour drift but can also be on soil or in water as run off or through soil profile]	10	10

and performance of spray formulations can be greatly influenced by the formulants and or adjuvants, either by affecting flow rate, droplet size, dynamic surface tension, spreading and wetting of foliage, or the resultant form of deposit, influencing uptake and translocation.

Delivery

There have been a number of changes in sprayer design to accommodate user demands. In Australia, average sprayer speed is now around 20 km h^{-1} and with a few spraying at 40 km h^{-1}; average boom width is now over 25 m and with many at 40 m; tank volume is mostly over 5000 L with a few at 10,000 L; and many sprayers are now fitted with twin booms to accommodate a wider range of sprayer speed. These demands have meant that droplet drift is exacerbated because as sprayer speeds increases detrainment of droplets, hence drift, increases (Nilars 2002, Nuyttens *et al*. 2006) in part because 110° nozzles remain the most popular when it has been clearly shown that 80° nozzles generate much less droplet drift (Nilars 2002).

Wider booms mean that boom movement, particularly in the horizontal plane, can be worsened with increasing speed leading to less uniform deposition due to the ends of the boom virtually stopping, thus increasing deposition, and then accelerating, hence lessening deposition.

While there are twin boom sprayers that can have either or both spray lines delivery the solution there are few nozzle combinations that can be used to maintain the same spray quality when switching from one line to the other or when using both at the same time. In most instances a doubling in flow is required before any change can be effected and such a pressure change varies the spray quality with most hydraulic nozzles, but the user has no knowledge of this.

There have been no tests to determine mixing efficiency in large tanks, but it is considered unlikely that dispersions of dry flowables are within the ±15% current ENTAM [EN 12761-2:1.1.1.5 Mixing] requirement (Ucar *et al.* 2000). Recently direct injection equipment has been introduced in part to overcome the challenge of even mixing, but advice about its limitation is often not proffered. For example, users are not advised that not all formulation types are suitable. For example dry flowables tend to settle out when mixed, thus unless a mixing device is included in the concentrate container hence the delivered concentration may vary with time; with suspension concentrates viscosity increases with decreasing temperatures making it difficult to transfer them from the drum to the concentrate tank; or that the time taken to reach the nozzle from the point of entry can be as much as 20 seconds. The sprayer will have travelled over 100 m if moving at 20 km h^{-1} (Stafford and Miller 1993). Additionally decontamination of the injection system can be difficult. Such systems do have advantages in that concentrates can be returned to the container if not used; if the weather during spraying becomes adverse the tank will not contain unused spray mixture; decontamination of the tank, the main pump and lines may not be required;

The complex interaction of boom width, tank size, sprayer speed and application volume on the time it takes to empty a tank are given in Table 2. A user should aim for a minimum of one hours spraying time as often filling/ferrying can be equally as long. A simple program is required showing these interactions so as to enable a person purchasing a sprayer to select appropriate tank size/sprayer speed/ boom width combinations on a more assured basis.

Considerable attention has been given to the physical process of spray delivery and its off-site component, 'drift'. The basic determinants are droplet size, droplet velocity, release height and meteorological effects. Since fall distance is also greater for wider booms, typically 600 to 700 mm, droplet evaporation can be an issue when spraying in summer, leading to potentially more drift. Hence a simple selection of nozzle type and droplet size may be inadequate. In this case the addition of anti-evaporant or anti-drift agent (both intended to maintain or increase droplet size) has been exploited. A real-time meteorological system could additionally prevent application when the wind direction and or thermal air movement are inappropriate. Easy to say but difficult to implement or justify economically. Perhaps the ultimate solution is real-time interactive spray formulation production, based on operating conditions and location of the applicator within the spray zone. This may sound esoteric, but smart systems such as these have been suggested and are under consideration for ground based application systems (Ganzelmeier 2005).

Ground based application systems have focused on nozzle selection and application criteria, through a more prescriptive approach, than through optimisation of application models. However, this may be changing, as concerns develop over eco-system loading, herbicide persistence, run-off from arable systems into irrigation ditches or waterways, movement through soil profiles into underground water and or contamination of bystanders. It has been pointed out that physical application and formulation factors need to be tailored to specific applications (Miller *et al.* 2001). In the case of ground applications, droplet drift effects are typically in the order of a few metres, compared with the hundreds of metres possible with aerial applications. However, this may in turn generate a higher pesticide deposit per unit area, and if close to water bodies, exceed permitted levels or be a risk to soil and aquatic organisms or hazard to bystanders (Mathers *et al*. 2006). One proposal is that spraying at field edges should be through nozzles that produce coarser droplets. This could again be semi-automated or under the control of the operator. Though this would improve deposition on-site, it may not do so on-target, as it is well known that there is less retention of larger drops by (hard to wet) plant foliage. It is possible that a deliberate change in formulation during application, such as the addition of adjuvants, could be a solution.

One further aspect of drift mitigation that has been investigated experimentally and theoretically, is the use of windbreaks or shelterbelts. These are common in orchard situations, but less so in other agricultural sectors. However, their value as a spray drift mitigating option is becoming recognised as it is found that spray drift can be reduced to less than a percent of in-swathe deposition (Ucar and Hall 2001, Brown *et al*. 2004). However, although it is recognised that interception efficiency varies with shelterbelt material or dimensions, the factors contributing to this with live shelterbelts is still poorly understood

Adhesion, retention, distribution

There have been a few studies of spray retention by crops throughout their growing season aimed at quantifying soil deposition rather than spray efficacy effects (van de Zande *et al*. 2003). There have also been a number of other studies to measure spray retention by crops. For example the effect of changing droplet trajectory on retention by wheat and barley (Combellack and Richardson 1985); the effect of hydraulic nozzle size on retention and efficacy on weeds and wheat (Dempsey *et al*. 1985, Moerkerk and Combellack 1992); nozzle type and spray volume on retention by weeds and crop (Ayres *et al*. 1985); effect of adjuvants on the location of herbicide

Table 2. Effect of tank size and application volume rate on time (Hrs) to empty tank using 30 m boom at 25 km h^{-1}.

	25 L ha^{-1}		50 L ha^{-1}		75 L ha^{-1}		100 L ha^{-1}	
Tank size	Ha	Hrs	Ha	Hrs	Ha	Hrs	Ha	Hrs
2500 L	100	1.07	50	0.33	33.3	0.22	25	0.17
5000 L	200	2.13	100	1.07	66.7	0.44	50	0.33
7500 L	300	3.20	150	2.13	100	1.07	75	1.07

deposits on weeds (Wynen and Combellack 1992); retention on peas, beans and barley (Holloway *et al*. 2000). Though such studies give guidance for improved retention for some arable crops, they are not applicable for all crops in all situations. Hence, correct formulation properties are essential to provide biological efficacy.

It is well known that small droplets (>50 µm diameter) will adhere to plant surfaces but larger droplets (250 to 500 µm and upwards) can rebound or shatter (Hartley and Brunskill 1958). Since small droplets are prone to drift, we have the classic conundrum of how to achieve maximum adhesion/retention, with minimum drift. The situation is complicated by different crops and weeds, as well as the herbicide, having different optimal requirements because of differences in surface structure (Harr *et al*. 1991). The 'wettability', as measured by the droplet contact angle of upper vs lower surfaces, varies between species (Harr *et al*. 1991, Forster and Zabkiewicz 2001). This implies that not only adhesion/retention will vary, but also droplet spread after adhesion will vary. Data shows that reflective surfaces are typically dominated by crystalline wax platelets and those that are less reflective by smooth wax (Harr *et al*. 1991).

Initial retention is dependent on physical processes comprising three competitive forces: inertial, surface tension and visco-elastic. These are best described by three characterisation parameters: Reynolds No. = ratio inertial/visco-elastic forces; Weber Number = ratio inertial/surface tension forces and Capillary number = visco-elastic/surface tension forces. A model for primary adhesion that omits the physical forces has been suggested (Forster *et al*. 2005). It considers the influences of leaf surface character, droplet velocity and spray solution dynamic surface tension. Similar plant and spray solution parameters are involved in retention models (Grayson *et al*. 1993, Forster *et al*. 2004a) but such models are for specific crop types and plant phenology (which still requires better characterisation), and do not embrace the three competitive forces, so a universal model does not yet exist.

These retention models are also limited because they do not include droplet velocities which vary with nozzle type, size and formulation nor the three competitive forces (inertial, surface tension and visco-elastic) on impact. In the case of field crop sprayers or air-assisted systems, droplet velocities may be higher than terminal, so primary retention interactions will be different.

Practical solutions which have met with some success, are the addition of 'stickers', which are generally high molecular weight additives, providing greater viscosity or visco-elasticity to reduce droplet rebound. Although providing better adhesion, such

Table 3a. Summary surface features monocotyledons (Adapted from Harr *et al*. 1991).

		Hairs mm^2		Stomata mm^2		Contact angle°	
Species	Wax	Upper	Lower	Upper	Lower	H_2O	NIS
Agropyron repens	xlline	1.8	5.1	4.6	0.7	R	84
Alopecurus myosuroides	xlline	1.2	0.2	3.1	2.0	R	119
Apera spica-venti	xlline	1.1	0	3.3	1.0	R	R
Avena fatua	xlline	0.7	0.1	1.6	1.2	R	84
Brachiaria plantaginea	xlline	0.1	0.5	7.4	4.3	R	79
Bromus secalinus	xlline	0.4	1.8	2.7	1.3	R	84
Cynodon dactylon	xlline	0.5	0.3	2.5	0.6	R	77
Cyperus rotundus	smooth	0	0	0	3.8	<20	<20
Digitaria sanguinalis	xlline	0.7	0.8	1.2	1.0	R	93
Echinochloa crus-galli	xlline	0.1	0	3.6	2.9	R	82
Panicum dichotomiflorum	xlline	0.1	0	4.3	3.1	R	85
Poa annua	xlline	0.8	0	3.9	0.9	R	R
Setaria faberi	xlline	0.2	0	4.2	2.5	R	84
Sorghum halepense	xlline	0	0	2.3	2.6	R	74

Legend: R = reflected; NIS = 0.1% Sandovit (surface tension 30 mN m^{-1}).

Table 3b. Summary surface features dicotyledons (Adapted from Harr *et al*. 1991).

		Trichomes mm^2		Stomata mm^2		Contact angle°	
Species	Wax	Upper	Lower	Upper	Lower	H_2O	NIS
Abutilon theophrasti	smooth	0.4	1.4	2.1	1.8	66	51
Amaranthus retroflexus	smooth	0	0	1.8	2.5	71	54
Capsella bursa-pastoris	smooth	1.1	0.7	2.5	3.2	99	55
Cassia obtusifolia	xlline	0	0	1.4	3.9	R	79
Chenopodium album	xlline	0.6	1.3	0.4	0.3	R	76
Datura stramonium	smooth	0.1	0.4	0.3	0.3	87	56
Gallium aparine	smooth	0.4	0	0	0.4	90	58
Ipomoea purpurea	smooth + ribbed	0.1	0.1	0.2	0.4	var	var
Polygonum lapathifolium	smooth + filamentous	0	0	0.4	0.4	99	57
Portulaca oleracea	smooth	0	0	3.9	1.8	78	58
Senecio vulgaris	smooth	0	0.1	0.9	2.8	81	62
Sida spinosa	smooth	5.3	4.1	1.8	5.5	<20	<20
Sinapis arvensis	smooth	0.2	0.4	7.5	0.7	88	55
Solanum nigrum	smooth	0.2	0.4	0.3	0.6	78	34
Stellaria media	smooth	0	0	0.5	0.4	100	47
Xanthium orientale	smooth	2.2	2.1	2.0	3.9	<20	<20

Legend: R = reflected, var = variable, NIS = 0.1% Sandovit (surface tension 30 mN m^{-1}).

Table 4. Effect of nozzle size and formulation on droplet velocity (m sec^{-1}).

	Nozzle		
Spray	11001	11003	11008
Water	5.5	12.1	14.3
Water +Agral	4.0	11.6	14.0
Water + LI700	8.2	14.3	16.1
Water + Axion	6.0	11.9	13.8

additives may not be very useful where good foliar coverage is essential, as this would again require small droplet production and potentially increase drift.

An alternative approach may be the opposite strategy, which is the use of additives to make larger droplets shatter on impact with the leaf, and create smaller droplets *in situ* within the canopy. This would be an elegant solution to spray drift but may only be applicable to certain canopy types. These adhesion enhancing adjuvants may give not only good adhesion/retention, but by their nature also cause droplet spread. A further possibility is to fill the droplet with air bubbles using twin fluid or air induction nozzles and appropriate adjuvants (Combellack and Miller 2001) thus reducing impact velocities and reducing rebound forces to improve adhesion.

Though adhesion and retention properties can be modified substantially by adjuvants, their influence on subsequent performance must also be taken into account, in particular their effect on uptake and translocation.

Uptake and translocation

It was postulated several decades ago that there could be mass flow of spray solution into leaves through their stomata (Schonherr and Bukovac 1972, Green and Bukovac 1974). The latter authors found that there was evidence of stomatal infiltration after just two minutes of exposure albeit in only 0.5 to 4.4% of stomata. Stomatal penetration was achieved in practice in the 1980s (Field and Bishop 1988, Stevens and Zabkiewicz 1988) through the introduction of organosilicone surfactants. However, this mechanism is not effective generically for the reason that not all plants have stomata on upper leaf surfaces or the size of the stomatal pore is too small or upraised. Furthermore, under stress, stomata close, which also occurs at night making spraying at this time less reliable with some products. .

Various aspects of cuticular structure in relation to the fundamental mechanisms of uptake have been considered (Riederer and Markstadter 1996). More recently reviews of the mechanisms involved have been published. Kerstiens (2006) reviewed water transport in plant cuticles and concluded that cuticles act as a solution-diffusion membrane for water. Schonherr (2006) concluded that ionic polar compounds rely on dipole-dipole, valency and electrostatic interactions to enable passage of herbicides across cuticular membranes through structures called aqueous pores. In his review of sorption and diffusion of lipophilic molecules in cuticular waxes Schreiber (2006) noted that accelerators, selected alcohol ethoxylates and n-alkyl esters, did not solubilise crystalline wax but enhanced pesticide transfer across cuticular wax by plasticising the amorphous wax fraction. Bucholz (2006) considered the role of the lipophilic pathway for diffusing non-electrolytes across plant cuticles and concluded, as others have (Schonherr and Baur 1996, Kirkwood 1999, Schonherr 2006), that there are three steps involved: sorption into the cuticular lipids, diffusion across the cuticular membrane and finally desorption into the apoplast of the epidermal cells.

However, there is a much simpler effect on the leaf surface that needs to be considered. It has been known that in the case of herbicides such as glyphosate, higher concentrations, or lower carrier volumes (essentially higher concentrations also) can improve uptake. If a spray formulation contains adjuvants that cause droplet spread on a leaf surface, this will in effect lower the mass of active per unit area, without any change in solution concentration until the spray droplet begins to evaporate. Ultimately there will be a 'solution residue', where the concentration of the active bears no resemblance to the starting spray solution concentration (Zabkiewicz 2003). It has been found (Forster *et al*. 2004b) that this solution residue or 'initial dose' (ID) can be related to the mass uptake of pesticides with different lipophilicities, in combination with different surfactants and on several plant species. This relationship has been validated with a wide range of formulations and plants, representing typical field rates and formulations (Forster *et al*. 2006).

Transport through the cuticle is considered to be a three stage diffusion mechanism. Namely absorption into the cuticle, diffusion through the cuticle and finally desorption from the cuticle into the internal leaf cells (Kirkwood 1999, Buchholz 2006, Zabkiewicz 2006). The principal factors affecting uptake rates of non-electrolytes are:

Solute mobility: which is affected by temperature, solute molar volumes, and cuticular wax composition.

Limiting skin: or the limiting skin tortuosity which is the length of the diffusion path through the 'limiting skin'. This is only a proportion of, and not the entire cuticle, and is influenced by the size and orientation of the cuticular wax crystals.

Driving force: which is affected by the starting and continuing concentration of a.i. in the 'solution' on the cuticle surface, in the cuticular layers, and in the epidermal cell wall. Overall, in simple terms:

uptake = solute mobility × cuticle tortuosity × driving force.

Adjuvants have been classified into 'accelerator' and 'passive' categories, and it is probable that they will affect each of these terms. The results of Forster *et al*. (2004b) would indicate that the driving force (related to the initial dose) is dominant in typical plant systems using accelerator adjuvants and hydrophilic to moderately lipophilic herbicides. However, it is unlikely to be predominant in all situations and all plant species. Therefore a much better understanding of plant leaf cuticular structures, as well as structure activity relationships for adjuvants, is still required to progress to a successful quantitative model of uptake.

Translocation has received the least attention, though long distance transport has been well studied and reviewed (Price 1976, Price 1982, Coupland 1988). In the case of foliar applied herbicides, it is known that lipophilicity is important, as these compounds have to cross hydrophobic membranes or structures other than the cuticle proper (Schreiber 2006). Hydrophilic molecules are readily transported in either the phloem or the xylem, though their initial movements through the cuticle, epidermal cells and into the mesophyll are not well understood (Devine and Hall 1990). The presence of separate 'hydrophilic' and 'lipophilic' pathways as part of the uptake process, may in turn determine the efficiency of the subsequent translocation pathway, but it is also difficult to define when uptake becomes translocation. Adjuvants are known to facilitate cuticular 'transport' (foliar uptake) but are not thought to play any significant part in further short or long-distance translocation processes. However, in theory, if adjuvants could reach the cellular plasmalemma, then they could affect the initial stage of the sub-cuticular transport process. The advantage of the mass uptake relationship developed recently is that it can provide information akin to that used for drug delivery dose prescriptions. Knowing the mass uptake, an estimation can be made of the mass translocated in specific systems; with subsequent studies on the influence of physiological and environmental influences, appropriate 'dosages' could be applied at specific growth stages or conditions. It can also be used to estimate the change in overall efficacy of spray formulations, as to date no generic quantitative relationship had been identified.

Conclusions

The future focus in the use of pesticides should be on delivery of the active to the target site, which is not the total planted area, but the plant(s) within it, by using appropriate formulations and droplet characteristics to control spray distribution, uptake and translocation (if required). It would seem that due to the complexity of the system, it is inevitable that this can only be completed through the development of computer based decision support systems. This in turn requires the development of models for each of the processes.

Deposition into target areas can be modelled, though this approach is not used much by most of the primary sectors. The requirement to place deposits onto specific parts of a plant, or all over a plant, needs to be addressed through a much better approach to modelling retention (instead of empirical data sets) which in turn requires a better description of plant development and (foliar) surface characteristics. The principal factors controlling foliar uptake appear to be solute mobility in the cuticle, cuticle tortuosity and solute driving force. Apart from the last factor, the other two are poorly understood and not easy to measure. Whole plant translocation models exist, but it is the short-term or short-distance controls that need to be elucidated and related to the initial mass uptake.

More complex models of uptake or total pesticide efficacy are being developed and show promise (Satchivi *et al*. 2000a,b, Lamb *et al*. 2001), but their universal applicability and acceptance will not occur until the input parameters have been substantially simplified or can be measured easily. At present, as with all models, their greatest value may lie in identifying the gaps in our knowledge, so that we focus on the most important elements

The integration of spray deposit profiles within geographic information systems can provide information that can be subsequently related to pest or weed competition levels, crop productivity and cumulative residue profiles. The development of a comprehensive decision support system (DSS) has the further benefits of providing tailored sub-sets of information that can be used by individual operators, for operational optimisation, such as selection of appropriate pesticides or application technology and maximising on-target deposits. This DSS can in turn become part of an agrichemical management system, which can be applied on a local, regional or national scale and related to long term pesticide eco-system interactions. It is suggested that implementation of such a system will enable less herbicide to be used and a lowering of adverse environmental effects.

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Prioritising roadsides and reserves for weed control in the Shire of Yarra Ranges

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Summary The Shire of Yarra Ranges is responsible for managing over 3000 sites (reserves and roadsides) spread across a large and diverse landscape that contains a wide variety of ecological and social values. The Shire's Weed Management Strategy (2005) recognised many limitations in adopting a species based approach to weed management for its bushland areas, particularly given the vast majority of weed species encountered were not listed as Noxious.

A site based approach rather than species based relies on the ability to prioritise a large number of highly variable sites. With a lack of existing mechanisms to do this prioritising, the Weed Management Strategy developed the Threat Matrix, designed specifically for this task. The Threat Matrix gives value to a range of descriptors for each site, some of which are held within existing GIS layers, others collected in the field.

The methodology and collection techniques are not difficult and do not involve specialist or expensive equipment. A large number of sites can be surveyed in a relatively short period of time, providing a very useful dataset of information that gives the ability to 'see' the whole Shire in a much more holistic way. Only by having the data describing and comparing all the sites in one place, can well informed decisions be made. Additionally, the resulting 'snapshot' can be used as a monitoring function in the future to critically appraise weed management progress.

Introduction

The Shire of Yarra Ranges hosts some of the most important biodiversity assets in Victoria. It is home to all three land based State emblems (common heath, Leadbeater's possum and helmeted honeyeater) and contains critical habitat for many endangered and endemic species. The Shire covers 2472 km^2 which takes in the eastern urban fringe of Melbourne (Lilydale to Belgrave), the Dandenong Ranges, significant agricultural lands including the Yarra Valley winery region and large areas of state forest, National Parks and Melbourne's water catchments. The Shire covers the upper 51% of the Yarra catchment and 10% of the Dandenong catchment which flow into Port Phillip Bay.

The problem of how to allocate a weed budget across such a large and varied municipality as the Shire of Yarra Ranges was what led to the development of the Threat Matrix. The Shire's Weed Management Strategy (2005) noted that reserves and roadsides were valued for a wide range of reasons, but that the protection of biodiversity was the most significant reason for weed control works.

In such a large municipality, and with thousands of sites (reserves and roadsides) the Shire is responsible for managing, it is a very difficult task to adequately manage such a diversity of sites without a database describing – and putting values to – each of the sites concerned and their own individual values.

During the process of writing the Weed Management Strategy, an innovative method of prioritising all these sites was developed, the Threat Matrix. The Threat Matrix gave weighting to a range of 'values' each site possessed, from ecological to social, that could be measured either in the office or in the field, and by assigning value scores to these, has resulted in a unique way of providing a ranking score for each site.

By combining the new Threat Matrix scoring with the current State-wide system of 'Habitat Hectares' (describing vegetation quality), a site valuation methodology has been developed that can be used to assist the allocation of resources across the Shire's sites and to recognise the value in weed control.

The field assessment has also assisted with other projects with weed relevance (schools programs, community engagement, education etc) and when combined with statistically targeted mapping done with the GPS, allows monitoring mapping of weed populations which assists with evaluation of on ground management practices into the future.

Materials

The Threat Matrix site prioritisation system requires very little in the way of physical materials beyond a computer and datasheets, it is more a matter of the information that it is based on that is of importance.

Part A of the Threat Matrix uses 'desktop' information accessed via computer while Part B is based on field assessment data. In the case of implementing this at the Shire, the desktop information was gained from the Shire's GIS Intramaps system, but for other users this may include publicly available internet based layers (e.g. DSE MapShare, Victorian Resources Online, Viridans, Google Earth etc) that help describe the sites in question. The field assessment only needs a field datasheet, but does require the knowledge of how to do a Habitat Hectare assessment and the ability to identify weeds.

The information collected from Parts A and B were (initially) collated onto an Excel spreadsheet, but other database systems could also be used.

Project development and methods

How the Threat Matrix was developed

In developing a system to prioritise and rank sites, an evaluation was carried out of what information was available that could usefully describe the sites as well as what could reasonably be expected to be collected. Each type of information to be used was given a weighting in terms of its importance in the overall value of the site and following field testing of the scoring, some adjustments were made. (It should be noted that the system can be modified to suit whatever information is available and the values given to different descriptors is subjective so could be changed to give more weighting, for example, to social values instead of ecological values). Care was taken to balance values that applied to one type of site but not others (e.g. roadsides but not reserves), to avoid unfair weighting to sites with additional descriptors (e.g. one descriptor – Roadside Conservation Significance, only applies to roads).

To avoid the necessity of field visiting all 3000+ sites, but at the same time not wanting to leave any out of the analysis, the Threat Matrix was divided into two sections, Part A and Part B (as described above). Initially it was hoped Threat Matrix Part A (TMA) would be a coarse filter, using values that could be auto-generated from existing GIS layers. Threat Matrix Part B (TMB) would then provide additional filtering with additional information collected from site visits to only the best sites identified in TMA. However, the Part A assessment alone proved far less predictive with some sites with excellent vegetation quality getting poor scores (due to being a common Ecological Vegetation Class – EVC) while some poor quality sites gained high scores due to having an Endangered EVC – even if it was now a mown football ground).

As a result, the process of putting sites through TMA became a manual one as did the method of reducing the overall number of sites to something manageable. This was done through manually checking aerial photographs of all 765 reserves and removing those that did not appear to have enough vegetation to warrant Shire contractors carrying out weed control. The list of 2234 roadsides was cut using the Roadside Conservation Significance GIS layer, so all 'High' and 'Very High' conservation roads were retained on the list while 'Medium' and 'Low' were removed. Some additional sites also made the list that were currently being managed for other reasons or under separate programs.

Threat Matrix Part B (TMB) assessments made in the field became a fairly quick process with an average 10–25 sites a day able to be visited and assessed. The Habitat Hectare sheet established by the DSE was streamlined to a faster version to speed up this assessment, while maintaining its comparative value to the state system. Field assessments provided vegetation quality (HabHa score), an overall weed cover score (from HabHa score sheet) and a basic weed list. The weed list was a simple presence/ absence list of what was on site. This information was not required for the TM ranking, but has proved valuable for coarse scale weed mapping and as a reminder of what is on each site.

The final database

An Excel spreadsheet database was set up with the information collected including:

- Site location details
  - Name of reserve, address, suburb/ town
  - Melway ref
  - Shire of Yarra Ranges (SYR) GIS site identification code
- Area (ha for reserves) or length (km for roads) of site
- Area of vegetation on site or the area as described by the assessment (e.g. site may have sports ovals, car park, buildings etc. that are not included in this total)
- Threat Matrix A information
  - Botanical or Zoological Significance Overlay (from Planning Scheme)
  - Roadside Conservation Significance (RCS) score
  - EVCs and threat level (e.g. Endangered, Rare, Least Concern etc)
  - Land adjoining the site (agricultural, urban, forest, river, National Park)
  - Importance as a corridor (habitat connection)
  - Edge score (ratio of edge length to site area)
- Threat Matrix B information from site visit
  - Habitat Hectare score (vegetation quality)
  - Overall % weed cover (from Habitat Hectare score – see discussion below)
  - Weed species present on site (1=present, 0=absent/not observed)
- Threat Matrix A + B scores (to give site ranking)
- Additional field notes
  - 'Nutshell' description of site, main features
  - Management comments, possible priorities, time needed
  - Additional site location information and access difficulties

As the database has developed, additional information has been added including:

- 'Friends of'/community groups working on site
- Budgets for weed work
- Contractors work carried out
- Mobile phone coverage (for OH&S, to see where coverage extends)

Results and discussion

The 'weed mapping project' (as it was known, which was more accurately a site prioritisation project) began on 6 February, 2006. The project was delivered by David Blair from 'Our Common Ground' as a consultant, working full time for the first six months and part time for the remainder until funding ceased on 30 June, 2007 when the project ended.

Main achievements

- 3000 sites of Shire managed land listed (2234 roads, 765 reserves)
- 600 sites field assessed for:
  - Threat Matrix score (site values and budget allocation tool)
  - Vegetation quality
  - Weed cover and weed species present
- 'Top 20' list of most common weeds across the Shire produced
- Integration of weed distribution and threat knowledge with other programs
- Raising of SYR profile as 'leading the way' in weed management and initiatives
- Enhanced environment and increased cost effectiveness due to more strategic locating of control works
- Benchmark data for Habitat Hectare scoring collected
- Greater ability to receive grants and funding due to proven strategic approach
- Greater ability to work with State agencies in weed control, data sharing capability

The data gathered provides a suite of information that can be used for a wide range of purposes. The primary purpose of developing this spreadsheet has been the need for the Shire to make strategic decisions around the prioritisation of sites for contractor action and budget allocation. However the spreadsheet is capable of much wider analysis - it can be 'sorted' to manipulate the data in a number of interesting ways that allows a better understanding through creating various 'big pictures' of the Shire and its assets.

For example, see Table 1.

Ranking sites – triple bottom line

All 600 sites are now ranked with a combined TMA/TMB score, ranging from 1 (least valuable site) to 44 (most valuable – note, the TM is an open ended scale, so if additional data fields are used, scores for these same sites could be higher). This gives a clear ranking that, given the range of environmental and social values considered important, each site can now be judged against all others across the Shire to determine the relative value of each site in an environmental and social way (through TM) as well as an economic way (site value – see below). This has assisted

Table 1.

Spreadsheet sorted by:	Analysis possible:
Threat Matrix score (A+B)	Prioritise all sites for their 'value'
Weed species	▪ Coarse scale maps of weed locations showing: o Identification of 'new and emerging' species o Distribution analysis, how widespread different species are ▪ Assist with management (know what spp are on site) ▪ Assist community group enquiries re spp. present ▪ 'Top 20' most common weed species list ▪ Track spread of weed species over time
Weed cover	Proportion of sites under different weed loads
Locality (town/suburb or electoral regions, Melway ref)	▪ Which areas have working community groups ▪ Distribution of resources ▪ Weed loads (% cover × area of land) ▪ Weed species in certain area
Habitat Hectares	Total # Habitat Hectares, therefore monitoring of weed cover provides possible evaluation of management strategy success through time
Budget allocations	Distribution of resources, how this relates to TM score

with directing *where* resources for weed management should go.

Vegetation accounting – NVMF
It was found that across the 600 sites (which cover 1332 ha of forested land) there were a total of 609 Habitat Hectares. This was the first time this had been measured for the Shire and therefore set a benchmark to see if the Shire is achieving a 'Net Gain' as described under the State Government's 'Native Vegetation Management Framework'. This method of vegetation accounting will increasingly be used across the State and to have this baseline information will be valuable for many future planning and vegetation management aspects of the Shire's work or for the setting up of a 'Bush Broker' system.

Bush Broker – Vegetation offset trading scheme Under the 'Native Vegetation Management Framework', development in Victoria requires an overall 'Net Gain' to be achieved in vegetation quality or quantity. An improvement may not always be possible on the site where the development is to occur, therefore some landholders may choose to trade vegetation offsets. The Bush Broker system was developed to allow the trading between those who have made 'habitat gains' and those who need to offset what 'habitat losses' their development has resulted in.

Site values and predictive budgets
Placing dollar values on environmental sites is notoriously difficult – but this is effectively what is demanded of the Vegetation Management Officer who must decide how to divide an overall budget for bushland maintenance over hundreds of sites. The modelling produced by this TM analysis does not attempt to put overall values on these land assets, however with the information now gathered, the overall weed budget can be divided amongst the sites using a combination of what the site has (size and vegetation quality) and how important it is (through the TM scoring).

The budget/site data can be manipulated in a wide variety of ways. An example of this is given by the following:

- Site value
- Predictive budget

Site value This should not be confused with the amount that needs to be spent on each site as it only looks at what a site is worth as a proportion of the overall weed budget, not what it needs to control its weeds, nor what the site is 'worth' ecologically or socially. This value can assist with budget allocation, but there are both external variables and inaccuracies within the model that require actual budgets to be set for each site taking these additional variables into account, the most obvious being weed cover – see example below.

The site value divides the total weed management budget by the number of Habitat Hectares being managed across the Shire. In this way large sites or sites with excellent vegetation quality gain more funding than smaller/poorer quality sites (Equation 1).

The site value can then be further adjusted using the Threat Matrix scores, thereby giving extra weighting to our 'best' sites ('best' due to all the various values weighed up in the TM calculations – ecology, social, safety etc) so the concentration of value is on the better sites, with less on the poorer sites (Equation 2).

Cascading budget The original intention of the Threat Matrix ranking of sites was that in the first year, the best sites (whatever proportion of the overall number of sites that ends up being) would have weed control carried out on them. The following year, given some of the best sites are now under control, the budget can spread further down the list, picking up the next best sites that were missed in the previous year. The intention was that over time, the best sites took less and less to maintain so the budget could cover an increasing number of sites. In this way the budget savings from having better vegetation quality on the top sites, 'cascades' down the list.

If it is found the budget was not reaching down far enough, or a greater proportion of the overall list needed to be covered, the TMA/B 'average' can be adjusted (to a higher number) to allow the budget to reach further down the list.

Rather than trying to estimate what each site:

a) **deserves** (how significant it is from an ecological and social perspective) and then trying to work out therefore what it
b) **requires** (dependant on weed loads and area to be weeded)

This system would provide a budget that fitted the importance of the site and what it had on it to protect. It made no allowance for the current weed loads and therefore how much work was required to control what was there. For some sites the budget allocated would allow only for coarse control of the very worst mature weeds (i.e. sites with very high weed loads) while others will be 'clean' before the budget is spent (i.e. sites with very few weeds).

The allocations suggest what each site was worth from our Habitat Hectare/Threat Matrix point of view. In cases where the site was in good condition and little needed to be spent (but a healthy budget was available), the extra budget 'cascaded' down to the first sites under the 'cut off'. Given large budgets are found at the top of the list (where the best sites are) and sites at the bottom of the list have smaller suggested budgets, excess from good sites would most likely be spread across several sites, doing a little on each (coarse weed control). In this way, over time, as better budgets become available for these lower sites, the coarse scale containment of the worst species would have been done, and a finer scale of control works (which takes greater time/budget) could be implemented. But budgets are always kept in proportion to the values of the site.

The primary problem with this method was that it required the field contractor to make the decision when to stop and move on to the next reserve and to keep a record of how much budget would then cascade down if it had not all been spent. To overcome this problem, a 'predictive budget' was produced which attempted to use the site values combined with the weed cover to predict what might be spent on each reserve (Equation 3).

Weed cover is scored as <5% weed cover = 0.05, 5–25% weed cover = 0.25, 25–50% weed cover = 0.5, >50% weed cover = 1.0. The Budget balancing coefficient is the number required to make the total for all sites (or however many you wish to spread the budget over) equal the overall budget. It is likely to be around 5, depending on how weedy the sites are.

Equation 1.

$$\text{Site value (HabHa)} = \frac{\text{Overall budget}}{\text{Total Habitat Hectares}}$$

Equation 2.

$$\text{Site value (HH and TM)} = \frac{\text{Overall budget} \times \text{TMA + TMB score for site}}{\text{TMA + TMB 'average' for all sites*}}$$

*Note that the figure used for the TMA + TMB 'average' for all sites is really just a coefficient that makes the books balance. This value can be varied to give greater or lower value to all sites which could allow for more or fewer sites to be covered by the available budget, for example if these figures are used as predictive budgets. If the 'average' is increased arbitrarily (e.g. to 22), the budget will be spread over more sites, conversely, if the figure is lowered (e.g. to 15), the same budget would cover fewer sites (or a greater budget would be needed to cover all sites).

Equation 3.

$$\text{Predictive budget} = \text{Site value} \times \text{Weed cover \%} \times \text{Budget balancing coefficient}$$

Weed cover scoring It is worth noting that the weed cover scores were all obtained from the Habitat Hectare scores which assume any non-indigenous vegetation to be a 'weed'. Obviously many exotic plants will not be treated by SYR contractors – they may not be serious enough to warrant treatment or they may be part of landscaping, gardens or playing fields/lawns. A better method (see future directions, below) would be to record a second weed cover score, just for those species contractors are likely to treat. This will give a much more useful value to this predictive budgeting.

Minimum site budget For sites on the lower end of the scoring system, their predictive budget allocation may be as little as a few dollars. Obviously contractors could not even drive to a site let alone carry out control work on these sites for that amount, so the setting of a minimum budget (e.g. $200?) is recommended, so all sites with predictive budgets lower than this be allocated this amount of money (Table 2).

Separate budget items – other works, new and emerging weeds and requests Given there are numerous pressures on the weed control budget, some of which arise throughout the year (new found or seasonal outbreaks, responses to residents, unforseen events, control of 'new and emerging species' etc), as well as other works such as revegetation, fencing or signage, it may be prudent to keep a proportion of the budget aside for general works not related to the core weed management. This could be a set % of the overall budget, it could be budget that has 'cascaded' down from the original list, or is separated in some other way.

This separate budget would allow a predetermined amount to go to contingencies so the primary control work is not compromised from requests, but similarly to ensure that these requests are not ignored.

Example of budgeting (Table 2) The two reserves in Table 2 have the same TM value. The table shows that one reserve (Everard Park) is valuable because it has an Endangered EVC and is popular for recreation, despite having high weed loads and poor vegetation quality. The other reserve (Wards Road), is highly valuable due to its excellent vegetation quality. However despite Wards Road Reserve having a higher site value (and could therefore justify more being spent on it), because it has very low weed cover, it requires only $154 ha^{-1} to manage, where Everard Park with weeds, revegetation and fencing requirements needs $1250 ha^{-1}. This shows the value of getting (and keeping) reserves in good condition. Once the weed loads are under control, it takes comparatively little to maintain (and the ecological benefits are much greater also).

Assumptions and inaccuracies The information gathered and the resulting database used to produce the predictive budget relied on a number of assumptions and had certain known inaccuracies. Despite this, the overall integrity of the database and the conceptual ideas held within it are still robust enough to be worthwhile.

Assumptions and inaccuracies included:

- Most roadsides were assumed to have an average 10 m wide 'footprint' for the road (6 m of road surface and 4 m of poor or no vegetation). Therefore 1 km of road with the standard 20 m reserve width was assumed to = 1 ha of vegetation. Wider road reserves were calculated individually, particularly where road width also varies
- Vegetation quality (HabHa score) was consistent along the lengths described
- Area of **native** vegetation could be accurately measured from aerial photos
- Treeless vegetation (seen on aerial photos) was assumed to be exotic (e.g. grass)
- Information for where the community carry out weeding work is not complete, particularly where weeding is done by individuals, not recognised groups
- Larger reserves were assessed looking at the more accessible parts and assuming the rest of the reserve was of similar quality
- RCS data mostly 10+ years old
- Limitations on Habitat Hectare scoring method; not suited to all situations where assessments were made

Coarse scale weed species mapping
With the weed species listed for each site (presence/absence only) and subsequently added to the GIS database as a separate layer for each weed species, a coarse scale map can now be produced to show the location of all the main weed species found on Council land.

This information is useful to show the extent of different weed species, particularly 'new and emerging' weeds or highly localised species such as bridal creeper, asparagus fern or wild tobacco tree which are all spreading quickly through different parts of the Shire. As managers of these weeds, the Shire can now target outlying populations for eradication and make genuine attempts at containing the core populations. It also allows highly targeted community education campaigns in the areas affected.

Knowing the weed species on a site also helps contractors know what herbicides/tools to take as well as improving timing (seasonal and daily weather variation) such as doing dig/pulling work on wet days, spraying on dry days.

Weed cover across Shire sites
Analysing the categories of weed cover (<5%, 5–25%, 25–50% and >50% cover) gave us an overall snapshot of how weedy the Shire was at the time of surveying (2006/07).

As can be seen in Figure 1, there was a high proportion (26%) of sites that had

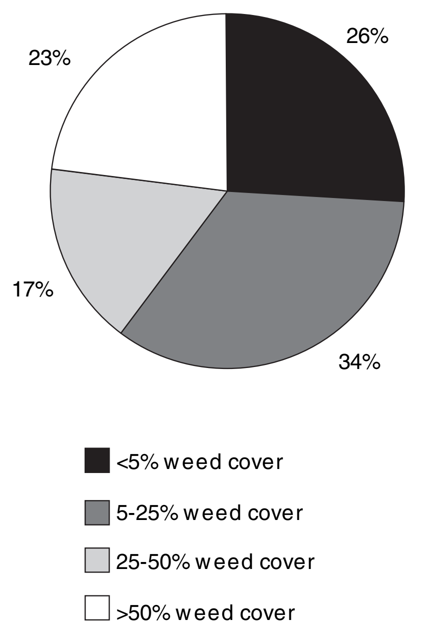


Figure 1. Proportion of SYR sites with varying percentage weed cover.

Table 2. Example of budgeting.

Wards Road Reserve (Monbulk)	Everard Park (Yarra River, Healesville)
26 ha	12 ha
Threat Matrix score 25	Threat Matrix score 25
Vegetation quality 0.73 (excellent)	Vegetation quality 0.35 (fair)
Vegetation type (EVC) – Least Concern (common)	Vegetation type (EVC) – Endangered
Weed cover <5%	Weed cover 25–50%
'Site value' $21,752	'Site value' $ 4712
Budget 2006/07 $4000	Budget 2006/07 $15,000

virtually no weed cover (<5%). These sites could be tackled confidently, knowing that with minimal effort, weeds on these sites would be under control (or even eradicated). These sites should subsequently only require monitoring and occasional light weeding. The largest proportion of sites (34%) had light to moderate weed infestations (5–25% cover). The aim for these sites would most likely be initial containment with the aim of eradication (of certain species) over a 2–10 year period.

The remaining 40% of sites (17% with 25–50% cover, 23% with >50% cover) would require substantial control efforts. Initially this would simply be aiming at containment of the worst/ most invasive species with gradual improvement over time until full containment could occur. This may take 20–40+ years (depending on how this is funded) and in many cases would require the cooperation of adjoining landholders.

It should be remembered that the most weedy 40% of sites represents 250 sites or 460 ha of highly weed infested land, which gives some scale to the weed problem within this Shire. It is difficult to estimate what it would take to bring these reserves and roadsides to <5% weed cover, but is likely it would be in the order of $5–50 million over five years. However to maintain these sites at <5% (if we got them to this) for five years would probably be in the order of $1 million ($200,000 p.a.), showing the significant cost savings of getting reserves to a manageable level.

Occurrence of weed species

With the major weed species listed for each site visited, a calculation was made showing what proportion of sites had each particular weed species. The resulting graph (Figure 2) shows all species that were found on at least 10% of sites.

It should be noted some species are common because they are highly invasive and have spread widely (e.g. Cotoneaster, Blackberry), while others are common primarily due to their popularity in being planted in gardens (e.g. Agapanthus).

For a full list of species, see Appendix A.

Victoria's worst? The case for expanding the Noxious weed listing

As can be seen from the list in Appendix A, the vast majority of weeds threatening the Shire's native forests are **not** listed under the *Catchment and Land Protection Act 1994* (CaLP) as Noxious (as marked with *). Indeed the only species that DPI actively targeted during the project period was ragwort (and some minor blackberry control), which due to its shade intolerant nature, is of little threat to most forest ecosystems.

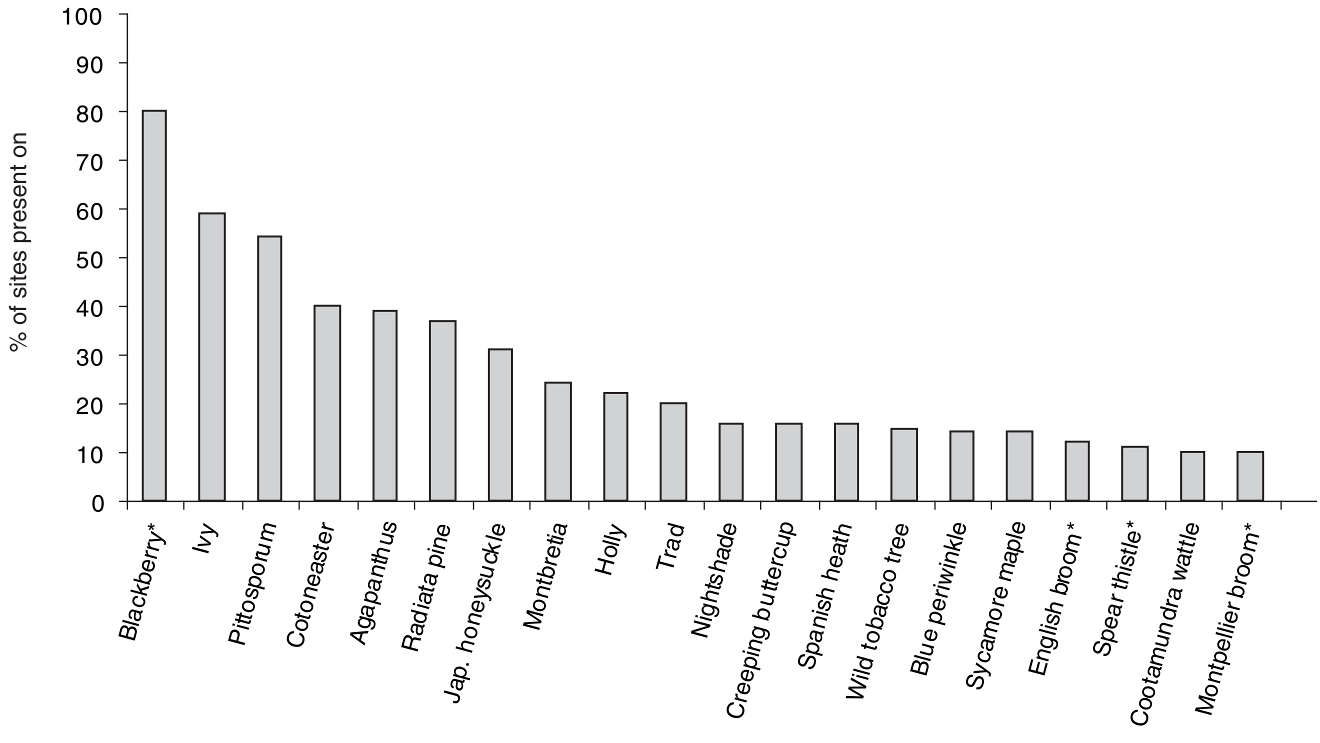
This list demonstrates the need for urgent revision of the CaLP listings to extend beyond 'agricultural' weeds, to include more 'environmental' weeds, a review which had begun as the project was nearing completion.

The comprehensive dataset obtained through the weed mapping project was used to inform DSE of which weed species the SYR felt should be listed as Noxious. Should the key environmental weeds of this Shire be listed, in the long term this would significantly assist our efforts to control weeds as any listed species are no longer able to be bought and sold and landholders have an obligation to remove them from their properties – one of the major limitations and weaknesses in the Shire's ability to effectively manage weeds.

Additional programs and benefits arising from weed mapping.

Field observations One of the benefits from weed mapping most of the reserves and roadsides in the Shire was incidental observations. These ranged from damage to infrastructure, illegal activities (rubbish and weed dumping, firewood collection, motorbike riding, hunting etc), rediscovery of otherwise forgotten sites and the observance of new weed populations. While most of these activities were too late for action, some, like dumped weeds proved highly cost effective through stopping new weed infestations becoming established.

Letters to residents requesting weed removal Where Shire/public land was in good condition, but under threat of infection by weeds from neighbouring private land, letters were being sent to residents requesting they control their weeds. Letters were highly targeted using observations



Species targeted by DPI under Noxious weed program: ragwort (2% – and none of those sites have >5% cover of this weed)

* denotes a Noxious weed

Figure 2. Occurrence of different weed species on SYR sites (% of sites present on).

made by the Weed Officer to the specific species they had on their land being included in the letter.

Greater understanding of weed ecology Through extensive field observations across the Shire and discussions with contractors and the public, a much greater knowledge of weed ecology for this Shire was achieved and therefore the ability to put realistic management into action was greater. Knowledge included how problematic different species were and in what conditions.

Trimble GPS mapping Following the initial site visit and ranking of all 600 sites, a selection of sites had weed locations accurately mapped using a Trimble GPS unit. This involved a second site visit and walking over the whole site (or sub section of the site) mapping the coverage of the major weeds (those likely to be managed by contractors).

A total of 50 sites were GPS mapped. These were selected to provide a statistically valid sample that could be compared to weed cover in the future to measure the success of management practices. The proposed statistical modelling was Generalised Linear Mixed Model (LIMS) with the design variables being Road, Reserve and TM score. Co-variable was whether the site was a Blackspot (specific weed control program) or not and the response variables were the weeds on site. While the sampling was essentially random within these design variables, sites were checked to ensure adequate spread across the geographical region of the Shire was achieved as well.

Mapping of sites with the GPS took considerably longer than the initial site visits, with an average of 2–4 sites per day being mapped. The sites were mapped using both point and polygon data with a range of description fields for each point collected based around the '11 Core Attributes' described in National and State Weed Strategies.

Future directions

Future surveying, expanding the list The 600 sites assessed were selected from over 3000 sites, the remainder of which have not been assessed other than brief visual checking of aerial photographs. In cutting the list, there were many sites that nearly made the cut, and would be good to do after this first year of assessment.

Future surveying, corrections to the dataset and monitoring Over time, weed cover on these sites will change. It is estimated all 600 sites could be re-surveyed in 40–60 days of surveying plus time for data input (note that Trimble GPS mapping takes longer – closer to 1–4 sites per day on average). This would keep the database up to date and allow progressive monitoring to occur.

Weed cover – species controlled by contractors As mentioned above, to gain more useful predictive budgets, the weed cover that is recorded would be more useful if it were just of species likely to be controlled by SYR bushland contractors. When the full list of sites is resurveyed, this additional information should be collected.

Integration with community programs Weeds on private land continue to be one of the most serious issues hampering long term control of weeds in the Shire. Current laws, obligations and compliance are all insufficient to prevent new weeds being planted and existing weeds from being controlled. There are a number of programs that have been suggested in the Weed Management Strategy and several that have begun implementation. It is recommended that a revision be done of the WMS programs taking into account the additional information now collected through the weed mapping project.

Case study – bridal creeper

During the mapping of the 600 sites across the Shire, it became clear that certain weeds were limited in their extent, localised to specific areas. For most species, given the lack of weed spread history, it is difficult to determine if it has limited extent due to a lack of weedy potential, or if they are genuinely 'new and emerging' and should be controlled. One weed that was found to be quite limited in spread, but known to be highly invasive across Victoria was bridal creeper.

Bridal creeper or smilax (*Asparagus asparagoides*) is listed as a Weed of National Significance (WONS), and as such is recognised as being one of the worst 20 weeds in Australia. Bridal Creeper is wide spread across Victoria and has just (in 2006), been listed as Noxious (Restricted) under the *Catchment and Land Protection Act 1994*.

Through the preliminary mapping done, and through casual observations made during this process, it was noticed that Bridal Creeper had a core population in the Seville/Wandin North/Gruyere area, but only isolated occurrences of limited extent outside this core area. Some of the outlying populations included Yarra Glen, Healesville, Narre Warren East, Montrose, Chirnside Park, Yellingbo and Coldstream. While this appears wide spread, in total there are less than 30 sites beyond the core area with many of these infestations covering less than 20 m^2. For a shire as large as Yarra Ranges, this is a very limited spread.

This information, gathered through the weed mapping program, now allows the SYR to urgently address this weed. The strategy involves several aspects:

- Urgent control of isolated populations with the hope of eradication from those areas (Healesville, Coldstream, Narre Warren East, Montrose)
- Containment of larger populations (Yarra Glen, Chirnside Park) and 'core' area, working strategically to 'pull in the edges' of these populations and prevent further spread with an aim of eventual eradication over many years
- Community consultation – feedback on new Bridal Creeper locations, encouragement and advice relating to control on their properties
- Coordination of weed control efforts between other agencies within the SYR, and between SYR and adjoining Shires.

Bridal creeper highlights the 'broad picture' that this mapping project produces. Without this overall snapshot of the Shire, recognition of 'new and emerging' weeds is very difficult and an effective overall management solution is nearly impossible.

All locations of bridal creeper known by the Weed Strategy Officer have been mapped with the Trimble GPS, thus movement of this species should be able to be closely monitored.

Glossary

CaLP	Catchment and Land Protection Act (1994)
EVC	Ecological Vegetation Class
HabHa	Habitat Hectare
Intramaps	Shire's GIS mapping system
GIS	Geographical Information System
GPS	Global Positioning System
RCS	Roadside Conservation Significance
NVMF	Native Vegetation Management Framework
TM	Threat Matrix
TMA	Threat Matrix Part A
TMB	Threat Matrix Part B
SYR	Shire of Yarra Ranges
WMS	Weed Management Strategy

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Appendix A. Occurrence of different weed species on SYR sites.

Weed Species	% sites on	Noxious?
Blackberry (*Rubus fruticosus* spp. agg.)	80%	Y
Ivy (*Hedera helix* and *Delairea odorata*)	59%	
Sweet pittosporum (*Pittosporum undulatum*)	54%	
Cotoneaster (*Cotoneaster* spp.)	40%	
Agapanthus (*Agapanthus praecox*)	39%	
Radiata pine (*Pinus radiata*)	37%	
Japanese honeysuckle (*Lonicera japonica*)	31%	
Montbretia (*Crocosmia × crocosmiiflora*)	24%	
Holly (*Ilex aquifolium*)	22%	
Wandering trad (*Tradescantia fluminensis*)	20%	
Black nightshade (*Solanum nigrum*)	16%	
Creeping buttercup (*Ranunculus repens*)	16%	
Spanish heath (*Erica lusitania*)	16%	
Wild tobacco tree (*Solanum mauritianum*)	15%	
Blue periwinkle (*Vinca major*)	14%	
Sycamore maple (*Acer pseudoplatanus*)	14%	
English broom (*Cytisus scoparius*)	12%	Y
Spear thistle (*Cirsium vulgare*)	11%	Y
Cootamundra wattle (*Acacia baileyana*)	10%	
Montpellier or Cape broom (*Genista monspessulana*)	10%	Y
Sallow wattle (*Acacia longifolia*)	9%	
Willow (*Salix* spp.)	9%	Y
Bulbil watsonia (*Watsonia meriana* var. *bulbillifera*)	9%	Y
Hawthorn (*Crataegus monogyna*)	9%	Y
Pampas grass (*Cortaderia selloana*)	8%	
Arum lily (*Zantedeschia aethiopica*)	8%	
Angled onion (*Allium triquetrum*)	9%	Y
Cedar wattle (*Acacia elata*)	7%	
Tutsan (*Hypericum androsaemum*)	7%	Y
Mirrorbush, taupata (*Coprosma repens*)	6%	
Ginger lily (*Hedychium gardnerianum*)	6%	
Red cestrum (*Cestrum elegans*)	6%	
Boneseed (*Chrysanthemoides monilifera*)	5%	Y
Butterfly bush (*Buddleja davidii*)	5%	
Laurel (various) (*Prunus* spp.)	5%	
Bridal creeper (*Asparagus asparagoides*)	5%	Y
Asparagus fern (*Asparagus scandens*)	5%	
Privet (*Ligustrum vulgare*)	4%	
Desert ash (*Fraxinus angustifolia* ssp. *angustifolia*)	4%	
Bluebell creeper (*Sollya heterophylla*)	4%	
Acanthus, bear's breeches (*Acanthus mollis*)	4%	
Banana passionfruit (*Passiflora* sp. Aff. *Mollissima*)	3%	
Forget-me-not (*Myosotis sylvatica*)	3%	
Loquat (*Eriobotya japonica*)	3%	
Himalayan honeysuckle (*Leycesteria formosa*)	3%	
Willow hakea (*Hakea salicifolia*)	3%	
Bamboo (various) (*Phyllostachys* spp.)	3%	
Strawberry tree (*Arbutus unedo*)	2%	
Karamu (*Coprosma robusta*)	2%	
Gorse, furze (*Ulex europaeus*)	2%	Y
Ragwort (*Senecio jacobaea*)	2%	Y
Fuchsia (*Fuchsia magellanica*)	2%	
Cape Leeuwin or false wattle (*Paraserianthis lopantha*)	1%	
Winter heliotrope (*Petasites fragrans*)	1%	

Grassy weeds as fiery competitors or phantom companions? – Lessons learnt from conservation and land management

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Recently, while googling, I came across a map of the distribution of Chilean Needle Grass (CNG) in Victoria (DPI 2003) which struck me for the story it told. CNG (*Nassella neesiana*) is one of Australia's twenty worst 'Weeds of Significance' (WONS 2000). I have been five years on the Chilean Needle Grass National Task, a group attempting to take a national level approach to limiting, controlling and, hopefully in some areas, eradicating CNG from the landscape. It is estimated that CNG has the potential to cause up to 50% in lost production on farmland with high levels of infestation, due to poor palatability of fodder, puncture of carcasses by needle-sharp seeds, spoilage of wool due to seed contamination, and other effects. Control of CNG on farmland has been estimated to be around \$25 ha^{-1}. CNG is also at least as damaging to biodiversity as it is to agricultural production, being an active invader of native grassy ecosystems which have numerous rare and threatened species (WONS 2000). What struck me about the Victorian distribution map of CNG was the strong association of CNG occurrence with towns and cities, within a web of highways that stretch out from Melbourne.

The spread of CNG is related to its heavy animal-borne seed. It is now reasonably well established that highways are a major pathway for spread due to the ways it can attach to humans as well as animals (including domestic stock), and the effectiveness of mowing at seed-set on flinging the seed up roadsides and out into paddocks.

CNG is perhaps as good as any weed to use for examining our relationships with noxious and other highly harmful weeds, because many of the aspects of CNG biology, ecology and infestation are reasonably well known. It is a good case study because it is relatively new as a major infestation in eastern Australia. CNG is also one of nine closely related grassy weeds from South America that have recently become prominent in eastern Australia, which include serrated tussock (*Nassella trichotoma*) and cane needle grass (*Nassella hyalina*). So a case study of CNG addresses the question: 'What do we need to do to control, limit and eradicate major weeds undergoing active invasion?' perhaps more clearly than by looking at weeds fully out of control across diverse landscapes, with numerous issues for control, which tend to muddy underlying trends. CNG is still only across a small percentage of its potential range. It has only recently been detected (and probably only recently introduced) to the states of Tasmania, Queensland and South Australia, and is yet to be detected in Western Australia, where according to climate modelling, it has the potential for major spread. Whether CNG can be prevented from entering WA, eradicated in Tasmania and SA, and either removed or contained within Queensland, will be a test of our capacity to control weeds overall – for current and potential spread of CNG in Australia, see (WONS 2000).

A great deal of effort has already gone into understanding the biology and ecology of CNG. As far as fire and water is concerned, it appears to be well adapted to our climate and ecological conditions. Burning can reduce CNG seed formation for a year (data not yet published), but burning kills few plants, and seed set resumes in only one season after burning. This is not surprising as CNG and its many troublesome *Nassella*-like relatives now in Australia, derive from the temperate grasslands of South America, with similar climate, fire, soils and grazing pressures to our own (WONS 2000). It may even be that CNG, like serrated tussock and other *Nassella* species, is even ahead of the game, being adapted to a climate which is only now developing in Australia, as we feel the local and regional consequences of global climate change. Many of our newly emerging weeds may have already responding, via selection, to the possibility that we may no longer be in an extended drought, but that the weather pattern has changed permanently and what we are now experiencing is more the average than the exception (Young 2007). We also know that competitive replacement of CNG by more desirable plant species, rather than simple removal and hope for the best, is important for effective control of CNG, partly because it has such a large and long-lived seed bank (WONS 2000).

CNG is highly successful at being a phantom companion, as indicated in the distribution referred to at the start of this paper, because our current social and environmental practices promote its distribution and establishment.

Any solution that controls CNG will need to address each of these factors, and their interactions. In addition, any

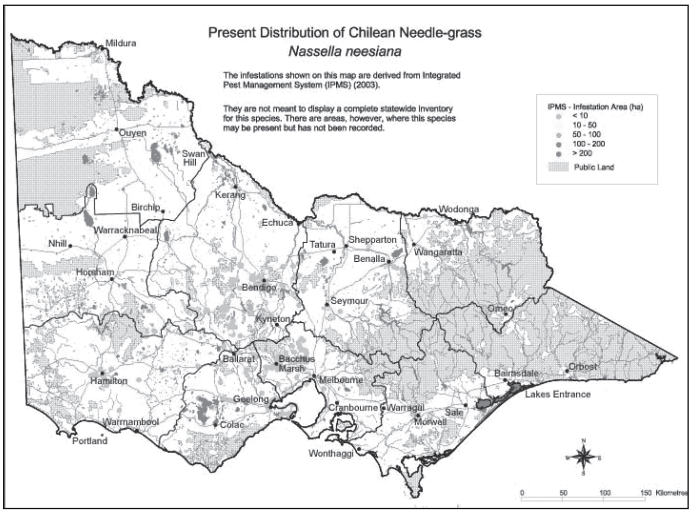

Figure 1. Map of Chilean needle grass in Victoria in 2003. Source (DPI 2003).

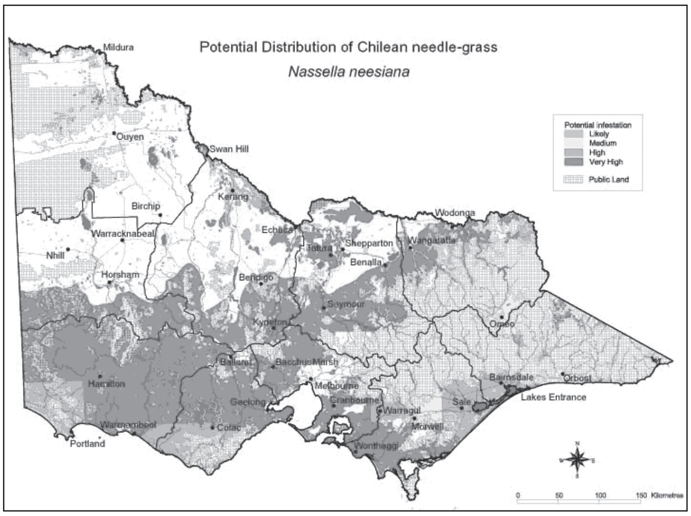

Figure 2. Potential spread of CNG in Victoria. Source (DPI 2003).

effective strategy will need to take into account our emerging understanding of how people best learn and change to achieve more sustainable outcomes. We know, for example, that information alone, and the distribution of information, to those spreading the weeds and those responsible for controlling spread, will not solve the problem. What leads to effective learning and change is taken up further below. A good example of the challenges facing us in the control of weeds, and the need for integrated approaches across ecology, control science, institutional context and effective behaviour change, is the challenge of how to prevent CNG from spreading along roadsides.

Current mowing along major roadsides is organised to meet specific institutional objectives. These are primarily for safety, with short mowing at regular intervals through the year on the verge of the road (e.g. within 5 m), and aesthetics, with less frequent mowing in other roadside grassy areas. There are huge areas to be managed, so the process is streamlined and strategically planned to provide for safety for workers and drivers, as well as identification of special services and natural areas requiring specific management. To schedule specific weed management into this demanding and complex strategic approach is potentially difficult, but if methods can be found to integrate weed management with existing systems and primary needs of the institutions, then the strategic systems should be able to carry these out. The challenge is how to find ways to best manage CNG using our latest understandings of both its biology and ecology, and how our current institutional practices can be put to best effect to wind it back, rather than promoting its spread.

Removal by spraying out, the current main method for CNG control along roadsides, may not work effectively. This is partly because of the high cost in any one year of a major spray-out program, partly because CNG is not easy to identify from other more useful grasses, and partly because large areas need to be treated. An additional complicating factor is that herbicide can remove not just CNG, but other useful competitive plants, leaving CNG to re-establish quickly from its high seedbank. Slashing practices along roadsides continue to promote CNG because ways to control CNG have not been effectively built into yearly work cycle of mowing and weed control. This is because CNG is not seen as a priority weed, and to see it so is challenging because most of the current control methods do not fit in with standard institutional practices and budgetary conventions. Also, approaches to education of road management institutions and workers has focused primarily on distributing information and expecting change – as is explained below, we now know that information alone does not lead to effective learning and change.

An alternative approach to CNG weed management that takes account, not only of what is needed from scientific research, but also from institutional understanding and action for change, has been outlined in Williams and Hocking (2005). This is based on extensive experience of working with land managers, to progressively manage CNG down, in an integrated way with the resources, timescales and procedural constraints of the land managers. For example, it is easier for most roadside managers to build a small allocation for CNG into their yearly budgets, and spread this over several years, than for a large scale, one off allocation, especially when the weed is not of high priority. There are also institutional expectations that the amount of money and resources assigned to control would decrease over time, or be allocated more to new areas of control, as the managing-down strategies take effect.

The approach reported in Williams and Hocking (2005) was based around management of CNG in high quality conservation areas. In a subsequent trial study, we have worked with VicRoads to investigate control methods along roadsides in Victoria. A joint analysis, which included institutional constraints, revealed that CNG was sitting up higher than most other vegetation in road verges, and this provided the opportunity to integrate weed management with existing mowing regimes, by replacing the mowing at key times of the year with a wick wiping methodology, which brushed herbicide on the projecting CNG leaves and flowering tillers. Previous wick wiping trials on serrated tussock using similar principles had not been fully effective (Miller and Wilsher 1999). However, we pursued this approach because we envisaged that it would be possible to integrate wick-wiping into existing mowing regimes over a number of years, and that this would progressively manage the densities of CNG along roadsides down, rather than the current mowing practices which inadvertently manage CNG densities up. What we have found (Hocking 2007), to be reported soon via research papers, is that the first run of wick wiping has been more successful than predicted, and that one or two additional years of treatment, or follow-up selective spray out of individual tussocks, may remove CNG altogether from these areas. This method is partly successful because it leaves more preferable vegetation in place as competitive repressors of CNG regeneration from the seedbank.

What the CNG case study highlights is that we need to approach research on weed management not just from a scientific perspective, although understanding weed biology and ecology is an important contribution. We also need research that begins at least equally from an understanding of the institutional and social settings of the weed, and investigates integrated approaches to weed management that can fit with institutional and wider community interests and expectations.

Weeds may be defined as 'Plants that are unwanted in the place in which they grow' but this definition skips over the reality that it depends on who doesn't want them, for what reasons, how much they don't want them, and what resources that can be brought to bear on the problem. Learning and behaviour change for sustainability tells us there is something more than this also for weed management. Action for control and eradication of weeds, just as for other environmental issues, does not flow automatically from raising awareness that a weed is a problem or providing a range of methods for control. Information alone is an important but insufficient part of action for change. People do not change their behaviour or take action to protect the environment just because they are told, and become aware of, the need for action and the impacts of no action. This has been highlighted in a major project I have recently been involved in, to implement professional development for facilitators of sustainability (Hocking, Ray & Day 2006). What research tells us, validated by the Guide Beside action research program which captures the practical experience of numerous facilitators of sustainability, is that information and awareness is only one strand in a multiplicity of factors that lead to learning and change. Table 1 outlines some key elements.

Notice that high on the scale of importance in actually triggering change (although all of the above interact together) is personal support and encouragement – the 'trusted other'. Each of the above elements interact to enhance the likelihood of change – for example, access to information and development of skills may become much more effective if the people and context of information provision and skills development has a personally connected element – that is, a sense of trust and engagement that results in more effective learning, and that allows individuals to come at the problem in individual ways, taking account of their particular circumstances, and to find individually appropriate solutions.

According to the literature and experience, there is an alternative to the learning and change approach outlined above, but it is not a very attractive one. This approach is perhaps best summed up in two of the outcomes of a major Victorian statewide survey on attitudes to the environment, which was representative of Victorians (DSE 2006) – note that the survey was conducted in 2004, prior to the current water crisis in Victoria (and Australia). To the question:

Table 1. Some key elements of learning and change for sustainability (adapted from Robinson 2005).

Change Factor	Estimated Contribution to Change
Pre-disposing/motivation factors 'I want to'	70–90% of voluntary change is motivated by the individual's frustration, dissatisfaction or guilt with their current behaviours.
Enabling resources/factors 'I know I should'	75–80% of change is dependent on external services/products
Triggering situations and factors 'OK … I'll give it a go!'	64–75% of voluntary change is triggered by interactions with family, friends or workmates
Satisfying factors 'That was OK'	100% of sustained change is accompanied by sustained personal satisfaction

A. Do you think climate change is already having an impact on our natural environment? – 76% of Victorians said YES
B. What is needed for us to take action on environmental issues? – 72% of Victorians believe that environmental concerns need to become a crisis before they are responded to.

A crisis is one way of eliciting a response to weeds. We have already seen the effectiveness of a crisis in mobilising people for learning and change with a number of Australia's worst weeds. Serrated tussock (*Nassella trichotoma*), a close relative of CNG is a good example of a weed that began as a minor problem in the 1990s and rapidly became a major crisis, with perhaps climate change being an underlying contributing factor. CNG has all the hallmarks of a similar building crisis.

The question for those of us who work on weeds is, do we need to reach a crisis before we have effective action? Is it possible to intervene through our understanding of weed biology and ecology, as well as human institutions, and what it takes for effective learning and action to take place, to avert the major impact of a weed spreading so that it becomes fully out of control?

If we count ourselves as amongst the community of researchers, extension officers, educators and concerned citizens who want to make a difference in our fiery engagement with weeds, then we must address all of the factors needed for effective action, unless we want to commit ourselves to the pessimistic inevitability of action following a crisis.

Is CNG a fiery competitor or a phantom companion? I suspect it is being successful at spreading because it is able to be both. To 'defeat the menace' we will need to take effective action to counter both its competitive and companionable attributes – the scientific and social in an integrated way – which is in line with the best of learning and action for sustainability as we are beginning to understand it.

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Horsetail (*Equisetum* spp.) and knotweeds (*Fallopia* spp.) – progress on eradication of two of Victoria's State Prohibited Weeds

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Abstract Horsetail (*Equisetum* species) and knotweeds (*Fallopia* species) are State Prohibited Weeds, a category of noxious weed considered to have the highest biosecurity risk to Victoria. Overseas, especially in North America and Europe, Horsetail and Knotweeds are considered very serious weeds and are much more widely distributed than they are in Australia. The main means of reproduction and dispersal of both weeds is via root fragments following soil disturbance, and in the case of knotweed, both root and stem fragments. This means that excavation of infestations as a means of eradication is risky and, without proper guidance and adherence to strict hygiene and disposal protocols, is actually likely to spread propagules to other areas. Chemical control is usually the preferred option, but there are also challenges in that established horsetail infestations can be difficult to kill with herbicides. In Victoria, horsetail and knotweeds have been banned from sale as garden plants since 2003, and the known infestation sites are largely confined to private and public gardens, mostly resulting from historical plantings. The Department of Primary Industries' Weed Alert team runs the detection and eradication program for these species in Victoria. This paper will provide background to the biology of horsetail and knotweeds, the threat they pose as weeds, their known distribution in Victoria, and the progress on their eradication in Victoria.

Keywords Horsetail, *Equisetum*, knotweeds, *Fallopia*, Japanese knotweed, *Fallopia japonica*, giant knotweed, *Fallopia sachalinensis*, State Prohibited Weed, eradication.

Introduction

In May 2003, all species of horsetail (*Equisetum* spp.) and three species of knotweed (*Fallopia japonica*, *F. sachalinensis* and *F.* × *bohemica*) were declared State Prohibited Weeds under the *Catchment and Land Protection Act 1994*. These species were declared in this category to help prevent their establishment in Victoria, as they were assessed as highly invasive, known to be serious weeds overseas, and known infestations in Victoria were considered very small and largely confined to gardens and nurseries. Plants declared as State Prohibited Weeds are to be eradicated from the State.

Materials and methods

Framework

In Victoria, State Prohibited Weeds are managed under the Weed Alert program. Weed Alert is a State Government program developed to prevent the introduction of serious new weeds to Victoria, and to eradicate the most serious incursions that have established. The program, delivered by the Department of Primary Industries (DPI) focuses on State Prohibited Weeds and Victorian Alert Weeds by overseeing the surveillance, collection, identification, assessment of and response to these species. 'Weed Spotters' are enlisted to assist with the surveillance part of the process. The 'Weed Alert Plan Victoria 2006/2007' (Blood in publication) describes how the surveillance and response to potential, new and emerging weeds is managed in Victoria.

Surveillance

DPI has utilised a variety of means of detecting infestations of *Equisetum* and *Fallopia*. For example, the Weed Spotter network is always on the look out for any new incursions of these species. Other means of detection of these species has resulted from searching botanical databases; receiving reports from herbarium staff, other botanical professionals or the general public; as a result of direct DPI inspections of gardens and nurseries by DPI; and investigations 'tracing-forward' and 'tracing-back' from known infestation sites.

Control of State Prohibited Weeds

In Victoria, the public is encouraged to report occurrences of *Equisetum*, *Fallopia* and any other State Prohibited Weeds to DPI (through the Weed Alert Program), but landowners with these weeds growing on their properties are not encouraged to try to treat this class of weed themselves. Without adherence to best-practice management of *Fallopia* or *Equisetum*, a treatment operation may fail, or worse still, end up spreading propagules to other areas. Since these species are under a State Government eradication campaign, the key message is for the public to report occurrences of these weeds to DPI but then to leave it to DPI to manage the infestations. To this end, DPI may use chemical, physical or a combination of chemical and physical means to treat State Prohibited Weeds according to prescriptions developed for the management of these species.

Site monitoring and data management

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

Biology and threat of horsetail and knotweeds

Horsetail (Equisetum species)

Equisetum is the single genus in the family Equisetaceae, a primitive group of spore-bearing plants, allied to ferns. There are about 30 world species of *Equisetum*, although the genus has a complicated taxonomy, which includes naturally occurring hybrids, subspecies and recognised varieties that are often difficult to identify (Burrill and Parker 1994, Rook 2002, Faithfull 2003). The genus is almost cosmopolitan, with only Australia and New Zealand lacking native species. Although *Equisetum* species produce spores, the main means of reproduction and dispersal in many environments is vegetatively via root fragments following soil disturbance, and some species are able to root from stem fragments (K. Blood personal communication 2006). *Equisetum* species often favour wet places. The long rhizomatous roots divide frequently, spread underground many metres horizontally and may descend to depths well over one metre. Some species also produce tubers on the rhizomes. From these rhizomes arise jointed, hollow stems. Some species die back for the winter and new stems re-emerge each spring, fertile stems with spore cones emerge first, followed by new stems and leaves. Other species have aerial stems which persist all year round. Spore-producing cones are borne at the ends of the main stems of these species (Burrill and Parker 1994, Faithfull 2003).

Weed status and impacts In parts of North America *E. arvense* is a pest in pastures, hayfields, grain fields, orchards, nurseries, and small fruit crops, especially on poorly drained soils (Cody and Wagner 1980). In high densities, horsetails reduce crop yields by producing inhibitory substances that depress the growth of neighbouring plants (Cooperative Research Centre for Australian Weed Management 2003). They can be very difficult to control because of their extensive, inaccessible, underground organs (Faithfull 2003). *Equisetum arvense* is often considered the most troublesome weed in the genus. This species is a weed in Europe, North America, South America, Africa, Asia and New Zealand (Weiss and Iaconis 2002). In Australia, all *Equisetum* species are declared noxious weeds in all states and territories of Australia (Weeds Australia database 2007). At the national level, live *Equisetum* plant material is a prohibited import to Australia (Australian Quarantine and Inspection Service 2007), and the genus is a listing on the National Environmental Alert List (Department of Environment and Water Resources 2007).

Reproduction, growth and spread Reproduction occurs almost entirely by vegetative means (mainly from rhizomes). Small pieces of tuber or rhizome broken from the parent plant can grow into new plants (Royer and Dickinson 1999), and stem sections can form roots in moist environments (K. Blood personal communication 2006). Horsetails also produce tiny spores that may be spread by wind and water, but these spores die of water stress unless they land on a site with prolonged wet conditions, such as in wetland habitats, and once released the spores are only viable for about 48 hours (Royer and Dickinson 1999). With these limitations on reproduction by spores, vegetative reproduction is far more common. Fragments of rhizomes and tubers can be spread to other sites by cultivation, road-making equipment, grading and cartage of contaminated soils, in dumped garden waste and water (Blood 2001). The sale/trade of potted plants of *Equisetum* by nurseries, markets, or enthusiasts is a major vector for horsetail dispersal. Such trade was more frequent prior to the declaration of horsetail in Victoria in 2003, but horsetails are still occasionally being discovered as traded or in gardens as historical plantings resulting from past trade (Author personal observations).

Knotweeds (Fallopia species)

Fallopia is a genus in the family Polygonaceae. *Fallopia* are fast-growing perennials that form dense leafy thickets, flowering in summer with most of the foliage dying down over autumn and re-emerging in the spring. They hybridise readily. Only three taxa are declared in Victoria: *F. japonica* (Japanese knotweed), native to Japan, Korea, Taiwan and China; *F. sachalinensis* (giant knotweed), native to northern Japan and the Sakhalin Peninsula (Russia); and *F.* × *bohemica* (Japanese knotweed hybrid – a hybrid between *F. japonica* and *F. sachalinensis*). Only *F. japonica* and *F. sachalinensis* have been recorded in Victoria. *F. japonica* tends to grow to heights of 1–2 m, whilst *F. sachalinensis* tends to grow 2–4 m high. The stems of these species are hollow and bamboo-like, arising from rhizomes. The leaves are often heart-shaped, although variable, with leaves of *F. sachalinensis* the largest, measuring 15–40 cm long by 10–25 cm wide. The roots consist of spreading rhizomes that are able to penetrate to depths of 6 m and to laterally spread 20 m from a growing plant (Gillespie and Faithfull 2004).

Weed status and impacts Knotweeds were introduced to the UK in the early 1800s and to the USA in the late 1800s as ornamentals. They are now serious weeds in the UK, Europe, USA, Canada and New Zealand. Knotweeds rapidly invade riverbanks and sites subject to disturbance, displacing all other vegetation by shading and root competition. They die back over winter, leaving bare soils open to erosion. The rhizomes are able to regrow from small cuttings, making mature infestations extremely difficult to remove, and they can emerge from deep down to penetrate asphalt (Gillespie and Faithfull 2004). Knotweeds are also a pest in urban gardens and degrade urban infrastructure by sending up shoots from their deep underground rhizomes which penetrate asphalt, paved areas, and building materials. In Australia, *Fallopia* species are not declared in any State or Territory except in Victoria (Weeds Australia database 2007) and their importation to Australia is not prohibited (Australian Quarantine and Inspection Service 2007).

Reproduction, growth and spread Reproduction occurs most commonly by vegetative means. Fragments of rhizome or green stem broken from the parent plant can grow into new plants. Knotweeds do produce seeds, but it seems that seedling reproduction is rarely encountered, at least in North America and Europe (Ainsworth and Weiss 2002). Fragments of rhizomes or green stems can be spread to other sites by digging, road-making equipment, grading and cartage of contaminated soils, in moving water, or in dumped garden waste. It seems *Fallopia* species have historically been far less commonly offered for sale in Victoria than *Equisetum* species, and there have been no reports of illegal trade since *Fallopia* was declared in Victoria in 2003 (Author personal observations).

Discussion

Infested area and infestation site numbers

Groves and Panetta (2002) provide some general principles for feasibility of eradication of incursions. These include an infested area limit of less than 100 ha and the number of infestation sites being three or less as being indicative as feasible for eradication. Table 1 shows that the infested areas of *Equisetum* (0.39 ha) and *Fallopia* (0.11 ha) are actually very small, and are well within the feasibility of eradication criteria. Table 2 and Table 3 show the number of current infestation sites for both

Table 1. *Equisetum* and *Fallopia* number of infestation sites detected in Victoria as at August 2007.

Botanical name	Common name	Total number of known infestation sites at August 2007	Total infested area (ha) at August 2007
Equisetum species	Horsetail	43	0.39
Fallopia species	Knotweeds	11	0.11

Table 2. *Equisetum* species detected as garden infestations in Victoria as at August 2007.

Species	Number of known infestation sites detected in Victoria	Eradication status[A]
Equisetum hyemale	40	Treatment/monitoring/eradicated (6)
Equisetum arvense	1	Treatment
Equisetum sylvaticum	1	Treatment
Equisetum palustre	1	Treatment
TOTAL	43 sites, 37 active sites	

[A] Eradication status, after Panetta (2007). The first status is the 'treatment' phase, the second is 'monitoring', and 'eradicated' is the final status of a site.

Table 3. *Fallopia* species detected as garden infestations in Victoria as at August 2007.

Species	Number of known infestation sites detected in Victoria	Eradication status[A]
Fallopia japonica	8	Treatment/monitoring
Fallopia sachalinensis	3	Treatment/monitoring
Fallopia × *bohemica*	0	n/a
TOTAL	11	

[A] Eradication status, after Panetta (2007). The first status is the 'treatment' phase, the second is 'monitoring', and 'eradicated' is the final status of a site.

Equisetum (37) and *Fallopia* (11). It can be seen these are over the three site limit for feasible eradications. However, it needs to be realised that these principles were supposed to be general, and may not apply to every eradication campaign. It also needs to be noted that many of the sites in the 'treatment' phase will be progressed into the 'monitoring' phase within a year or two, and then some of these sites should be able to be confirmed as eradicated within a few years. This will bring down the total site numbers. Of course, this doesn't take into account the possibility of further detection of new sites, which is considered highly likely for *Equisetum hyemale*, with as yet undetected historical plantings in gardens still likely to be detected in the future. Given the current low site numbers of *Fallopia* and the fact that *Fallopia* was not traded as much as *Equisetum* in the past, it is expected that only a small number of undiscovered historical plantings of *Fallopia* will be detected in the future.

Lack of a seedbank

Since Victorian infestations of *Fallopia* and *Equisetum* appear to be largely clonal infestations and have no effective 'seedbank', after treatment, the 'monitoring' phase need only extend as long as no regrowth from rhizomes has been noted. Of course this assumes that rhizomes will not have a dormant state and act as a 'budbank'. With the monitoring of *Fallopia* and *Equisetum* infestations in Victoria, it has been presumed that if there has been no emergence of any shoots from a monitored infestation site for three consecutive years after the last treatment of any shoots that have emerged, eradication of the infestation is very likely to have been achieved, and it has been noted as such on the database.

Targeting individual species of Equisetum and Fallopia for eradication.

Table 2 and Table 3 indicate that three species of *Equisetum* and one species of *Fallopia* have very low infestation site numbers for the State, just one site each in the case of the *Equisetum* species. Notwithstanding that there may still be further detections of these species made in the future, it should be very likely for DPI to be able to eradicate the currently known infestations of these species for Victoria within just a few years.

Conclusion

Provided there is continued adherence to best-practice treatment and monitoring of known infestation sites, it is likely that the known infestations of *Fallopia sachalinensis*, *F. japonica*, *Equisetum arvense*, *E. sylvaticum* and *E. palustre* will be eradicated from Victoria in the very near future. Continued vigilance with the treatment and monitoring of the more numerous known infestation sites of *Equisetum hyemale* should see these sites eradicated in the near future. It is expected that there will be new detections of as yet unknown historical plantings in gardens of *Equisetum hyemale*, and possibly of other *Equisetum* species. It is expected that few new *Fallopia* sites will be found in Victoria. It is eventually expected that the number of new detections of historical plantings in gardens of *Equisetum* and *Fallopia* will fall to a very low level, as it is assumed that there are now few, if any, *Equisetum* and *Fallopia* still being traded in Victoria to provide a source of new garden infestations.

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Early detection for water weeds in Australia

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Summary A new project initiated by the National Aquatic Weeds Management Group and NSW Department of Primary Industries aims to increase the adoption of early detection procedures for water weeds in Australia.

Formal early detection procedures have been developed for weed control authorities and waterway managers to enable a proactive approach to early detection. These procedures build on the current practices of weed control authorities and increase their capacity to identify water weeds, assess the water weed risk in their area and to conduct surveys at high risk sites.

Informal early detection procedures have been developed for community groups and regular users of the waterways with the aim of increasing the likelihood of opportunistic water weed detections. They involve increasing understanding of the water weed threat and abilities to recognise and report incursions to the relevant authority.

These procedures improve our ability to detect water weeds early. This increases the likelihood of successful containment or eradication and reduces control costs by treating incursions before they become well established.

This paper will discuss the processes for implementing an early detection program and the benefits this approach will bring to waterway management in the north central regions of Victoria and nationally.

Introduction

Water weeds are fast growing invasive plants that can rapidly infest a waterway. They can form large floating mats and dense stands under the water or along banks where they interfere with the normal functioning of the waterbody, destroying environmental, economic and social values.

Managing water weed infestations is challenging due to their rapid growth rates, their ability to spread by seed and/or plant fragments, and the difficulties and costs associated with controlling weeds in an aquatic situation. The most strategic and cost effective form of water weed management is to detect and treat the infestation early.

Community groups, regular users of waterways, field workers, weed control authorities and waterway managers can play a vital role in detecting aquatic weeds early, assisting in the subsequent management of our waterways.

The project

The Aquatic Weed Early Detection Project is an initiative of the National Aquatic Weed Management Group and its initial development began in 2005 when community networks and control authorities were approached and training resources were developed.

The project began in November 2006 funded by the Australian Government Defeating the Weeds Menace program and NSW Department of Primary Industries. The main objective of the two year project is to increase the adoption of early detection procedures for water Weeds of National Significance (WONS) and other high priority water weeds in three key areas (southeast Queensland, northern New South Wales and north central regions of Victoria).

The formal early detection procedures have been developed for weed control authorities and waterway managers to take a proactive approach to early detection. These procedures build on the current practices of weed control authorities and increase their capacity to identify water weeds, assess the water weed risk in their area and to conduct surveys at high risk sites. This is being achieved by providing training, technical advice and on ground assistance with the initial assessment and survey of the management area.

The informal early detection procedures have been developed for community groups, regular users of the waterways, and those outside of the weeds field. The aim is to increase the likelihood of opportunistic water weed detections. It involves developing their understanding of the water weed threat and their ability to recognise and report incursions to the relevant authority. This is being achieved by providing training, education materials and technical advice to interested community members and water quality monitoring organisations such as Waterwatch Victoria.

Collaboration with existing weed detection organisations

The successful collaboration between the Early Detection Project and the existing weed detection organisation, Weed Spotters, has been vital for developing and implementing early detection procedures for water weeds in Victoria. This collaboration ensures that new infestations are reported to and followed up by the relevant agencies.

The Early Detection Project has provided Weed Spotter members with training and education materials for identifying and detecting water weeds in their local area. Furthermore, over 60 project participants have registered as Weed Spotters.

The Weed Spotters network and Weed Alert Contact Officers (WACOs) have provided the participants of the project with training in the reporting protocols that have been previously established for reporting Victorian State Prohibited, Alert and new and emerging weeds. Weed Spotters also provide participants with access to further training, resources and links to the large network of volunteers.

Target audience of the Early Detection Project

- Community groups,
- Water quality monitoring networks (Waterwatch),
- Weed Spotters,
- Regular waterway users,
- Local and state government,
- Catchment Management Authorities (CMA's), and
- Field workers and weed management contractors.

Target Weeds of the Early Detection Project in north central Victoria

State government, regional CMAs and local councils were consulted to determine what water weeds pose the greatest threat in the north central regions of Victoria. These include the WoNS salvinia (*Salvinia molesta*), alligator weed (*Alternanthera philoxeroides*) and cabomba (*Cabomba caroliniana*); the National Alert species Senegal tea (*Gymnocoronis spilanthoides*), lagarosiphon (*Lagarosiphon major*) and horsetails (*Equisetum* sp.); the state prohibited weed water hyacinth (*Eichhornia crassipes*), and regionally significant such as sagittaria (*Sagittaria platyphylla*) and elodea (*Elodea canadensis*).

Training

Workshops are presented by the Early Detection Project in conjunction with Weed Spotters who provide training in the established reporting protocols for Victoria. The workshops are based on the Recognising Weeds in our Water Training Course (VET resource RTC2016A) which includes the following subjects:

- The impacts of water weeds,
- How they are introduced and spread,
- Where do they grow,
- Recognition techniques,
- Disposal of unwanted plant material,

- Identifying characteristics of noxious water weeds and similar looking plants, and
- How to conduct a water weeds risk assessment and survey in you local area.

Resources to the project

A number of resources are utilised by the Early Detection Project, including a reviewed version of the Recognising Weeds in our Waters presentation, the new Early Detection procedures presentation and live water weed specimens. Each participant in the workshop receives the following training materials:

- Recognising Weeds in our Waters Workbook,
- The Early Detection Survey Manual,
- An water weed WEEDeck,
- Brochures and weed alerts from State/ Territory agencies,
- A Early Detection Project flyer,
- A Workshop Evaluation form, and
- A Weed Spotter reporting sheet.

The Early Detection Survey – a formal approach

The Early Detection Survey is a formal and proactive approach to detecting water weeds, aimed at weed control authorities but also appropriate for community organisations ready to carry out more formal procedures. It allows us to determine which sites within a management area could be at risk of water weed introduction and/or provide ideal habitat and conduct routine surveys at these sites. It contains parts: (1) the local area assessment; (2) the survey and (3) data management/ reporting.

Part 1: Local area assessment

The local area assessment is an in-office evaluation of the management area that determines which sites could be at risk of water weed introduction and/or provide the ideal conditions for growth by:

- Learning to identify water weeds and determine which ones threaten your local waterways by attending the Recognising Weeds in our Waters workshops or utilise identification recourses.
- Seeking expert advice and collating maps, photos and information about previous water weed infestations and actions in your area.
- Identifying and recording the sites where weeds could be introduced to your local waterways. Water weeds are predominantly introduced and spread by human activities (see Table 1). Therefore, weeds are often found in accessible areas of the waterways at:
  - bridge crossings,
  - major roads,
  - public parks beside water bodies,
  - boat ramps,
  - streams or wet areas where earth moving activities have recently occurred, and
  - water bodies in urban areas i.e. stormwater retention ponds.
- Identifying and recording the sites that provide an ideal habitat for water weed growth. Water weeds require predominantly slow moving, permanent and shallow freshwater to grow. They are more likely to grow well in degraded waterways with elevated nutrient levels, direct sunlight and warmer water temperatures. They can be found growing in the following types of waterways:
  - streams,
  - lakes,
  - wetlands,
  - farm dams,
  - water storage facilities,
  - stormwater retention ponds,
  - irrigation channels,
  - canal estates,
  - urban drains, and
  - irrigated crops (rice and turf).
- Prioritising the recorded sites by using the matrix in Table 2 by determining if the site is a high, medium or low risk. As a general rule at least 80% of your sites should fit into the high risk category. Sites with low or medium risk are useful to survey if there are significant environmental, economic or social assets downstream.
- Determining how many sites can be surveyed and how often. Generally 10–15 sites per day can be inspected by a two person crew and at least two inspections of each site per year is recommended.

Table 1. Vectors capable of spreading water weeds.

- Boats and recreational craft
- Boat trailers
- Eel trapping equipment
- Fishing nets
- Dumping of aquarium or fishpond plants
- Irrigation channels
- Irrigation equipment
- Floods
- Hobbyists
- Earth moving equipment, trench diggers
- Wildlife (birds, mammals etc.)
- Floods
- Contaminated plants
- Mulching
- Incorrect disposal of plants
- Fire fighting equipment (i.e. Heletankers)
- Cropping (turf production and distribution)
- Cattle and horses
- Slashers
- Deliberate plantings by aquarium plant traders
- Mistakenly grown as a vegetable (Alligator weed)

Table 2. A matrix for prioritising aquatic weed survey sites.

Risk of introduction (human activity) →

Conditions for growth	Limited human access to stream	Moderate human access (bridge crossings, parks, boat ramps)	High human access (bridge crossings, parks boat ramps)
Fast flowing. Few if any ponded areas. Riparian cover intact.	**Low Risk**	**Low Risk**	**Medium Risk**
Slow moving and ponded. Moderately degraded. Partial riparian cover.	**Low Risk**	**Medium Risk**	**High Risk**
Slow moving and ponded. Highly degraded. Limited riparian cover. High nutrient loads.	**Medium Risk**	**High Risk**	**High Risk**

- Determining when to survey the sites. The survey should be conducted when the conditions are safe for the participants and plants are easiest to detect e.g. when flowering.

Part 2: Survey

Once the high risk sites have been identified its time to get out of the office and conduct a survey. At each site walk along the bank and closely observe the water surface, banks and submerged environments for floating, submerged and emergent weeds. Structures such as bridge crossings will allow you to inspect the middle of the water body. Even if the site appears to be weed free check around logs, fences or other snags where water weeds may have been trapped during previous flooding. Record information about the site in your database or complete a Site Survey Data Sheet. If you find a water weed:

- Double check the plant's identification using the identification resources.
- Determine the upper most limit of the infestation. Work your way upstream until upper limits are found (sometimes a boat may be necessary useful for this). The upper limit may be an isolated swamp or farm dam which may only join the stream in times of high flow.
- Photograph the weed close- up and in its habitat.
- Report the weed to the relevant authority (Report all State Prohibited, Alert and new and emerging weeds to Weed Spotters). Weed Spotters has protocols established to ensure that the plant's identification is confirmed, that the relevant authorities are contacted and that the Weed Spotter is kept informed by the Weed Alert Contact Officer.

Part 3: Data management and reporting.

It is important to record the site information, survey results and follow-up survey dates in your database or complete a Site Survey Data Sheet and report this to the Early Detection Project for mapping. All the site details need to be recorded even when no water weeds are present. Please note that because survey sites are not randomly selected, data cannot be used to infer characteristics of areas not surveyed.

The following nationally agreed attributes for surveying and mapping Weeds of National Significance are required to ensure that consistent and reliable information is collected (Thackway *et al.* 2004):

- Site name,
- Date,
- Latitude and longitude of site (point format),
- Length of water body surveyed,
- Waterway description,
- Site facilities/structures/modification,
- Depth,
- Substrate,
- Water weeds present,
- Habitat area,
- Coverage,
- Growth stage,
- Treatment, and
- Photos available.

Informal early detection procedures

Community members, field staff and those outside the weed industry can play a vital role in detecting and reporting water weeds early by:

- Learning how to recognise and report water weeds that threaten local waterways at the Recognising Weeds in our Waters Workshops or utilise identification recourses.
- Keeping an eye out for water weeds while conducting monitoring and other activities in the waterways. Being particularly vigilant at high risk sites where water weeds are likely to be introduced and/or provide the ideal conditions for growth. See table 2.
- If you find a suspected water weed contact the relevant authority (Report all State Prohibited, Alert and new and emerging weeds to Weed Spotters).

Evaluation

The Early Detection Project has already trained over 180 people in the high priority areas of Southeast Queensland, Northern New South Wales and the north central regions of Victoria. As a result of the joint workshops conducted with Weed Spotters in Victoria, over 80 participants registered as Weed Spotter members.

All workshop participants are given the opportunity to rate the effectiveness of the workshop, the methodology and resources and provide comments and suggestions in the Workshop Evaluation Form. The response to the workshops has been very positive with all participants reporting an increase in their knowledge of water weeds and rating the workshops as useful or very useful. This feedback has also been used to review and update training techniques, course content, resources and survey methodology.

Many enthusiastic participants are keen to apply the early detection techniques learnt at the workshops to their local area. Several organisations have already conducted an assessment of their local area and carried out the initial surveys with a small number of new infestations detected and reported.

The future

The Early Detection Project will continue to provide training, support and a range of activities in the high priority regions, probably expanding to other areas of Australia in 2008.

New water weed detections will be collated and mapped. The early detection methodology will be reviewed and finalised to be applied nationally, to ensure that stakeholders have the capacity to continue early detection beyond the end of the project.

Conclusions

The Early Detection Project has already raised the awareness of water weeds and the importance of early detection in the north central regions of Victoria by engaging with the community and relevant organisations, providing training, resources and linkages with established weed detection networks. Community groups, field workers, weed control authorities and waterway managers can play an important role in detecting water weed infestations early. This will enable weed managers to have a better understanding of the distribution of water weeds and prioritise the subsequent management actions to prevent their spread.

Due to the keen interest shown by the participants, the project appears well on target to meet the objective of increasing the adoption of early detection procedures for water weeds in Australia.

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Weed proofing Australia: a way forward on invasive garden plants[1]

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Introduction

> *The control of invasive plants represents an immense new challenge for Australia in the opening decades of the 21st century. For the sake of our future economy and our environment, we must tackle the problem more effectively.*
> Dr Rachel McFadyen, Killing Us Softly – Australia's Green Stalkers (2003, p. 3)

In 2004, an infestation of Mexican feathergrass (*Nassella tenuissima*) – the first in Australia – was found escaping from a Tamworth garden. It is an attractive ornamental tussock grass imported legally into Australia in about 1996, propagated and then widely sold. It is a known grazing and environmental weed that economists estimated would cost graziers $39m if it escaped, and has the potential to invade 14 million hectares (Groves *et al.* 2005). Meat and Livestock Australia are on the record saying that: 'it's the last thing we want. It would be an absolute disaster for Australia (Williams 2004).

The example of this high-risk invasive garden plant highlights a bigger problem. Seven out of 10 of Australia's environmental and agricultural weeds are escaped invasive garden plants, and the bulk of the potential invasive plants already here are introduced garden plants. Those that have already escaped cost farmers $100m's each year – just three escaped invasive garden plants cost farmers nearly $100m y^{-1}: rubber vine costs $27m y^{-1} in control lost production costs, Paterson's curse costs $30m y^{-1}, and lippia costs $38m y^{-1} – and contribute to the $1 in every $7 of income that farmers' lose to weeds each year (Sinden 2004). Just one escaped invasive garden plant, lantana, degrades 4 million hectares of Australia, and many others pose direct threats to threatened species.

As a consequence, a key focus of Australia's weed defence system needs to be tackling the invasive garden plants issue head on. We need to get it right so farmers, national park managers, bushcare, landcare and other community groups aren't subjected to continued and new waves of costly escaped invasive garden plants.

This paper outlines a strategic response to this challenge – one that can enable both the garden industry and Australian communities to play a significant and positive role in weed proofing Australia. It includes opportunities to create new markets for low risk plants, and to enable the garden industry to move decisively onto the front foot in responding to the invasive plant problem and future civil liability risk.

Issues

Some of the issues that need to be resolved through the proposed policy package are:

- Uncertainty about the weed status of garden plant species in the garden industry,
- Lack of comprehensive and detailed knowledge about the nature and extent of the garden industry pathway for propagation and movement of invasive plant species,
- A suite of poorly harmonised weed lists,
- No convenient information measures in place to enable consumers to easily identify and properly care for medium risk garden plant in response to growing social concern about weed impacts, and
- Potential for industry leaders to be commercially undermined by those in the industry not adopting positive measures.

A way forward: a 10 point plan

Australia has the challenge of working out an effective, least cost solution to tackling the causes and sources of the invasive garden plant problem. We have a superb opportunity to work out this solution in a strategic and systematic way so that all stakeholders go into a change process with their eyes open and are able to participate in an ordered transition.

The starting point is the need to recognise that most garden plants in trade have no weed history and can be considered environmentally safe. This creates an opportunity to shift the market towards the majority of low risk plant species.

Many garden plant species currently being traded, however, are or have the potential to cause serious harm to farmers, the agricultural industry, areas of high conservation value and the broader environment. In short, these invasive plants present a clear strategic risk to Australia's agricultural profitability and our natural assets, and as such warrants concerted action by governments, industry and the community to mitigate this risk and facilitate a transition toward a prosperous garden plant market based on low-risk plants.

It is important to also recognise that the existence of these high risk plants in Australia's garden plant market is a legacy of Australia's quarantine regime that existed before the mid-1990s that focused on contaminants and a relatively small number of serious agricultural weeds. These plant species would not be able to be legally imported into Australia today.

A policy package is needed that strives to achieve a 2015 vision of a prosperous garden industry built on the sale of low-risk garden plants, encouraged by an empowered and enabled community that wants to reduce their weed spread risk footprint.

The policy package needs to deliver the following outcomes by 2010:

Environmental

- Only new low risk plant species are legally permitted into Australia by 2006,
- No high risk garden plants are traded, focusing on those yet to naturalise or become widespread,
- Increase in detection and eradication of new high risk garden plant incursions.

Social

- Australians are empowered and enabled to reduce their weed spread risk,
- In major cities and towns, individuals able to join community-expert networks to detect and eradicate new high risk garden plant incursions,
- Garden industry supports, and is enabled to play a significant role in reducing Australia's weed spread risk,
- Garden plant species that present a high risk of demanding significant Australian community group effort to restore bush and land are removed from sale.

Economic

- Garden plant species that present a high risk (and potential and/or actual cost) to Australia's agricultural industries are removed from sale,
- Garden plant species that present a high risk (and potential and/or actual cost) to government agencies responsible for managing national parks and other crown lands are removed from sale,

Footnote

[1] This paper was first published in the document Weeds in the Media (2006) CRC for Australian Weed Management. Adelaide.

- Garden businesses unduly financially impacted by the policy receive one-off transition reimbursement where appropriate (i.e. significant loss in market value of existing Plant Breeder Rights),
- New market demand created for low-risk garden plants.

This can be achieved through a 10 point policy package:

1. Close Australia's front door to new weeds.
2. Give garden industry and communities certainty about the weed status of garden plants.
3. Better understand the extent and risk from continued trade in invasive garden plants.
4. Build knowledge about sterile garden plants and the dynamics of invasiveness.
5. Build garden industry understanding about the risks and costs associated with invasive garden plants, and capacity for positive action.
6. Mobilise garden industry to respond positively to the invasive species challenge.
7. Protect garden industry leaders and reduce transaction and compliance costs by establishing a streamlined national regulatory framework.
8. Phase out supply and trade of high risk invasive plants nationally.
9. Encourage gardeners to increase product demand for low risk garden plants.
10. Mobilise communities to search and destroy new infestations of escaped invasive garden plants.

The diagram in Figure 1 shows how this 10 point plan targets different stages and audiences along the pathway from propagation to escape of high-risk invasive garden plants.

1. Close Australia's front door to new weeds

Comprehensive permitted list/weed risk assessment system by 2006

In early 2005, the Australian Government committed to close a quarantine law loophole that allowed nearly half of all plant species on Earth to be imported into Australia with no weed risk assessment – including over 3335 known weeds not yet found in Australia (Glanznig 2005). These known weeds became prohibited imports in June 2005 (Macdonald 2005). In 2006, when the loophole was fully closed all proposed imports of new plant species not on the national permitted list became subject to a weed risk assessment, with only those that present a low risk to Australian agriculture and the environment able to be legally imported. This strengthened quarantine regime will keep new invasive weeds out of Australia, but still allow plant species on the permitted list, including new cultivars and varieties of garden plants, fruits and vegetables already on the list. There has been some misinformation that new varieties of common garden plants or vegetables already on the permitted list, such as roses, lettuce and tomatoes, would be banned. This is simply not true.

2. Give garden industry and communities certainty about the weed status of garden plants

National list of invasive plant species

The weed issue is characterised by a multitude of weed lists, combined with varying degrees of uncertainty and confusion about which garden plant species are invasive. To fix this problem, both the Nursery and Garden Industry Australia (NGIA 2004) and WWF (Glanznig *et al.* 2004) are calling for governments to develop one national 'master' list of invasive plants under which State, regional and local lists are nested. This should build on the existing national list of naturalised plant species (Groves *et al*. 2003).

The National List should be divided into various threat or risk based categories, which clearly delineates between high-risk and medium risk plant species.

3. Better understand the extent and risk from continued trade in invasive garden plants

The landmark 2005 CSIRO 'Jumping the Garden Fence' report highlighted the impacts of invasive garden plants on the environment and agriculture, the significant number of high-risk invasive garden plant species still in trade, as well as poorly harmonised State and Territory noxious weed lists. However, the last reasonably comprehensive audit of known weeds in trade in the garden industry was done for 1998/99 by the WA Department of Agriculture.

There is a pressing need for a national audit of garden plant species in recent trade, to identify a comprehensive shadow list of high risk plant species that need to be removed from trade to reduce the risk of them causing significant harm to agriculture and/or the environment, particularly those yet to naturalise or become widespread.

This national shadow list should be a focus for full weed assessments by government agencies (see Plan Point 8), and self regulation by nursery growers (see Plan Point 6).

4. Build knowledge about sterile garden plants and the dynamics of invasiveness

Research into why and what plants become invasive

Research into invasion biology and ecology is a growing field of scientific endeavour. The Australian Government recently committed to provide some additional funding through the 'Defeating the Weed Menace' Research and Development Plan, and the opportunity exists to make this a research stream in the proposed new Invasive Plants CRC.

Research to produce genuine sterile cultivars

There is a market opportunity to produce genuinely sterile cultivars of profitable invasive garden plants. To ensure that governments recognise these 100% sterile cultivars, they would need to be vetted through a national sterile cultivar accreditation scheme (see Plan Point 7), and to enable efficient compliance they would need to be able to be easily told apart from invasive varieties by having unique features, such as unique coloured flowers or stems for example.

The garden industry has the opportunity to explore this avenue further by becoming a partner of the new Invasive Plants CRC bid, and including a new research stream on sterile cultivars.

5. Build garden industry understanding about the risks and costs associated with invasive garden plants, and capacity for positive action

Garden industry invasive plants capacity building program

The garden industry needs to strategically reposition itself to play a major and positive role in the solution to the invasive plant problem. Governments and key scientific bodies, such as the Weeds CRC, need to support these efforts.

Opportunities include training, incorporation of invasive plants in accreditation standards, positioning garden centres as knowledge providers on invasive plant solutions to consumers, and becoming leaders in community involvement programs to replace high risk with low risk plants (e.g. Garden future fitting schemes (see Plan Point 9)).

National weed information system/portal

Currently, information to identify and manage weed issues is scattered among a wide range of sources. This makes it difficult for the community and garden industry alike to keep abreast of new information, as well as the changing legal status of plant species. What is needed is a one-stop-shop national weeds information portal that becomes the premier gateway for information about weeds in Australia. Both WWF and the Australian Institute of Horticulture support the development of a one-stop-shop national weeds information portal.

The Australian Government, acting on advice from the National Weeds Advisory Group (NWAG), is now developing a national weeds information portal under its 'Defeating the Weeds Menace' program.

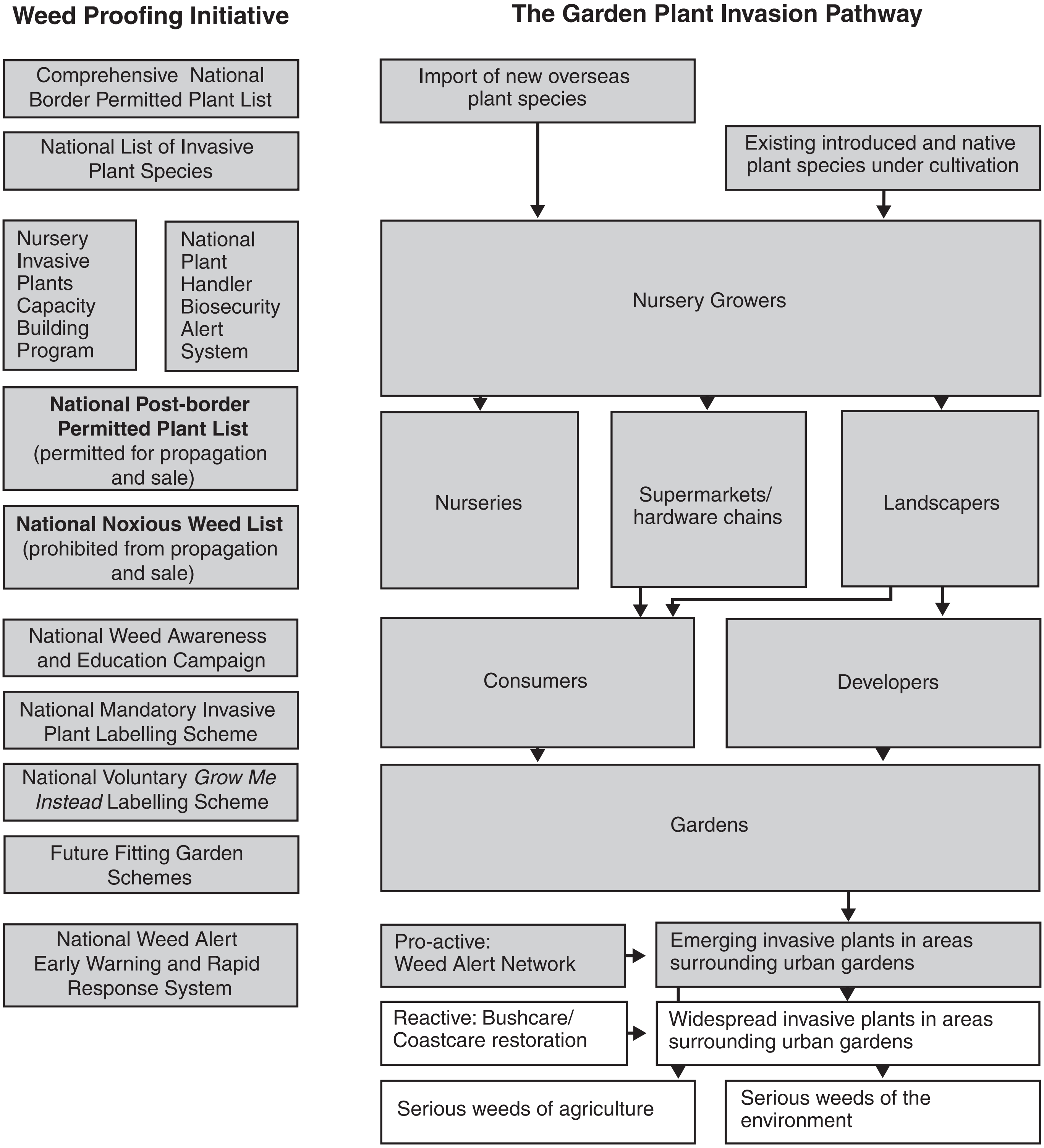

Figure 1. How this 10 point plan targets different stages and audiences along the pathway from propagation to escape of high-risk invasive garden plants.

6. Mobilise garden industry to respond positively to the invasive species challenge

Garden industry policies

Peak garden industry groups have a strong leadership role to play in the industry's response to the invasive garden plant challenge. The Australian Institute of Horticulture (AIH) recently released its updated weed and invasive plant policy (AIH 2006) and the Nursery and Garden Industry Australia (NGIA) policy was released in late May 2006. An opportunity exists in these policies to spell out the industry's duty of care to mitigate the risk posed by invasive garden plants (particularly high-risk invasive plants), as well as committing to develop appropriate codes of conduct.

It is instructive to note that WWF and the AIH share many policy positions, such as the need for a national standard weed risk assessment process, a national weed information portal, and a national mandatory invasive plant labelling system.

These industry policies also have an important visioning role, exemplified by the AIH commitment to support all programs that will ensure no new invasive plants become naturalised in Australia from 2010 onwards (AIH 2006).

Beyond compliance: institutionalising corporate social responsibility (CSR)
Australia is in a period of policy flux as governments move to strengthen measures for weed prevention and control; an example is the number of States and Territories that are currently reviewing their noxious weed lists (e.g. Vic, NSW, NT). Rigorous weed risk assessments of candidate weeds take time and as a result many States have a large backlog of plant species to be assessed. The consequence is that there are significant lead times between State agencies identifying a candidate weed and its final declaration as a noxious weed.

An alternative to this situation, is for garden plant growers to move beyond compliance by using resources such as the *Global Compendium of Weeds* and emerging studies to identify high risk candidate invasive garden plants, and in consultation with weed scientists, put them in a holding pattern until they can be properly risk assessed.

National plant handler biosecurity alert system
The garden industry is a national market. The movement of plants and soils around Australia could provide a vector for the movement of disease or invertebrate pests (such as Phytophthora or fire ants) to new regions. This is an important risk that needs to be managed. Part of the solution is a national rapid alert system to let plant handlers quickly know about new biosecurity risks and what they need to do to manage any risk.

7. Protect garden industry leaders and reduce transaction and compliance costs by establishing a streamlined national regulatory framework
The garden industry is a national market, though domestically weed control is covered by eight separate jurisdictions each with different laws and lists. The result is inefficiency and inconsistency. Governments need to take a stride forward and develop a stream-lined and coherent national framework of laws that build on a national standard weed risk assessment protocol, clear national weed priorities and nation-wide control of high risk invasive plants through a national noxious weed list, as well as a national labelling scheme.

Experience in the United States (Caton 2005), New Zealand and Australia (Moss, and Walmsley 2005) shows that to protect those industry leaders that do the right thing and remove high-risk species from trade, laws are needed to create a level playing field so all growers and sellers are required to remove high-risk plant species, so leaders are not commercially disadvantaged. Voluntary approaches alone do not work.

National post-border permitted plant list
The most cost effective way for governments to prevent new weed problems is to implement permitted list/weed risk assessment systems – essentially making any proposed new plant species a prohibited import until proven low-risk by a rigorous weed risk assessment process.

Western Australia already has a comprehensive permitted list/risk assessment system in place, while the Northern Territory has a partial permitted list/risk assessment system. Queensland and Tasmania are examining the feasibility of implementing a permitted list system. It makes a lot of sense to bring all these efforts together and fuse them into a national post-border permitted plant list to complement the Australian Government's national border permitted plant list. This double permitted list approach is the most effective and efficient policy approach to prevent new weed problems, and also remove the incentive to smuggle new invasive plant seeds into Australia from overseas and then exploit the weaknesses in narrow State and Territory prohibited lists.

National noxious weed list
It doesn't make sense, and is a waste of scarce funds, to have one government trying to control a plant species while it is being sold in another jurisdiction. CSIRO found that 40% of the naturalised invasive garden plants declared noxious in one jurisdiction were available for sale in another (Groves *et al.* 2005). This also applies between the Australian Government and State Governments, where one AQIS quarantine target weed and six national Alert weeds were still available for sale in 2004. (Glanznig *et al.* in press).

There are four leading countries working on weeds: South Africa, New Zealand, the United States, and Australia.

All of them, except Australia, have national noxious/pest plant lists. It is time for Australia to also implement one national list that reflects the national nature of the garden plant market and how it is promoted, and the national spread pathways of invasive plants. The focus of the proposed national noxious weed list should be on those high-risk plant species that are yet to naturalise, or are not yet widespread where restricting supply will result in a reduction of establishment and invasive success.

National mandatory invasive plant labelling scheme
Consumers have a right to know if they are buying a potentially invasive plant. They also need to know how to reduce their weed spread risk by knowing if the plant is suitable for the proposed location, how to maintain it, and how to dispose of green waste responsibly. This can be facilitated at Point of Sale through a label, as part of a broader education program, that gives consumers 'care' information – like medicines advising on number and size of doses – rather than 'don't' information – like cigarette labelling. Labelling will be particularly useful for the growing market of garden plants sold through hardware and supermarket chains, which do not offer advice to consumers.

WWF believes that the label should be designed in a way to show regional differences in invasiveness – perhaps a map of Australia showing suitable growing area where the plant is not known to be invasive in one colour, with areas where it is invasive highlighted in another colour. It also needs to include the proper botanical name to help avoid confusion.

A mandatory labelling scheme would also enable the garden industry to move to contain future civil liability risk. A study by the University of New England's Australian Centre for Agriculture and Law identified that the practice of knowingly selling invasive plants with no consumer disclosure presents a civil liability risk for the garden industry, and that a significant benefit of a national labelling scheme is to reduce the probability of the success of future claim/s against garden plant growers and sellers to pay for the 'clean up' costs of their invasive plants. This risk mitigation is analogous to fast food chains introducing low fat product lines and strengthening consumer disclosure of product ingredients to help contain the liability risk of claims that fast food caused their obesity problems (Martin *et al.* 2005).

Experience shows that to be work properly, the labelling scheme needs to be mandatory (Wilkenfeld 2003).

Both the Australian Institute of Horticulture (AIH 2006) and WWF support a national mandatory labelling scheme (Table 1).

National sterile cultivar accreditation scheme
There is currently some controversy about whether new varieties of lantana and black agapanthus are truly sterile. Some lantana varieties promoted as sterile, for example, were subsequently found to be able to cross breed with weedy forms of lantana. (Neal and Playford nd). To give consumers certainty and peace of mind, and also ensure that claims of 'non-invasiveness' on labels are not misleading, sterile plant varieties could be vetted through an independent and scientifically robust national sterile cultivar accreditation scheme. Varieties that were scientifically proved to be sterile could be accredited and branded as 'environmentally safe'. To provide a market incentive, these varieties would need to be exempted from sale bans, but to ensure easy compliance people would need to be able to easily tell the difference between invasive varieties and the sterile

Table 1. Relationship of proposed key elements in an effective national regulatory framework.

National List of Invasive Plant Species	High Risk Plant Species	National Noxious Weed List (prohibited for sale (accredited sterile cultivars/varieties excepted))	Quarantine List	
			Alert List	Type 1: Species/ Taxa Action Plan Type 2: No specific plan needed
			Control List	Type 1: Species/ Taxa Action Plan Type 2: No specific plan needed
	Medium Risk Plant Species	National Permitted Plant List (certain species in current trade permitted for sale subject to mandatory labelling. For new proposed plant species for trade, only those that are low risk plant would be permitted). National Mandatory Invasive Species Labelling Scheme		
	Low Risk Plant Species	National Permitted Plant List (permitted for sale) Voluntary 'Grow Me Instead' Labelling Scheme		
Definitions **High Risk Invasive Plant Species** refers to those introduced, and native plant species under cultivation that are known or have a reasonable probability of becoming invasive and harmful to agriculture and/or the environment in Australia. This would include plant species that are 'transformers', and/or have a direct impact on rare and threatened native species. A specific Weed Risk Assessment Score range may be used to assist determine high risk plant species.				
Medium Risk Invasive Plant Species refers to those introduced, and native plant species under cultivation, that are known or have a reasonable probability of naturalising, and are or have a reasonable probability of being a minor to significant problem in Australia. A specific Weed Risk Assessment Score range may be used to assist determine medium risk plant species.				
Low Risk Plant Species refers to those introduced and native plants plant species that have been assessed as low risk to the environment and agriculture at present. A specific Weed Risk Assessment Score range may be used to assist determine low risk plant species.				

variety, by breeding in a unique coloured flower or stem into the sterile varieties for example (see Plan Point 4 for R&D component).

8. Phase out supply and trade of high risk invasive plants nationally

National invasive garden plant accord

There is a pressing need to phase out the supply and trade of high risk invasive plants nationally, particularly those that are not yet naturalised or widespread. An example is the Australian Quarantine and Inspection Service (AQIS) quarantine weed, Ceylon hill cherry (*Rhodomyrtus tomentosa*) that failed a weed risk assessment and is now a prohibited import into Australia, is a serious weed in Florida and Hawaii, but according to *Aussie Plant Finder 2004* is still advertised for sale in NSW and Qld (Hibbert 2004).

To achieve this aim requires a national process that is scientifically robust, enables all stakeholders to have a say, and financial implications to be fully considered. If for example, Plant Breeder Rights (PBR) are unduly impacted, industry has strong grounds to negotiate a structural adjustment package.

The experience and process used to determine the Weeds of National Significance, as well as the New Zealand experience and process to develop the statutory 'National Pest Plant Accord' offer useful models that could assist develop the aspect of the proposed National Noxious Weed List that pertains to high-risk invasive garden plants.

A national invasive garden plant accord, or something analogous, is needed for Australia, that follows the basic process outlined below.

9. Encourage gardeners to increase product demand for low risk garden plants

National weed awareness and education campaign

Currently there is low awareness about weed issues by urban Australians. However, market research shows they have strong latent demand to do adopt behaviours that reduce weed spread risk, if it is easy and convenient.

A national weed awareness and education campaign is being planned by the Australian Government under its 'Defeating the Weeds Menace' program to mobilise community support and involvement. The increase in awareness about the large impacts of weeds and where they are coming from over the next several years will lead to strong community expectations for governments and the garden industry to implement effective solutions to the invasive plant problem.

National voluntary Grow Me Instead labelling scheme

A possible flip-side to the national mandatory invasive plant labelling scheme mentioned in Plan Point 7 is a national voluntary labelling scheme that leverages off the 'Grow Me Instead' brand. It could promote low risk garden plants as an alternative to higher risk garden plants. The scheme could complement a set of educational materials (e.g. brochures, posters, guides) developed for major urban centres.

Future-fitting garden scheme

Many gardens contain high risk invasive garden plants, including those yet to escape widely into the environment, such as Mexican feathergrass (*Nassella tenuissima*). Encouraging home owners to participate in schemes that audit their gardens and help them replace high risk plants with those that are environmentally safe needs to be part of the weed proofing solution. A council led model is the Greenweb program being implemented by local governments in Sydney, though apparently there is also a garden centre led model – Waterwise gardens – being trialled in Western Australia (Rebecca Dawson, personal communication).

Getting in early even before these invasive plants have the chance to escape and become a problem is one of the most cost-effective actions that we can take. This 'future-fitting' is analogous to homes installing more efficient lights or showerheads to save energy and water respectively.

If widely promoted, this scheme has the potential to create a new market for low risk plants. Now imagine if the NGIA and/or AIH partnered with organisations like WWF and/or major farmer bodies to promote this positive scheme. The WWF panda is one of the 10 most trusted brands in the developed world (Edelman 2003), and we have over 80 000 supporters in Australia. We also reach 100 000s of Australians through our public campaigns, such as 'The Future is Man Made' that includes invasive species as a campaign issue.

10. Mobilise communities to search and destroy new infestations of escaped invasive garden plants

National Weed Alert early warning and rapid response system

Early detection of new invaders is essential for cost-effective intervention. Evidence from Australia shows that most new plant invaders are escaped invasive garden plants that appear around population centres (Hosking *et al.* 2004). In New Zealand, which has studied this pattern in more detail, research found that of the first collection of naturalised plant species between 1985–2000, 91.5% were found within 1 km of the nearest building and 67% were found within 2 km of a town (Sullivan *et al.* 2004).

Victoria already has a world leading 'Weed Alert and Rapid Response System' (WARRS) in place. This needs to be rolled out nationally to encourage communities to take part in surveillance efforts. It has the potential to build on urban Bushcare programs, since people already active in restoring bushland may also be interested in monthly surveillance efforts to find new plant invaders that may harm the bush they hold dear. Garden centres could also promote local surveillance efforts.

Conclusion

The 10 point plan proposed in this paper has the potential to strategically reposition governments, the garden industry, NGOs and communities, so that they are working together collaboratively to markedly reduce the weed spread risk and future costs posed by invasive garden plants. Australia deserves nothing less.

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The role of the National Herbarium of Victoria (MEL) in the documentation of new weeds[1]

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Abstract Any attempt to document new weed species is reliant upon the accurate identification of the plants concerned. This can only be achieved with access to taxonomic literature, well-curated reference specimens and expert botanical knowledge. The National Herbarium of Victoria (MEL) is the central authority on the plant biodiversity of Victoria and the chief repository of plant specimens. A major role of the Herbarium is to collect and document the State's flora, including both native and naturalised species. The Herbarium houses a collection of approximately 1.2 million pressed and dried plants, and is particularly rich in historic and foreign-collected specimens. These specimens provide an invaluable permanent record of the occurrence of a plant species at a particular locality and time. The collections held at the National Herbarium, together with its comprehensive botanical library and wealth of botanical expertise, make it an essential resource for research on Victoria's flora.

Introduction

The National Herbarium of Victoria (MEL) is the central authority on the plant biodiversity of Victoria. Situated at the Royal Botanic Gardens in South Yarra, the herbarium houses the State Botanical Collection – a collection of approximately 1.2 million pressed and dried plant specimens; the most comprehensive library of botanical literature in Australia, and a significant collection of botanical artwork. The State Botanical Collection is an essential resource for research on Victoria's flora.

The National Herbarium is the oldest scientific institution in the State. It was founded in 1853 with the appointment of Ferdinand Mueller as the first Government Botanist of the colony of Victoria. As Government Botanist, Mueller's directive was to investigate Victoria's flora – a brief which remains a fitting description of the work of the National Herbarium today.

Born in Germany in 1825, Mueller trained as a pharmacist at the University of Kiel and became a skilled botanist (Morris 1974). Upon arriving in South Australia in 1847, Mueller began enthusiastically investigating the Australian flora. His botanical pursuits took precedence over other endeavours, and he amassed a private collection of over 4000 specimens. These specimens provided the foundation for the Melbourne collection, which, in 1894, was estimated to number over one million specimens (Cohn 2003).

Mueller was an exceptional botanist and a prolific collector, and became the focus of botanical endeavours in Australia. Upon being appointed Government Botanist, he was quick to undertake botanical explorations, and collected around 1500 previously unrecorded species for Victoria in his first 15 months in office (Willis 1990).

In addition to his own efforts, Mueller's collections were supplemented by material obtained from a wide variety of sources. Specimens collected on both official and private exploring expeditions (including those of Ludwig Leichhardt, Ernest Giles, John McDouall Stuart and William Tietkens) were sent to Mueller for identification and incorporated into the growing collection. Mueller also received specimens from prominent botanists in other colonies; through the exchange of material with overseas collectors, and from enthusiastic individuals throughout the colonies who he engaged as plant collectors.

The judicious purchase of important private herbaria (such as those of Otto Sonder, James Drummond and Joachim Steetz) contributed invaluable foreign material, as well as some of the earliest Australian collections, to Mueller's botanic museum (Cohn 2003). These acquisitions provided valuable comparative material that allowed the Australian flora to be accurately described. As well as being a valued resource for botanists around the world, the foreign collections are a vital tool in the identification of newly naturalised taxa in Victoria.

The collection continued to grow after Mueller's time, though not at the same phenomenal rate. Significant additions include the purchase of herbaria from Felix Reader, Max Koch and Raleigh Black (Short 1990), while continuing efforts from herbarium staff; exchange of specimens with other herbaria; and, notably, contributions from Cliff Beauglehole, Jim Willis, and the Victorian Field Naturalists, also enhanced the collection (Cohn 2005).

Today the National Herbarium contains around 1.2 million specimens – approximately 800,000 Australian specimens, and 400,000 collected overseas – and includes representatives of most of Australia's vascular flora, as well as algae, bryophyte, lichen and fungi collections of international significance. It is one of the largest herbarium collections in Australia, and the richest in historic and type specimens (Willis 1990). Approximately 37% of the Australian collection is Victorian, and provides a permanent and verifiable record of the State's flora. Records of all species, including new and emerging naturalised species, are substantiated by herbarium voucher specimens, making the National Herbarium a valuable resource for information on weedy taxa.

The documentation of Victoria's weed flora at MEL

Plant invasions, along with land-clearing and global warming, are a major contributing factor to the loss of global biodiversity. Naturalised taxa comprise approximately 20% of the total Australian flora (Hosking personal communication 2005) and 30% of the Victorian flora (Walsh and Stajsic 2007). More than 65% of Victoria is invaded by wholly or predominantly exotic vegetation (Stuwe 1986, Carr *et al.* 1992). The area occupied by naturalised species increases annually, and records of newly established species continually accumulate (Carr 1993). Hosking (personal communication 2004) estimated that 13 new weeds establish in Australia each year. The National Herbarium of Victoria regards the issue of plant invasions and the corresponding threats that are posed to native ecosystems and biodiversity as a critical conservation issue.

Footnote

[1] The term 'weeds' in this paper includes both naturalised and incipiently naturalised plants. As defined by Walsh and Stajsic (2007), naturalised plants are those alien plants that sustain self-replacing populations without direct intervention by people or in spite of human intervention, by recruitment from seeds or vegetative propagules (e.g. the bulbils of many exotic *Oxalis* species) or by vegetative spread (e.g. the extensive rhizome system of **Spartina* × *townsendii*). Incipiently naturalised taxa are those where the taxon is known to be not indigenous in Victoria and is represented by one or more populations, but the extent of naturalisation is uncertain and there is doubt whether it has become truly naturalised (as defined above) yet. Taxa in this category demonstrate the potential to become truly naturalised.

Documenting the State's flora

The documentation of new weeds is dependent on a thorough understanding of both the native and the naturalised flora that occur in the State; we can't know if a taxon is new to the State if we don't know what taxa are already present.

One of the most important resources produced by the National Herbarium is 'A Census of the Vascular Plants of Victoria'[2]. The *Census*, now in its eighth edition, lists the scientific names of all vascular plant taxa known to occur in the State. All taxa listed in the *Census* are substantiated by herbarium voucher specimens, most of which are housed at MEL, although some are housed in other recognised herbaria (Walsh and Stajsic 2007). Documenting the occurrence of new weeds in publications such as the *Census* plays a pivotal role in early intervention strategies and weed alert procedures.

An examination of past editions of the *Census* reveals valuable data about weed incursions in Victoria. As illustrated in Figure 1, the proportion of naturalised to native flora recorded in the *Census* has increased steadily in successive editions, with the greatest proportional increase in naturalised taxa occurring between the seventh (2003) and eighth (2007) editions.

It is interesting to note that not all of the 132 additional naturalised taxa listed in the 2007 *Census* were newly established in the period since the publication of the previous edition. Many of these taxa became naturalised many years prior to 2003 (Figure 2), but had previously escaped detection or classification as 'naturalised'.

The systematic databasing of the Australian Collection at MEL – initially under the J.T. Reid project (2000-2001) and later by the Australia's Virtual Herbarium (AVH) project (2001-2006) – has greatly facilitated the detection of weedy taxa in the herbarium collection that had previously escaped attention, and thus been omitted from early editions of the *Census*.

Another influential development has been the burgeoning interest in the encroachment of weeds in Victoria as an important conservation issue at MEL. The greater consideration of our weed flora prompted a refinement of the terminology used in the *Census*, and the introduction of the 'incipiently naturalised' category in Ross (2000). This term is used to describe taxa that are known to be introduced in Victoria, but are not yet known to be fully naturalised. In previous editions of the *Census*, taxa were generally listed only if they were fully naturalised. Consequently, many taxa which are now included as incipiently naturalised were absent in earlier editions.

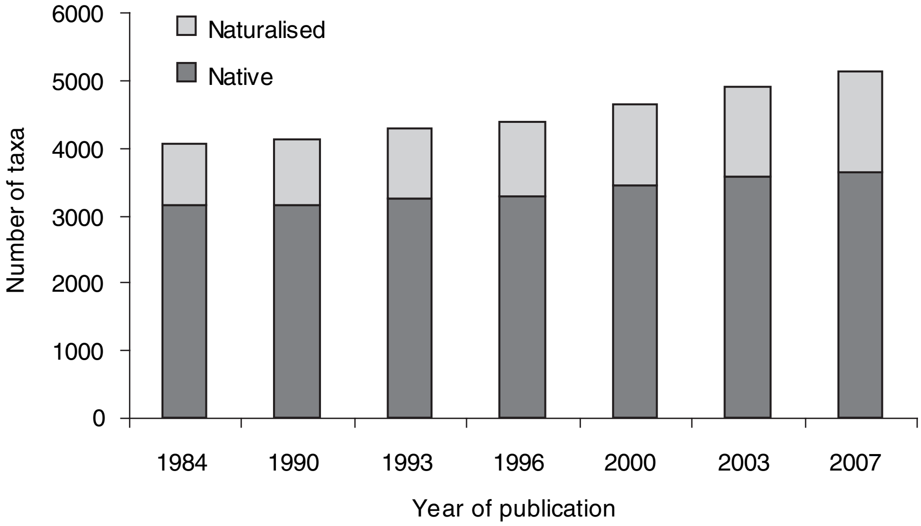

Figure 1. Native and naturalised vascular plants in Victoria (from 'A Census of the Vascular Plants of Victoria', editions 1–8). Data from the 1988 Census was omitted due to an error in the figures.

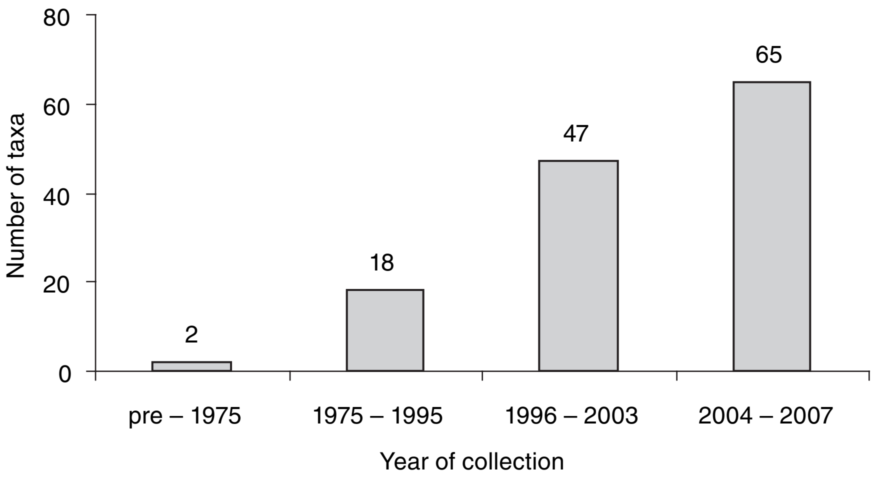

Figure 2. Collecting date of naturalised taxa in Victoria first recorded in 'A Census of the Vascular Plants of Victoria'(2007).

It is important to note that the naturalised status accorded to the taxa in Walsh and Stajsic (2007) is based strictly on the evidence available from specimens held at MEL. Although some taxa that are listed as incipiently naturalised may in some instances be fully naturalised, MEL does not hold voucher specimens that verify that status. It is vital that voucher specimens of naturalised taxa are lodged in herbaria in order to accurately and verifiably document weed establishment and expansion.

Identifying new weeds

Plant identification (also called determination) and the correct application of a name (nomenclature) are integral components of all taxonomic work. It is important to appreciate that, in formal processes of early detection and notification of new naturalisations, such as the Weed Alert Rapid Response (WARR) plan, no control or eradication procedures can be initiated prior to an authoritative determination being provided by a herbarium taxonomist. This is one of the pivotal roles that herbaria play in early detection and notification protocols.

In order to identify plant specimens correctly, it essential to possess a knowledge of taxonomic methods, extensive knowledge of the taxonomic literature, and experience in the identification of plants (Jones and Luchsinger 1979). Knowledge of the horticultural flora is particularly important given that almost 80% of recently recorded naturalisations in Victoria are of garden origin (Walsh and Stajsic 2007). Reliable determination can only be achieved by having access to comprehensive taxonomic literature, and a comprehensive herbarium collection that includes native, naturalised and horticultural taxa.

Footnote

[2] Hereafter referred to as the *Census*.

Determination
When confronted with a new naturalised plant, an experienced botanist can usually recognise the plant to either genus or family level (if not species level). Following the initial recognition, the unidentified specimen needs to be keyed out using botanical literature such as floras, monographs and revisions, where available. Specimens are then compared with species descriptions and any available illustrations.

Once we obtain a name for the unidentified specimen, it is then compared with a voucher specimen of the taxon, if one is held at the Herbarium. This is where MEL's extensive foreign collection, unique among Australian herbaria, provides an invaluable source of comparative material that greatly assists the identification of exotic species.

Due to the lack of comprehensive global revisions, specimens from some taxonomically difficult groups sometimes need to be sent to botanists at overseas herbaria for determination. A *Callitriche* specimen received at MEL, apparently of a taxon new to Victoria, provides a recent example. The specimen was originally believed to be **C. marginata* Torr., and was sent to an authority on the genus in England for confirmation of the identification. The specimen was redetermined to **C. deflexa* A.Br. Such misdeterminations can occur where there is poor literature and the lack of keys that include all the known taxa. In another instance, material of an invasive alien, *Ludwigia*, that was collected from the outer eastern suburbs was determined at MEL as **Ludwigia arcuata × repens*; the determination was confirmed by an authority on *Ludwigia* in Taiwan.

Nomenclature
During plant determination work, one may notice that the taxonomic literature might cite one or more synonyms for certain species which are treated in that account. Assuming that a taxon hasn't been divided into several other taxa, most synonyms are easily correlated with the currently accepted name. Nomenclatural checks are usually less labour intensive than the determination process, but there are exceptions to this, and the nomenclature of some taxa can be very complex and convoluted.

The purpose of nomenclature is to facilitate unambiguous communication about a taxon, i.e. to ensure that we all refer to a particular taxon using the same name. This usually works well, but there can be differences of opinion about nomenclature and taxonomic concepts between taxonomists. Consequently, different names may be applied to the same taxon in different states (or different countries).

This lack of uniform nomenclature can sometimes cause confusion. That is why, in 2004, the Council of Heads of Australasian Herbaria (CHAH) agreed to produce a new cooperative census of Australian vascular plants. This project is actively underway, and it is hoped that the *Australian Plant Census* (APC) will standardise the application of botanical names in Australia (for more information, see: http://www.anbg.gov.au/chah/apc/introduction.html).

Botanical name changes are often a source of confusion; however, they are an important component of plant taxonomy, which, like any other science, is dynamic and constantly evolving. Plant names are usually changed for one of the following two reasons:

1. Changed views on species delimitation: Two species, previously considered distinct, may, with new evidence, turn out to be the one taxon. Only one name can be applied to a single taxon, so the earliest published name will take priority, and the other name should no longer be used. On the other hand, what was considered a single species might turn out to include more than one taxon. If so, new names must be applied to the newly recognised taxa, in accordance with the rules set out in the International Code of Botanical Nomenclature (ICBN). One of the greatest benefits of collecting voucher specimens is that they enable previous identifications to be verified or amended when species' delimitations change, whereas it is often impossible to establish the current name for identifications based solely on sight records.
2. Changes in classification: Changes in plant groupings may result in a taxon being transferred from one genus to another. For example, based on the latest evidence, **Achnatherum caudatum* (Trin.) S.W.L.Jacobs & J.Everett has now been transferred to a new genus, *Amelichloa*, and is now referred to as **Amelichloa caudata* (Trin) Arriaga & Barkworth.

It is important to note that, in Australia, many weed names have been misapplied. A misapplication of a name occurs when a plant has been initially incorrectly identified, and the wrongly-applied name is subsequently published in botanical literature. For example, the name **Physalis viscosa* L. has been misapplied in Australia, and redetermined as several different taxa, with the Victorian populations now considered to be **Physalis hederifolia* A.Gray (J. Sullivan personal communication 2007). Other examples of misapplied weed names in Australia include: **Carthamus glaucus* M.Bieb., misapplied to **Carthamus leucocaulos* Sm; **Leucanthemum maximum* (Ramond) DC., misapplied to **Leucanthemum × superbum* (Bergmans ex J.W.Ingram) D.H.Kent; and **Lantana camara* L. var. *camara*, misapplied to **Lantana × strigocamara* R.W.Sanders.

As well as keeping track of nomenclatural changes and ensuring that the names applied to specimens in the State Botanical Collection are up-to-date, the National Herbarium also provides nomenclatural advice, and can help guide external clients through some of the more complex nomenclatural issues.

The importance of getting the identification right
The Herbarium's plant collection and library form a priceless storehouse of scientific information that is an indispensable aid for identifying new weeds. The advantage of using herbarium records is that they provide a permanent and verifiable record that substantiates the presence of a plant at a particular place and time. Specimens can be re-examined if there is dispute over the identity of the record. When documenting the flora of a given area one should be mindful of the fact that sight records not substantiated by voucher specimens are not verifiable, and may present problems to future researchers (Albrecht 1993).

The National Herbarium encourages those with an interest in naturalised plants to submit good quality, well preserved specimens with adequate field notes. This maximises the likelihood of obtaining a confident determination and provides us with the option of incorporating the specimens into the State Botanical Collection if desired (Albrecht 1993). Incomplete or poorly preserved specimens with inadequate accompanying information are often impossible to determine with confidence. Guidelines for the preparation and submission of voucher specimens can be found on the Royal Botanic Gardens website: http://www.rbg.vic.gov.au/research_and_conservation/plant_identifications/voucher_specimens.

Many people do not submit specimens to a herbarium for identification because they assume that they know the identity of the plant they're dealing with (Hosking *et al.* 1996). Failing to correctly identify a specimen can result in the inadvertent dispersal and establishment of weedy species, and delay their eradication or control. The potential implications of misidentifying plants are highlighted by the following examples. Several years ago, the weedy alien **Lampranthus tegens* (F.Muell.) N.E.Br. was planted at Moonee Ponds Creek in urban Melbourne, in the belief that it was the native pigface, *Disphyma crassifolium* (L.) L.Bolus. In a similar case, MEL received a specimen of **Amelichloa caudata* (Trin.) Arriaga and Barkworth (syn. **Achnatherum caudatum* (Trin.) S.W.L.Jacobs and J.Everett) about two or three years ago, which had been planted along a stream in Wangaratta in the belief that it was the native tussock grass, *Poa labillardierei* Steud.

A number of native plant nurseries in Melbourne have propagated and used the alien **Carpobrotus aequilaterus* (Haw.) N.E.Br. in revegetation schemes in the belief that they were using the native *Carpobrotus rossii* (Haw.) Schwantes (Stajsic personal observations). Similarly, one client submitted a specimen of a *Carex* obtained from a native plant nursery in Melbourne, which was distributing the plant as *Carex incomitata* K.R.Thiele (an uncommon native in the Melbourne area); the plant turned out to be the invasive alien **Carex divulsa* Stokes subsp. *divulsa.*

More recently, MEL received specimens of *Acacia cyclops* A.Cunn. ex G.Don from Barwon Heads near Geelong, for determination. This non-Victorian species had been propagated and used in revegetation schemes in the belief that it was the native *Acacia uncifolia* (J.M.Black) O'Leary (Reid and Murphy in press 2008). This was the first report of this invasive species for Victoria.

How are new weeds detected?

Seventy-nine percent of the additional alien taxa listed in Walsh and Stajsic (2007) since 2003 are regarded as being incipiently naturalised. This strongly supports the view that it is essential to detect new weed incursions early, while 'effective action is still possible and before the cost of control escalates and the weed infestation has compromised natural values' (Timmins and Braithwaite 2002). Early detection maximises the likelihood of successfully eradicating the weed, and reduces the negative effects on the natural environment.

Since 2002, MEL has collaborated with the Department of Primary Industries (DPI) in the WARR plan. The chief aims of the plan are to detect new incursions of new weeds before they become naturalised, and to instigate rapid notification of DPI staff in order to enable early remedial or eradication strategies. One of the potential benefits of this partnership for MEL is the receipt of herbarium voucher specimens to substantiate new weed records. MEL botanists also provide expert advice and warning of potential new weeds by helping compile 'target lists' of taxa that are either known to be serious environmental and economic weeds, but have not yet been recorded in Australia, or that have been recorded as weeds in other States, but, in Victoria, are currently known only from limited populations. Target lists are used to promote awareness of potential threats, and to focus survey efforts (Waterhouse 2003).

Hosking *et al*. (2004) point out that the majority of new plant naturalisations are detected or first recognised by those with a good knowledge of both the native and exotic flora. This observation is supported the *Census* data, where 76% of newly listed naturalised taxa in Walsh and Stajsic (2007) were first detected by herbarium staff or other botanists, or by knowledgeable members of the public. The remaining 24% were primarily fortuitous finds, detected mainly by members of the public.

One of the chief means by which botanists at MEL detect new weeds is by targeting areas that have proven likely to contain previously unrecorded naturalised taxa. Hosking *et al*. (2004) argue that an increased detection effort should initially target areas around population centres because most plants first naturalise in urban bushland and areas with a high concentration of gardens. Many new incursions originate from discarded garden refuse, or from propagules dispersed from gardens to native bushland by birds. In Victoria, two such areas that have yielded many new weeds over the last ten years are the Dandenong Ranges, and the Mt Macedon area.

Revegetation areas, particularly roadside plantations and soil conservation schemes, are another rich source of new weeds. Many of the taxa that naturalise at these sites are Australian natives. Carr *et al*. (1992) reported that at Anglesea in Victoria 36 of a total of 45 species planted in two revegetation areas were present as escapes in adjacent heathland and heathy woodland. Many of the Australian native naturalised taxa listed in both Ross and Walsh (2003) and in Walsh and Stajsic (2007), including *Acacia*, *Eucalyptus*, *Hakea* and *Melaleuca* species, were collected from roadside plantations. At the White Elephant Reserve in the Parwan Valley (near Bacchus Marsh), several Western Australian *Eucalyptus* species (including *Eucalyptus astringens* (Maiden) Maiden, *E. kondininensis* Maiden and Blakely, and *E. occidentalis* Endl.) have become naturalised. Other Australian natives naturalised at this site include *Callitris endlicheri* (Parl.) F.M.Bailey, *C. columellaris* F.Muell. and *Casuarina glauca* Sieber ex Spreng.

Several new weed taxa recently recorded for the first time in Australia were found at alpine ski resorts in Victoria. These include *Hieracium praealtum* Vill. ex Gochn. subsp. *bauhinii* (Besser) Petunn. at Falls Creek, and *Juncus ensifolius* Wikstr., which is abundant around Baw Baw Village and has spread along roadsides, ski runs and along the East Tanjil River (Stajsic and Hosking personal observation 2005). *Juncus ensifolius* Wikstr. has also been discovered at other ski resorts in Victoria.

Regional areas of long established agriculture should also be targeted, which is something that we are conscious of at MEL, and aim to do. These sites are subject to significant movement of stock, stock feed and agricultural machinery from around the state and throughout Australia, which may act as vectors for new weeds.

MEL botanists also work with DPI staff in conducting targeted searches for potentially invasive species. A recent example of this cooperation was an inspection of a newly discovered population of *Erica discolor* Andrews at Pomonal (near Grampians National Park), which yielded several other new weed records for Victoria, including *Erica glandulosa* Thunb. subsp. *glandulosa* and *Hakea prostrata* R.Br.

Although the above high risk areas are targeted by MEL botanists and others with a good knowledge of, and concern for, the native and naturalised flora, there are currently no systematic and regular surveys of these areas in Victoria. Unless we collect, document and positively identify new naturalisations, those responsible for managing the impact of weeds will be unaware of potential new problems in their jurisdictions (Hosking *et al*. 2004).

Accessing the resources of the National Herbarium of Victoria

The National Herbarium of Victoria is an invaluable and irreplaceable source of verifiable information on the State's flora. It is a dynamic collection that relies on the submission of good quality voucher specimens to maintain an up-to-date reference collection representative of Victoria's native and naturalised flora.

When Mueller founded the National Herbarium, he envisioned that it would be 'at all times accessible to the public' (Willis 1990). Unfortunately, a lack of resources has meant that this has rarely been the case throughout the Herbarium's history; however, access to the collections has improved dramatically in recent years, with the databasing of the Australian plant collections as part of the Australia's Virtual Herbarium (AVH) project. This collaborative project has allowed unprecedented online access to the species' distribution data held in Australia's major government-funded herbaria. The AVH website can be accessed via the Royal Botanic Gardens portal, at http://www.rbg.vic.gov.au/avh/.

Requests for more detailed information from MEL's collection are serviced at the discretion of the Collections Manager, and charges may be incurred. Enquiries should be directed to herbmel@rbg.vic.gov.au. Access to the Library and Collections is available to accredited researchers by appointment.

The Identifications and Information Service provides plant identifications, nomenclatural advice and information on plant distributions, and is the contact point for people wishing to submit voucher specimens to the Herbarium. The service is open from 10:00 AM – 1.00 PM each weekday. Please direct any correspondence to:

> Identifications and Information Service, Royal Botanic Gardens Melbourne Private Bag 2000, South Yarra Victoria 3141. Ph: (03) 9252 2315.

Copies of 'A Census of the Vascular Plants of Victoria 8th edition' (2007) can be obtained by contacting the Identifications and Information Service at the above address.

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Improving provincial Victoria's biosecurity by minimising the risk of new weed introductions

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Summary Recent research into the spread of weeds has found ordinary gardens are a major source of new weed introductions (Groves 2005). As part of the Victorian Government's 'Moving Forward: Making Provincial Victoria the Best Place to Live, Work and Invest' initiative, the Department of Primary Industries (DPI) is delivering a four year, $3.6 million project entitled 'Improving Victoria's Provincial Biosecurity' (IPVB) which aims to reduce the risks surrounding the introduction of high priority Victorian Alert Weeds in identified provincial urban and lifestyle regions in collaboration with DPI's Weed Alert Program. Social research has identified that lifestyle regions are expanding (Barr 2005), increasing the threat of new weed introductions in provincial Victoria.

Strategic engagement with industries and communities whose activities are linked to high risk weed introduction pathways in provincial Victoria provides an opportunity for proactive surveillance and adoption of preventative actions to reduce weed introduction.

Keywords: Provincial Victoria, lifestyle regions, introduction pathways, Victorian Alert Weeds, Improving Provincial Victoria's Biosecurity project (IPVB).

Introduction

Pest plants are key biosecurity threats to provincial Victoria's environmental, agricultural and community assets. In recent years, action to improve Victoria's surveillance and response to invading weeds through the Victorian Pest Management – A Framework for Action (VPMF) Weed Management Strategy, has seen the development and delivery of capacity building programs with key stakeholders on both public and private land to support a national biosecurity approach.

Parts of regional Victoria are enjoying a period of rapid growth in population, infrastructure, industry and investment. Recent research into pest plant origins has identified gardens as major sources of pest plant introduction (Groves 2005). Urban environments and their many gardens that interface with lifestyle regions are an area of ongoing weed introduction risk in provincial Victoria. Industry and community activities associated with these growth areas that are linked to pathways of introduction of new weeds are the focus of this project.

This paper presents a summary of a working project 'Improving Provincial Victoria's Biosecurity – High Priority Victorian Alert Weeds in High Risk Provincial Areas' that is working collaboratively with these industries and communities.

Assessing Victorian Alert Weeds

To work most effectively to protect Victoria from potential pest plant biosecurity threats, the IPVB project is working with a suite of weeds referred to as Victorian Alert Weeds. These are new weeds to Victoria that have the potential to threaten the State's environment and agriculture. Some of these are thought to be naturalised in small numbers but still eradicable, others are yet to reach Victoria but present a significant risk if they were to arrive and naturalise (Victorian Weed Alert Plan 2007). As these weeds are not declared under the *Catchment and Land Protection Act 1994*, there is no legislative barrier preventing their promotion, trade and movement around the State. These plants are being assessed using the Victorian Pest Plant Prioritisation Process, to identify the most serious threats. The distribution of each species is validated through surveillance to inform appropriate management strategies. The most serious will be recommended for declaration as noxious weeds.

Recognising invasion pathways

Invasion pathways are any means that lead to entry or spread of pests. The primary objective of a pathways analysis is to identify the species, assess the probability of its entry, the pathways by which it may enter Victoria or by which it may spread, and subsequently the consequences of its introduction. Pathway management is the most effective way to address unintentional introductions (King 2006).

Weed spread pathways are many and varied, examples include: naturally occurring (waterways), movement of inadvertently contaminated plant, equipment, goods, livestock or produce, deliberate introduction of plants, seeds and plant parts for business purposes and deliberate or inadvertent introduction of plants, seeds or plant parts by community members. Different industries are involved in activities that can potentially introduce and spread new weeds. As gardens are the most significant source of new weed introductions, the IPVB project will focus its engagement activities on the management of new weed introduction pathways associated with the garden industry and community garden interest groups in lifestyle regions.

The IPVB project aims to understand the risk, location and introduction pathways of Victorian Alert Weeds. Educating and working strategically with the community, industries and agencies can reduce the risk of damaging new weeds being introduced resulting in significant cost savings to agriculture, business and the environment.

Approach

One of the most significant transformations taking place in Victoria is the expansion of the 'new' urban lifestyle (amenity) regions through a growing demand for rural living (Barr 2005). The lifestyle (amenity) region provides a key focus for preventing the introduction and spread of new pests to Victoria. New species introduced through garden and landscape plantings can escape across the interface and threaten biodiversity, waterways, agricultural production and community assets. Engagement of agencies, industries, community groups and Weed Spotters involved in high risk introduction pathways, provides an opportunity for pro-active surveillance and adoption of preventative actions that will reduce the risk of introduction.

The project comprises two major components - the industry and agency component of the project that will have a focus across the central Victorian 'Lifestyle Amenity Region' and a more spatially discrete community component focusing on smaller priority regions (Figure 1).

The 'IPVB – High Priority Victorian Alert Weeds in High Risk Provincial Areas used a Priority Assessment Framework to develop a ranked list of priority areas. This comprised; potential/current distribution of previously assessed Victorian Alert Weeds, proximity to state borders and the major Hume Highway corridor, the number of households and potential gardens as an indicator of potential introduction points and level of interface with social, environmental and agricultural assets.

Industry and community engagement

DPI works proactively with a range of Victoria's key pest management stakeholders and has established strong partnerships with local government, industry, and the community. Understanding the

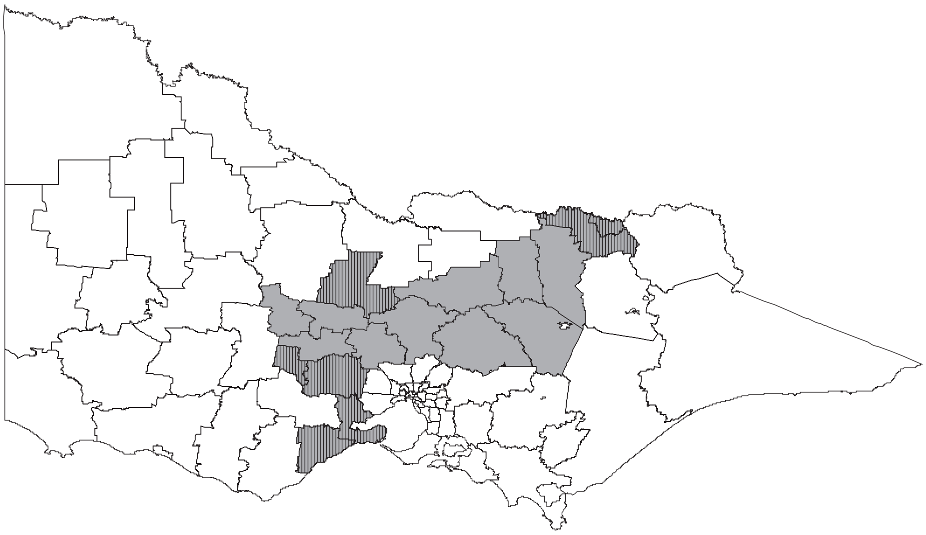

Figure 1. Focus areas for industry (shaded) and community groups (striped) across 17 municipalities for tackling the introduction of high risk Victorian Alert Weeds.

needs and drivers for each stakeholder group has been essential to developing this relationship. The business activities of many organisations have the potential to introduce new weeds into Victoria. For example when a pet shop sources aquatic plants from interstate. This level of risk has significantly increased in recent times, particularly where provincial urban areas interface with rural lifestyle areas. It is important to understand and work with these key segments of the community and industry to reduce the risks of introducing new weeds into Victoria.

The IPVB project aims to influence short term and long term behaviour change relating to weed management, in order to reduce the risk of introduction and incursion of high risk Victorian Alert Weeds in identified lifestyle regions. Industry mapping and stakeholder analysis has identified the stakeholders that are in the best position to assist with making these changes. They include environmental and non-environmental groups, industries and government agencies that can improve surveillance capacity to spot and report Victorian Alert Weeds through the Weed Spotter network. They also include plant interest groups, garden industry segments and government agencies who can assist with the development and implementation of mitigation strategies in high risk introduction pathways.

The IPVB project has undertaken stakeholder analysis to inform the development of engagement strategies to achieve the desired changes sought by the project. Examples of these desired changes include, increased surveillance of high risk Victorian Alert Weeds in identified lifestyle regions and industry participants implementing risk mitigation strategies for introduction of Victorian Alert Weeds.

The selection of engagement activities and products used to influence change will be tailored to meet the specific needs of each stakeholder as identified in the stakeholder analysis.

Discussion

The IPVB initiative will invest in tackling the introduction pathways of Victorian Alert Weeds as opposed to the more traditional management focus of tackling established weeds in rural segments. The IPVB initiative will be delivered in an environment of significant change. Globalisation, land use change and environmental events such as drought, are beyond the influence of the project. It is within this context that the IPVB project seeks to influence change in project stakeholder behaviour over the long term. To provide certainty of project impacts in such a dynamic environment a project management framework has been developed. A key component of this framework is a project evaluation plan which will measure project progress and its impact upon completion. The project framework will also take into account the need for flexibility to respond to influences beyond the control of the project.

With these project management processes in place over the next three years, the IPVB project will build upon previous initiatives and work in collaboration with the DPI Weed Alert program to reduce the risk of introduction and incursion of high risk Victorian Alert Weeds in identified rural lifestyle areas, thereby increasing weed management support to the community.

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Response of Chilean needle grass (*Nassella neesiana*) and phalaris (*Phalaris aquatica*) seedlings and mature plants to changes in soil phosphorus, nitrogen and soil pH

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Abstract

Chilean needle grass (*Nassella neesiana* (Trin. & Rupr.) Barkworth, CNG) is commonly found growing in pasture swards with more desirable and more palatable pasture species such as *Phalaris aquatica*. CNG is known to replace more desirable species and compete for soil resources in pasture and grazing situations. This paper describes an experiment which evaluated the relative responses of CNG and phalaris to different soil pH levels and the addition of phosphorus and nitrogen in a glasshouse environment. The application of these treatments was to establish what soil conditions favoured the growth of each of the species.

The addition of phosphorus generally increased the growth of both species. Phalaris plants were taller than CNG plants during the late seedling stages although CNG was taller by plant maturity across all soil pH treatments. Soil with neutral pH favoured both species. The plant height response of phalaris to soil phosphorus and pH was relatively larger than that of CNG plants. Overall, plant productivity was reduced across both species in acid or alkali soils without additional phosphorus.

Plants that were treated with nitrogen fertiliser were excluded from the analysis as they had symptoms of nitrogen burning and their growth was detrimentally affected.

Under glasshouse conditions, CNG was able grow more rapidly than phalaris, producing larger and taller plants, although its general trends were similar to phalaris. Although phalaris may be more responsive during early growth to certain soil management techniques, such as soil pH, the overall response of phalaris during later growth was less than that of CNG. These results suggest that CNG is likely to have a competitive advantage over phalaris in the field and that alteration of pH or soil phosphorus level is unlikely to alter that.

Arrowhead in Victoria: current control methods and potential for biological control

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Summary The exotic emergent aquatic weed arrowhead (*Sagittaria platyphylla*), originating from north and central America, is particularly invasive in northern Victoria and southern New South Wales including the Murray River. Chemical control is currently used to manage the species, but there would be significant advantages in developing biological control to provide a cost-effective means for controlling existing populations and limiting further spread.

Keywords: Arrowhead, aquatic weed, chemical control, biological control.

Introduction

Water resources in temperate Australia are under threat not only due to drought, over-exploitation and pollution, but also due to biotic invasions. A number of introduced aquatic plants are serious threats to Victorian waterways, wetlands, lakes, pondages and farm dams. The majority of these were introduced for the ornamental and aquarium trades, while others were introduced accidentally, for example, as contaminants. Indiscriminate dumping of unwanted aquarium and ornamental material has seen the naturalisation and rapid spread of a number of aquatic weed species, among them arrowhead.

Taxonomy

Arrowhead is a generic name that refers to exotic species from the Alismataceae family naturalised in Australia (Hnatiuk 1990); two species are considered as invasive. The first species, *Sagittaria montevidensis*, has two sub-species, both of which are present in Australia (Aston 1973): *S. montevidensis calycina* originates from north America while *S. montevidensis montevidensis* originates from south America. *S. montevidensis* is invasive in NSW in rice fields and irrigation channels (Sainty and Jacobs 1981). Some confusion existed on the taxonomic identity of the second species of *Sagittaria*, which is invasive in waterways in northern Victoria and southern NSW, as the names *Sagittaria graminea* or *S. platyphylla* are found in the literature. Material originally collected by Aston from northern Victoria, near Wunghnu, was identified as *Sagittaria graminea* Michx. var. *weatherbiana* (Fernald) Bogin (Aston 1967). Specimens collected in irrigation channels between Nathalia and Yarrawonga were identified as *Sagittaria graminea* var. *platyphylla* Engelmann (Conn 1994). Due to the difficulty in identifying arrowhead species and the small number of herbarium specimens kept at the Melbourne herbarium, surveys were conducted in 2005–06 throughout invaded areas in the irrigation districts of northern Victoria to collect suitable material for identification (Sellwood *et al.* 2006). Forty-one arrowhead infestations were surveyed and at each site, specimens were collected and preserved. Specimens from all surveyed sites were sent to Dr Brian Keener, a north-American specialist of the genus *Sagittaria*, at University of Alabama, Tuscaloosa, and all were identified as *Sagittaria platyphylla* (Engelmann) J.G. Smith. This taxon, previously known as *Sagittaria graminea* var. *platyphylla* Engelmann, was raised to the species level by Kortright (Kortright 1998). *S. platyphylla* is native to north and central America. Its distribution includes predominantly the southern states of the USA from Florida to Texas and extends to Mexico and Panama. In the USA, *S. platyphylla* grow in streams and lakes from sea level up to an altitude of 900 m (Haynes and Barre Hellquist 2000).

Status

Sagittaria spp. are not currently declared weeds in Victoria (under the *Catchment and Land Protection Act 1994*), New South Wales or Queensland. *Sagittaria platyphylla* and *Sagittaria montevidensis* are declared N1 weeds in South Australia (the presence of the weed is notifiable throughout the State (in some parts of the State only for *S. montevidensis*) and plants must be destroyed throughout the State (in some parts of the State only for *S. montevidensis*)). In Western Australia, they are declared as P1/2 weeds (P1 prevents the trade, sale or movement of the weed, P2 enforces the eradication of a weed not yet widely established in WA). In Tasmania, the weed is a declared species for which restrictions measures are specified in weed management plans.

A risk assessment has been carried out by scientists from the Department of Primary Industries as part of the Victorian noxious weeds review, in consultation with Catchment Management Authorities, and the weed was ranked as relatively invasive with a score of 0.58. A process to assess *Sagittaria* spp. for possible declaration as noxious weeds is underway.

Chemical control

Several herbicides are registered for control of *Sagittaria montevidensis* in rice crops. No herbicides are registered specifically for control of *Sagittaria platyphylla*. A small number of minor use permits have been issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA) to authorise work by Goulburn Murray Water Authority, Murray Irrigation Ltd and the Central Murray County Council, NSW and are available online at http://www.apvma.gov.au/permits/permits.shtml. Under permit, 2,4-D is used to control *S. platyphylla* in irrigation channels and specified natural waterways, a commercial product containing imazapyr and glyphosate is used in irrigation channels and drains and glyphosate is used in a range of circumstances. However, very high glyphosate rates (up to 40 L per hectare) are required.

A problem with herbicide application is that while emergent plants can be killed, submerged rosettes survive and require re-treatment when they become emergent. The use of herbicides has to be carried out with great care to ensure that maximum concentrations set to protect the environment or (in some cases) drinking water quality are not exceeded and that irrigation water is safe to use. A particular problem arises in billabongs where the shallow water and lack of flow make it difficult to apply the required herbicide rates without exceeding the allowable concentrations in water. When large areas of *Sagittaria* require treatment, it is sometimes necessary to spray sections progressively to avoid the water quality effects that would occur if a large weed mass was all killed at once.

Potential for biological control

Due to the many difficulties associated with chemical control and the rapid spread of *S. platyphylla* infestations, the Department of Primary Industries was contracted by the Goulburn-Broken Catchment Management Authority to investigate the potential for biological control of arrowhead. An extensive literature review was conducted to identify the flora and fauna associated with the weed in its native range and in Australia (Sagliocco and Bruzzese 2005). References to pathogens associated with Alismataceae overseas were rare and no record of fungal pathogens on *S. platyphylla* was found. A number of weevils

(Coleoptera: Curculionidae) are known to attack *Sagittaria* spp. in the USA (Blatchley and Leng 1916, Center *et al.* 1999, O'Brien 1981, 1977). Thirteen species of *Listronotus* are described as being associated with *Sagittaria* spp. (*S. sagittifolia*, *S. engelmanniana*, *S. lancifolia*, *S. latifolia*, *S. graminea*, *S. longiloba*, *S. cuneata* or *Sagittaria* sp.) Thirteen additional *Listronotus* species are also described, but their host-plant(s) are still unknown. However, they are likely to be within the genus *Sagittaria* due to the very high specialisation within the Curculionidae family. *Listronotus* spp. have been found to be the most common species feeding and breeding on *Sagittaria* spp. and were observed feeding on root collars, leaves, stems, stalks, flowers, fruiting heads (Center *et al.* 1999, O'Brien 1981) or to cause stem galls (O'Brien 1981). Also in the Curculionidae family, *Brachybamus electus* Germar, *Anchodemus angustus* LeConte and *Barinus bivittatus* LeConte have been recorded on *Sagittaria* spp., but their plant association is not mentioned (Blatchley and Leng 1916). Outside curculionids, *Plateumaris* (Coleoptera: Chrysomelidae) are also reported associated with *Sagittaria* roots (Jolivet and Hawkeswood 1995). Finally, the diptera leafminer *Hydrellia deceptor* Deonier (Diptera: Ephydridae) is reported associated with *Sagittaria* sp. in the USA (Deonier 1971, 1998).

Discussion

Although mapping of *S. platyphylla* infestations is incomplete, the rate and extent of invasion has increased dramatically from creeks to irrigation channels and wetlands, with the greatest threat being the invasion of the whole Murray River system. The lack of registered herbicides combined with the difficulties of application and the need to protect water resources from contamination make the chemical control of arrowhead extremely difficult. The genus *Sagittaria* is not native to Australia and does not contain economically important species. Thus biological control represents an attractive option to achieve long term control of existing populations and limit further spread.

As a priority, it is necessary to conduct genetic studies on populations of the weed in Australia to identify precisely its parent populations in North America. While the initial literature review has shown that a number of specialist herbivores exist in the genus *Listronotus*, further surveys in the southern USA and central America are necessary to complete this study and to conduct detailed observations on the ecology of *S. platyphylla* and its natural enemies. In North America, the wide range of *S. platyphylla* would allow for selection of appropriate species and biotypes of biological control agents adapted to climatic situations similar to Australia.

Biological control of aquatic weeds has been successful, even spectacular in some cases, and aquatic weeds count among the most successful cases in the history of biological control. While water supplies, usage and conservation come under increased scrutiny, it is desirable that co-operative arrangements are developed between the different organisations involved in water delivery and conservation, such as water users, the different levels of government and research scientists, to further investigate biological control of arrowhead.

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Weeding out Australia's worst willows

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Summary We compared two risk assessment methods that can be used to rank and categorise willow taxa based on their potential to have serious impacts on Australia's social, economic and environmental values. The first was a generic weed risk assessment and the second, a risk assessment process tailored to discriminate between willows. We then used the rankings from the tailored risk assessment to determine which willows pose the biggest threat to natural resources and hence recommend them as a high priority for weed management. The tailored assessment identified 13 taxa that can confidently be considered to have the most serious impacts. It also identified several low impact taxa, but the quality of the data available to assess these taxa was of a much lower calibre. A complete weed risk assessment of willows should also include consideration of invasiveness and distribution. These are yet to be undertaken, and will be crucial to determining the full risk potential of the members of this genus. Being able to differentiate willows in terms of their impacts takes us one step closer to being able to set strategic priorities for willow management across Australia.

Introduction

Willows (*Salix* spp.), is a taxonomically complex genus comprising more than 400 taxa worldwide (van Kraayenoord *et al.* 1995). More than 100 willow taxa have been introduced to Australia. Eleven species are naturalised (ARMCANZ 2001, APC 2007, APNI 2007), and there are also at least 25 described subspecific taxa and many hybrid combinations.

Willows were nominated, assessed and listed at the generic level for classification as Weeds of National Significance (WoNS) (Thorpe and Lynch 2000); however three *Salix* taxa were not included in the WoNS as they appeared to be 'non-weedy', and a further six were exempt from declaration in Victoria.

Willow infestations are targets for either eradication or containment in Australia (ARMCANZ 1999). Determining the feasibility control methods is complicated by the large number of taxa involved and the likelihood that some of these pose a larger weed threat than others. Furthermore, to ensure that willow management strategies are cost efficient, it is important to decide which willows require control, and which can be considered safe enough to leave *in situ*, or even continue to be planted.

Methods

Two risk assessment methodologies were used to assess willows. The methods section is in two parts: an analysis of the Victorian Pest Plant Prioritisation process used initially to assess willows, and a description of the process of developing a specific willows risk assessment tool.

Analysing the Victorian Pest Plant Prioritisation Process

The Victorian Pest Plant Prioritisation Process (PPPP) method used to assess the willows (Weiss *et al.* 2004) accords with the National Post border Weed Risk Management Protocol (SAI 2006). As such, the complete assessment process considered:

1. Invasiveness (or biological traits),
2. Potential for spread (by comparing current and potential distributions), and
3. Impacts on land use and ecosystems (or ecology).

This paper is primarily concerned with the impacts component of the assessment. The criteria that were used for this assessment are listed in Appendix 3. We examined the spread of scores that resulted from this assessment to determine how many questions were able to discriminate between the willows. A subset of 14 willow taxa was selected for this analysis.

Developing the criteria for assessing the impacts of willows

In February 2007 criteria were developed to assess the relative impacts of a range of willow taxa. Criteria were developed that would be used to assess the degree of impact that each willow taxon might have on social, economic and environmental values. These criteria needed to differentiate between willow taxa, and provide evidence for their impact on social, environmental or economic values.

The ranking criteria are presented in Appendix 1. Each criterion was based around a question, and scored either as 'high impact', 'moderately high impact', 'moderately low impact' or 'low impact', according to the descriptors that were developed for each intensity rating.

Once the assessment criteria were determined, a literature search was performed, and expert opinion sought, to find the answers to the 10 impacts questions for each willow taxon assessed. In all cases, the 'worst-case scenario' was used. If there was evidence that a willow was capable of having a large impact in a particular environment, it scored highly, even if its impact was lower in other types of environments.

A range of literature was used to perform the assessments, from journals, books and internet sites, to expert opinion. A confidence score was attributed to each question answered to give an indication of the quality of the data used to assess each taxon, according to the descriptions in Appendix 2.

The descriptive scores of high (H), medium high (MH), medium low (ML) and low (L) were converted into the following numerical scores: H = 1, MH = 0.67, ML = 0.33 and L = 0.

If there was insufficient evidence available to answer a question for a particular taxon, a score of medium (M) was chosen, with a value of 0.5; likely to cause the least amount of error, as it could only be inaccurate by ±0.5. In such a case as this, a confidence score of L was chosen.

Once all the questions had been answered for a willow taxon, the descriptive scores were converted to numerical scores. Each numerical score was divided by 10, so that when a taxon's scores for each question were added together, the score would fall between the values of 0 and 1. The higher the score, the greater was degree of impact that the willow could have. The willows were then ranked from the highest score to the lowest. Similarly, confidence scores were converted to a numerical value from 0 to 1. The full assessments, including the evidence used for each taxon are available at www.weeds.org.au/WoNS/willows. A summary of the scores is in Appendix 4.

Which willows to assess?

The 16 willow taxa assessed using the Victorian PPPP were chosen because they are declared noxious in Victoria, and are naturalised in Australia. However, to determine which taxa that should be high priorities for management, we assessed a larger list that included non-declared taxa, potential low risk candidates, and also tried to identify willows that might become weedy in Australia in the future. We limited the assessment list to taxa that have been introduced to Australia, including taxa that have naturalised in Australia; or have the potential to naturalise in Australia, either due to a history of naturalising overseas or because they exhibited invasive traits; or that appeared unlikely to become serious weeds in Australia.

We also assessed individually the three major groups of willows, the subgenera *Salix*, *Vetrix* and *Chamaetia* (Skvortsov 1999). Species within each *Salix* subgenus often share many biological and ecological traits.

A recent modelling exercise highlighted the weed risk associated with some exempt taxa (Stokes and Cunningham 2006), so willows that were exempted from noxious weed legislation in any Australian state were also assessed.

Analysing the willows impacts assessment
We examined the spread of scores that resulted from this assessment to determine how well these questions were able to discriminate between the willows. A subset of 14 willow taxa was selected for this analysis; those that were also assessed using the Victorian PPPP process.

Results

Results for the Victorian Pest Plant Prioritisation Process
Many of the criteria used to assess the weediness of willows were not able to discriminate between different taxa. In 13 of the 26 questions, all willows achieved the same score. Furthermore, in question 11 all the willows rated either H or MH, and in question 19, either L or ML (Figure 1). For more than half of the impacts assessment there was very little separation in the scores attained by each willow taxon.

Social impacts Only two social impacts criteria provided any separation value between the willow taxa: restricting access (1)[1] and reducing tourism (2). All taxa attained a low score for ability to injure to people (3) and high for ability to cause major damage to cultural sites or infrastructure (4).

Abiotic impacts Whilst some willows scored higher than others for impacts on water flow (5) and soil erosion (7), the other three questions relating to abiotic impacts did not differentiate the willow taxa assessed. All willows assessed were considered to have a high impact on water quality (6); to be capable of increasing vegetative biomass (8); and the potential to greatly reduce the frequency and intensity of fire risk (9) in the habitats in which they occurred.

Community/habitat impacts All assessed taxa were considered to have a high or moderately high impact on the structure of vegetation communities (11). There was some variation in the impacts on high value Ecological Vegetation Classes (EVCs) (10a), however, willows were not considered to impact on any low or medium value EVCs (10b and c).

Impacts on threatened flora (12) and fauna (13) were considered high for one species, medium high for most, and medium (which is the score for 'unknown') for a couple of the willow taxa.

Impacts on fauna All willows were documented as having a moderately high impact on native fauna (14). The ability of willows to provide some assistance in shelter to desirable species was considered high for one taxon, medium high for most, and medium (which is the score for 'unknown') for three of the willow taxa. No willow taxa were found to possess properties injurious to fauna (16).

Pest animal impacts There was some variation in the willows' potential to provide a food source to minor pest species (17) and capacity to provide harbour to pest animals (18).

Agricultural impacts The Victorian PPPP of willows indicated that willows generally have few impacts on agriculture. There was no information in the literature to indicate that any of the willow taxa have: affected agricultural quality (20) or land value (21), caused a change in land use (22), or provided a host to pests or diseases of agriculture (24), hence all taxa attained low scores for the criteria addressing these impacts. Impact on agricultural yield (19) varied from low to medium low and there was varying ability of willows to increase in harvest costs (23).

Results for the willows risk assessment
Compared to the willow impact scores from the Victorian PPPP (in Figure 1), the willows risk assessment resulted in a greater spread of scores across all the criteria (Figure 2).

The scores and ranks of the willows assessed appear in Table 1. The annotations relate to the reason(s) that each taxon was chosen for assessment.

Of the 20 taxa that had an impact score at or above the mean (0.60), 17 are naturalised in Australia This group includes two subgenera, *Salix*, ranked at two; and *Vetrix*, ranked at 10. *Salix daphnoides*, ranked at 17, is not naturalised in Australia, but

Footnote
[1] A numbered list of the criteria used in the Victorian PPPP is in Appendix 3, and these numbers appear in brackets in the text to indicate which criterion is being addressed. The criteria were broadly categorised according to the types of values that may be impacted by weeds: social, abiotic, community/habitat, fauna, pest animals and agricultural values. Full assessments for all of the plants that have been assessed using Victoria's PPPP can be found at www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_pest_plants.

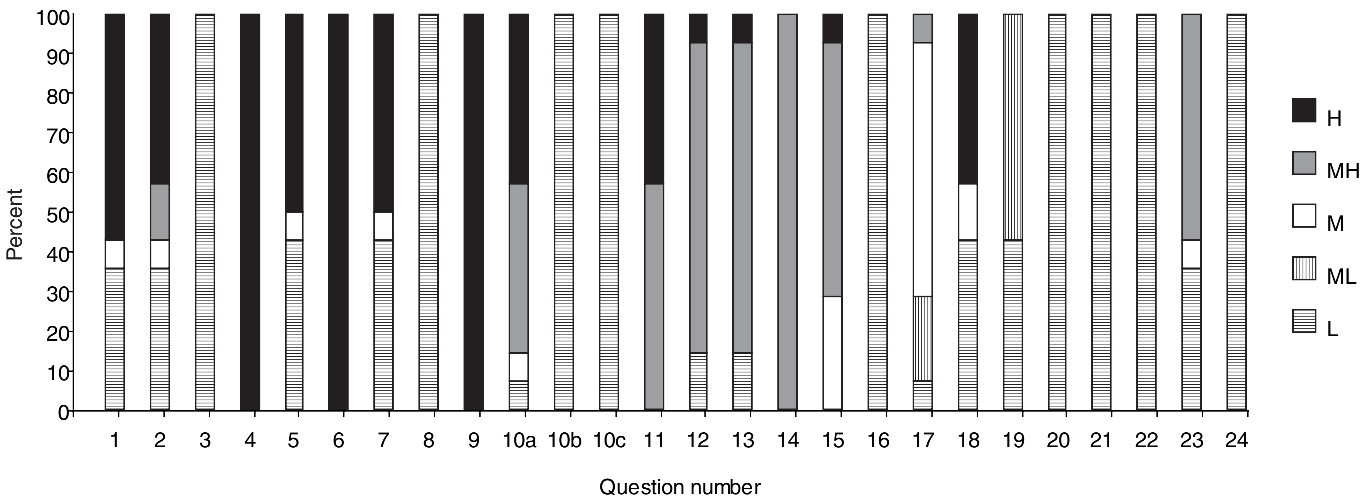

Figure 1. Spread of scores from the Victorian PPPP for the impacts of willows. Proportion of willows that scored H, MH, M, ML or L for each question.

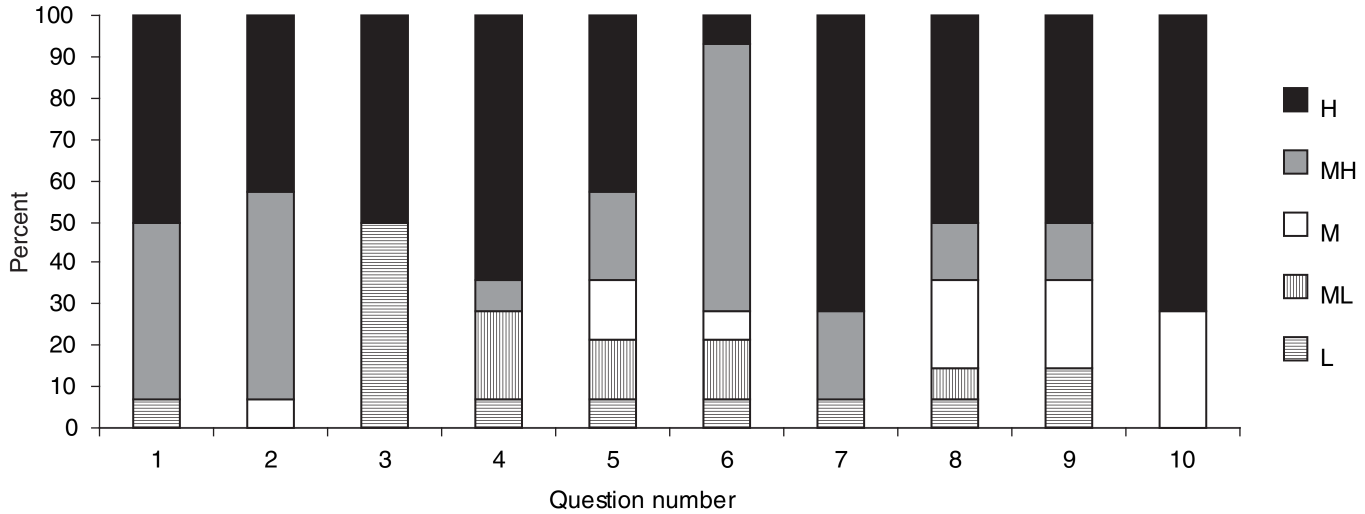

Figure 2. Spread of scores from the willow impacts risk assessment. Proportion of willows that scored H, MH, M, ML or L for each question.

Table 1. Scores and rank, from highest impact (1) to lowest (35) of willows assessed with the new impacts assessment.

Taxon	Common name	Score	Rank	Conf.
*S. × *rubens*	white crack willow	0.97	1	0.67
*S. subgenus *Salix*	tree willows, true willows	0.93	2	0.67
**S. fragilis*	crack willow	0.93	2	0.67
**S. nigra*	black willow	0.93	2	0.67
**S. alba*	white willow	0.90	5	0.67
*†*S. babylonica*	weeping willow	0.88	6	0.60
**S.* × *sepulcralis*	golden weeping willow	0.87	7	0.65
**S. cinerea*	grey sallow	0.83	8	0.67
**S. triandra*	almond willow	0.80	9	0.67
**S.* subgenus *Vetrix*	shrub willows, sallows, osiers	0.77	10	0.67
**S. purpurea*	purple osier	0.77	10	0.58
**S. viminalis*	common osier	0.77	12	0.62
%*S. exigua*	sandbar willow	0.75	13	0.60
*‡*S. alba* × *matsudana*	NZ hybrid willow	0.75	13	0.42
**S.* × *pendulina*	Wisconsin weeping willow	0.73	15	0.37
%*S. glauca*	Arctic grey willow	0.65	16	0.45
#*S. daphnoides*	violet willow	0.62	17	0.60
**S.* × *mollissima*		0.60	18	0.35
*†*S.* × *reichardtii*	pussy willow	0.60	18	0.43
**S. matsudana* (‡'Aurea' and 'Tortuosa')	tortured willow	0.60	20	0.63
*†*S.* × *calodendron*	pussy willow	0.58	21	0.30
#*S. eriocephala*		0.57	22	0.67
#*S. pentandra*	bay willow	0.57	23	0.30
%*S. gracilistyla*		0.55	24	0.63
**S. caprea* (‡'Pendula')	goat willow (great sallow)	0.52	25	0.58
**S.* × *sericans*	pussy willow	0.52	26	0.18
**S. glaucophylloides*	broadleaf willow	0.45	27	0.32
**S. aegyptiaca*	Egyptian willow	0.42	28	0.43
#*S. elaeagnos*	hoary willow (bitter willow)	0.35	29	0.58
‡*S. myrsinifolia*	dark-leaved willow	0.30	30	0.28
**S. humboldtiana 'Pyramidalis'*	Chilean pencil willow	0.22	31	0.48
S. subgenus *Chamaetia*	alpine, arctic willows	0.12	32	0.48
‡*S. alba* var. *caerulea*	cricket bat willow	0.10	33	0.52
^*S. integra* 'Hakuro-nishiki'	Nishiki willow	0.10	33	0.57
^*S.* × *'Boydii'*		0.00	35	0.53
Mean		0.60	–	0.53

*Naturalised in Australia. #Naturalised overseas. †Exempted from the WoNS. ‡Exempt from declaration in Victoria. %Exhibits invasive traits. ^Appears to be low-risk.

has become invasive in New Zealand (van Kraayenoord *et al.* 1995). The top 20 also includes two taxa that were exempted from the WoNS, and three taxa that were exempt from declaration in Victoria. The remaining two species in this highly ranked group, *S. exigua* and *S. glauca* do not have a history of becoming invasive, but were chosen for assessment because they exhibited traits that suggest they may become invasive.

The taxa with impact scores below the mean included many that have not naturalised beyond their native range, however, six of them have naturalised in Australia: *S. × calodendron*, *S. caprea*, *S. × sericans*, *S. glaucophylloides*, *S. aegyptiaca* and *S. humboldtiana* 'Pyramidalis'. Three of the taxa have naturalised overseas: *S. eriocephala*, *S. pentandra* and *S. eleaegnos*. *S. gracilistyla*, a non-naturalised willow that exhibits invasive traits, achieved a an impact score below the mean.

Salix × boydii, not known to be naturalised anywhere in the world, attained the lowest possible impact score of 0. This indicates that it was rated as low for every impact assessment criterion. Also ranked in the bottom six were four further non-naturalised taxa. Two of these are exempt from noxious weed declaration in Victoria. The only naturalised willow in the bottom six was *S. humboldtiana* 'Pyramidalis'.

The confidence score is an indication of the quality of data that was used to assess each willow. The average confidence score was 0.53. Lower confidence scores were found to be associated with taxa having low impacts. The top 13 ranked willows all had confidence scores above the mean. The very lowest confidence scores, below 0.33 (or ML in the scoring system) were attained by some Australian naturalised taxa: *S. calodendron*, *S. × sericans*, and *S. glaucophylloides*; by *S. pentandra* , which has naturalised in the USA (Argus 1986); and by *S. myrsinifolia*. All of these taxa scored below the mean on the impacts ranking, but we cannot be sure that their scores are accurate, due to a lack of data.

Discussion

The Victorian Pest Plant Prioritisation Process

Social impacts Certain willows form thickets as well as grow in-stream, which gives them the capacity to significantly restrict human access to watercourses, and well as restricting access by boats. These characteristics, combined with their ability to reduce channel capacity (Cremer 1995, Purtle *et al.* 2001) can lead to a reduction in tourism, and activities potentially affected include: boating, fishing, swimming, canoeing and bird watching. Single-trunked species and those valued aesthetically such as *Salix matsudana* and *S. glaucophylloides* (Ladson *et al.* 1997) were not considered to reduce tourism.

No reference to willows being directly injurious to people was found, therefore all taxa attained a low score for this criterion. Damage to buildings may occur when stream channel routes are altered as a result of blockage by willow roots, (Sarah Holland-Clift personal communication 2006) and during flooding episodes the build up of woody material from willows in rivers can destroy bridges (ARMCANZ 2001). Thus, willows generically were considered to have the potential to cause major damage to cultural sites or infrastructure and all taxa scored high for the criterion addressing this impact.

Abiotic impacts Willows were considered to have a high impact on water flow, if they had the capacity to grow within streambeds, therefore interrupting the flow of water (Purtle *et al.* 2001), or if their roots intruded extensively into stream beds (Ladson *et al.* 1997). Taxa confined to riverbanks were considered less likely to impact on flow. All willows assessed were considered to have a high impact on water quality because, as deciduous plants (Carr 1996), mass leaf fall in autumn can decrease dissolved oxygen levels, and willows can also cause intense shading as their canopies tend to be denser than native species (Ladson *et al.* 1997). Willows that encroach into the centre of streams interrupt water flow, which is then directed into banks causing erosion. In severe cases, extreme blockages can occur, causing streams to change course (Purtle *et al.* 2001). Therefore, taxa that encroach into streams have a high probability of increasing soil erosion. As woody shrubs or trees with the capacity to form dense thickets, (Carr 1996) all willows assessed were capable of increasing the vegetative biomass where they replaced lower or less dense vegetation, a regular occurrence on disturbed sites (Cremer 1999). Willows have low combustibility and flammability (Carcallet *et al.* 2001), and all taxa had the potential to greatly reduce the frequency and intensity of fire risk in the habitats in which they occurred. Whilst some willows scored higher than others for impacts on water flow and soil erosion, the other three questions relating to abiotic impacts did not differentiate the willow taxa assessed.

Community/habitat impacts The formation of dense thickets, intense canopy shade, and mat-forming roots of willows, can suppress and exclude indigenous understorey (Cremer 1999, Purtle *et al.* 2001), with the result that all assessed taxa were considered to have a high or moderately high impact on the structure of vegetation communities. They would consequently have a similarly high impact on invaded Ecological Vegetation Classes (EVCs), however, the degree of impact was considered dependant on the suitability of the climatic match for the species. Climatic modelling showed that some taxa are not likely to occur as invasive plants in Victoria, giving these taxa a low score both for this criterion, and also for impact on threatened flora. The vegetation communities of all water bodies in Victoria were considered to comprise high value EVCs, therefore willows were not considered to impact on any low or medium value EVCs.

Although willows are well documented as having a significant impact on vegetation communities, little information was found in regard to their impact on threatened flora. Only *S. cinerea* was specifically identified, being described as the most serious willow preventing the recruitment of *Eucalyptus camphora*, a dominant component of the rare sedge-rich *E. camphora* Swamp community, listed under the *Flora and Fauna Guarantee Act 1988* (Ladson *et al.* 1997).

Climatic suitability was the main factor separating willows in the two questions that showed much variability in the community/habitat section of the impact assessments.

Impacts on fauna Willows are documented as having a significant impact on native fauna, with the ability to decrease available habitat and reduce population numbers. For example, shading from willows decreases primary production and impacts on aquatic invertebrates and fish (Ladson *et al.* 1997). Willows suppress and kill indigenous vegetation that would otherwise provide valuable habitat and food for insects, birds and other vertebrates, and bare banks beneath willows provide little protection for fauna such as frogs, water rats, snakes and lizards. Willows do not provide nectar for birds, have few hollows (Purtle *et al.* 2001) and provide less large woody debris in stream than native tree species, important habitat for aquatic fauna (Ladson *et al.* 1997).

Again, no information was found specifically documenting the impact of particular willow taxa on threatened fauna, except for *S. cinerea*, which is described as having the potential to destroy important habitat of the endangered Leadbeaters possum and helmeted honeyeater, as well as the rare broad toothed rat (Ladson *et al.* 1997).

Possums are known to graze and defoliate willows (ARMCANZ 2001). Thicket forming willows provide cover for wildlife in the USA (Anderson 2006); therefore willows are likely to provide some assistance in shelter to desirable species (15). *Salix glaucophylloides* is unpalatable (Webb *et al.* 1998) and as having a single trunk (Haines 2003), so it was considered to provide very little benefit to fauna. No reference was found in the literature to suggest that any willow taxa possess properties injurious to fauna, and consequently all taxa attained a low score for the criterion associated with this impact.

Pest animal impacts Only *S. purpurea* was documented as providing a food source to rabbits, a serious pest (Dickerson 2002). *Salix alba* and *S. exigua* were described as being palatable (Anderson 2006), and rodents are documented as eating the buds of *S. nigra*, therefore, these willows have potential to provide a food source to minor pest species.

Willow stands are described as providing excellent cover for wildlife in the USA (Anderson 2006), therefore, thicket forming taxa, such as *S. exigua*, *S. cinerea*, *S. fragilis*, *S. purpurea*, *S.* × *rubens* and *S. viminalis* (Anderson 2006, Cremer 1995, 1999, 2001, Webb *et al.* 1988) are likely to have the capacity to provide harbour and permanent warrens to rabbits and foxes. Non-thicket forming willows are unlikely to provide harbour.

Agricultural impacts The Victorian PPPP of willows indicated that willows generally have few impacts on agriculture. There was no information in the literature to indicate that any of the willow taxa have affected agricultural quality or land value, caused a change in land use, or provided a host to pests or diseases of agriculture, hence all taxa attained low scores for the criteria addressing these impacts. Several species were described as agricultural weeds in USA and New Zealand (Holm *et al.* 1979), but as they are not recorded as invaders of pasture or crops, their impacts are likely to be associated with waterways. Their ability to form dense thickets restricting access for irrigation is likely to be the only impact they have on agriculture, and willow root mats are described as reducing access to flowing water (Sarah Holland-Clift personal communication 2006). This may have a minor impact on agricultural yield, as well as cause a minor increase in harvest costs due to the requirement to maintain waterways for irrigation purposes.

Willows are clearly able to seriously impact many of our social and environmental values, but their impacts tend to be confined to habitat niches in riparian and wetland areas (Richardson *et al.* 2006), largely affecting abiotic components of aquatic systems as well as biodiversity. Many similarities exist between different willows because they are a closely related group of taxa that grow in similar habitats and the minor variation was not adequately captured by the Victorian PPPP. Another factor that reduced the separation value of the Victorian PPPP of willows was that many of the criteria are not particularly applicable to willows.

A generic weed risk assessment needs to be suitable to assess a large number of different species, which the Victorian PPPP was developed to achieve. However, it was not designed to detect the differences between similar and closely related taxa, such as the willows. Aquatic plants also tended to attain similar scores using this PPPP, so an aquatic weed risk assessment was also developed for Victoria (Weiss 2007), New Zealand has a weed risk assessment tailored to aquatic plants as well (Champion and Clayton 2001).

Defined groups of weeds affecting particular values or a specific habitat type can be subject to specialised weed risk assessment tools. New weed risk assessment tools should be tailored to pick up specific negative characteristics and impacts of the target group. Willows contain many potentially serious weedy taxa, therefore developing an effective weed risk assessment tool identifies which are likely to be the most serious weeds.

The impacts that willows have are largely related to several main characteristics, such as, the ability to form dense thickets, grow within streams, undertake mass autumn leaf drop and develop large, invasive root systems. Impact assessment criteria for willows therefore need to utilise these characteristics. However, the impact criteria must discriminate between different willow taxa. The aim of the willow risk assessment is to determine which are the worst willows in Australia; which should be the focus of our management efforts.

Willows impacts assessment

The willows risk assessment process revealed that the two subgenera *Salix* and *Vetrix* have above-average potential for impact, and the subgenus *Chamaetia* was very low. The assessment of the three subgenera aimed to give an overview of the weed risk posed by each subgeneric group of willows. As *Chamaetia* are not naturalised anywhere in the world, despite a history of translocation dating back to at least 1906 (Tennant 2004) it appears likely that many of the willows in this subgenus present a low weed risk.

Of the 20 willow taxa with high impact scores, the 17 naturalised taxa are of most concern. Since they have proven capable of establishing in the Australian landscape they are likely to become the highest priorities for management. Two willow species (*S. babylonica* and *S.* × *reichardtii*) from this high impact group that were exempted from WoNS are of particular concern, as are the taxa that were exempted in Victoria (*S. alba* × *matsudana*, and *S. matsudana* vars. 'Aurea' and 'Tortuosa). Whilst they are valued for their aesthetic qualities (van Kraayenoord *et al.* 1995), their potential to affect social, economic and environmental entities suggests that they will also require management intervention.

Also of concern is *S. daphnoides*, naturalised in New Zealand (van Kraayenoord *et al.* 1995), but only recorded in horticulture in Australia. This species should be designated as a target for eradication. *Salix glauca* and *S. exigua* scored above average in the impacts assessment but, despite being introduced to several new countries for their aesthetic value (Newsholme 1992), have not naturalised beyond their native range anywhere in the world. A full risk assessment process that includes the invasiveness and potential distribution for these taxa will have a provide better assessment of which of these taxa are likely to be the highest priority for management.

Salix caprea, *S. aegyptiaca* and *S. humboldtiana* 'Pyramidalis,' are naturalised in Australia, but had low impact scores indicating these species should be lower priority for management. There are very few records of these taxa naturalising and assessments of their invasiveness and distributions may add to this preliminary evidence that they don't pose a large risk to Australia's natural resources. The low scores of several taxa (*S.* × *calodendron*, *S.* × *sericans* and *S. glaucophylloides*) were also associated with low confidence scores, indicating that little high quality data could be used for assessing these species.

An ability to naturalise elsewhere in the world is cited as the best predictor of a plant's ability to naturalise in Australia (Panetta 1993). Whilst *S. eriocephala*, *S. pentandra* and *S. eleaegnos* have not yet naturalised in Australia, their invasive histories in UK, USA. and New Zealand (Stace *et al.* 2006, Argus 1986, van Kraayenoord *et al*. 1995) respectively, makes them high risk plants in Australia. Although, *S. gracilistyla* was given a score below the mean and is not known to be naturalised, it does exhibit invasive traits, such as the ability to spread to form dense thickets (van Kraayenoord *et al.* 1995). Pre-emptive removal from horticulture would be a prudent approach for these species.

The subgenus *Chamaetia* and horticulturally-valued taxa, such as *S.* × *boydii*, *S. myrsinifolia*, *S. integra* 'Hakuro-nishiki;' and the cricket bat willow *S. alba* var. *caerulea* had amongst the lowest impact scores. None of these taxa have a history of invasiveness, despite having been cultivated for many years. Introductions of these taxa occurred in 1900 (for *S. alba* var. *caerulea*), whilst *S.* × *boydii* has been in Australia for 14 years, *S. myrsinifolia* for 19 years and members of the subgenus *Chamaetia* began arriving more than 20 years ago, although some as recently as 2002 (Robert Ingram personal communication 2007). This suggests that many of these willows may be suitable for cultivation, although invasiveness and distribution assessments are required. The decision to exempt *S. alba* var. *caerulea* and *S. myrsinifolia* from noxious weed legislation in Victoria the appear to be supported by this assessment.

The apparent low risk of the dwarf/alpine willows remain equivocal. *Salix glauca* belongs to the subgenus *Chamaetia* and it did achieve an above-average impact score. However this species differs from most *Chamaetia* in its ability to form thickets, and extensive shrublands (Welsh 1974, Skvortsov 1999).

The above-average confidence scores of the top 13 taxa highlights these as the highest priority for management. The very low confidence scores for some naturalised taxa suggest further risk assessment effort is required particularly for *S.* × *calodendron*, *S.* × *sericans*, *S. glaucophylloides* and *S. pentandra*.

The willows that aren't naturalised are the ones that we know the least about. The association of low confidence scores with lower impacts may be due to a tendency of scientific interest towards species that have been observed impacting on social, agricultural or natural resources.

Of the non-naturalised taxa, we can be more sure that *S. integra* and *S. gracilistyla* are low impact taxa, and that *S. exigua* may have high impacts, than of *S. myrsinifolia* being low impact. Further research to increase the quality of the data used for assessing impacts is recommended for most of the lowest-ranked taxa. Of particular concern is *S. myrsinifolia*, which had an extremely low confidence score, and *S. humboldtiana* 'Pyramidalis,' already naturalised here. Without further research we run the risk of assuming that taxa, such as this last one, are low risk, because our assessments have been based on little data.

Some criteria used to assess the impacts of willows may be considered more important in determining which taxa should be a prioritised for management. The relative importance of each criterion can be manipulated using a pair wise comparison tool in an Analytical Hierarchy Process, as was used for the Victorian PPPP (Weiss *et al.* 2004). New scores and ranks can be calculated using weighted factors which could change the relative rankings of willow taxa.

The post-border weed risk management protocol (SAI 2006) describes how weed risk can be determined by comparing the *likelihood* that a plant might naturalise in an area, with the *consequences* of that naturalisation. *Likelihood* will be assessed by analysing the invasiveness, or biological traits of each taxon, such as ability to establish, reproduce and disperse. The *consequences* of a taxon's ability to naturalise can be determined by the product of its impact and its potential distribution. The potential distribution of each willow will be extrapolated from current distribution data. When this process is complete, our willow rankings can be utilised to fully inform management requirements for willows in Australia.

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Appendix 1. Criteria used in the willows impacts assessment

Criteria	Intensity rating	Score
Socio-economic		
1. How much damage could be caused to human-built infrastructure?	Visual effect; little to negligible structural damage.	L
	Able to be remedied as a normal part of everyday maintenance e.g. pruning	ML
	Maintenance requires specialised equipment, such as for clearing drains	MH
	Major damage to bridges, culverts, weirs, dams etc. requiring repair.	H
2. How much horticultural/agricultural value does the willow have?	Attractive/useful foliage/catkins/stems; OR valued as a fodder, shade, wood, windbreak or avenue tree; AND require knowledge to propagate, AND are single-sex clones	L
	Attractive/useful foliage/catkins/stems; OR valued as a fodder, shade, wood, windbreak or avenue tree; AND require knowledge to propagate.	ML
	Some horticultural/agricultural value, but easy to propagate, bisexual or male and female, naturalised in Australia	MH
	No aesthetic value, easy to propagate, bisexual or male and female, naturalised in Australia	H
3. To what extent could the willow impact on the health and safety of waterway/riparian users?	Little to no impact on public safety. Willow is low-growing and/or has branches that are too thin to cause serious health damage.	L
	n/a	ML
	Moderately likely to cause serious injury or death of waterway/riparian users. E.g. tree willow/tall shrub with large, but flexible branches.	MH
	Most likely to cause serious injury or death of waterway/riparian users. E.g. tree willow with brittle branches. Risk of death to water skiers.	H
4. To what extent could the taxon impact on recreation in/on waterways? E.g. swimming, boating (including canoeing, skiing, rafting), fishing, bird watching, passive enjoyment e.g. picnics	Little to no impact on activities. Weeds not obvious to average visitors.	L
	<4 activities affected. Minor effects to aesthetics or uses. E.g. willows able to form monocultures that reduce bird life and impede river views for passive enjoyment, but access for swimming, boating and fishing is still possible.	ML
	4+ activities impeded. E.g. stream deep enough to boat/swim, but access impeded by willows on the bank.	MH
	Major impact. 4+ activities prohibited. E.g. willows encroach into stream, making it too shallow to swim/boat.	H

continued/…

…/Appendix 1 continued.

Criteria	Intensity rating	Score
Stream health		
5. To what extent could the willow impact on the flow of water in streams and on water availability[A]?	Little or negligible impact on flow capacity or water availability. Willow grows offstream with no root or stem growth in stream.	L
	Minor impact of flow by roots or foliage. Roots sometimes grow instream. Capable of removing more water than vegetation lacking instream root systems.	ML
	Major impact on flow by roots and foliage including major root structure. Roots and stems often grow instream. Capable of using large quantities of water.	MH
	Always extensive roots and stems growing in stream, causing streams to become shallower and wider. Also capable of using the most water.	H
6. To what degree could the willow cause bed and bank erosion?	Low probability of large scale soil movement. Does not grow in riparian areas.	L
	Moderate probability of large scale soil movement. Terrestrial species that suppresses the understorey and lacks extensive root system, allowing erosion of the banks by overland runoff.	ML
	High probability of large scale soil movement, but effects remain in stream. Willow roots and stems encroach instream to create a wider, shallower stream.	MH
	High probability of large scale soil movement and major off site implications and bank failure. Willows are confined to the banks, but under flood conditions the stream is diverted behind the willows, scouring out large areas of land. E.g. *S. exigua*	H
7. To what extent could the willow affect water quality (and consequently, instream native biodiversity) i.e. nutrient pulsing, light availability and temperature change.	Plant is low growing and unlikely to affect the shading of waterways or to drop many leaves into the stream AND/OR doesn't grow near waterways	L
	n/a	ML
	Grows along the bank to 4+ m tall such that large amounts of leaf litter will fall into the stream and/or has the ability to cause unseasonal opening in the canopy by significantly out competing native vegetation.	MH
	Plant overhangs stream, or encroaches into stream such that most of its foliage will fall into the water. Weeping tree or prostrate form.	H
Biodiversity		
8. To what extent could this willow affect riparian/wetland habitat structure/layers? i.e. ground layer (forbs, grasses, herbs) shrub layer, tree layer	Minor or negligible effect on <20% of the floral strata/layers present; usually only affecting one of the strata OR not known as a weed anywhere in the world.	L
	Minor effect on 20–60% of the floral strata. Does not form large thickets.	ML
	Minor effect on >60% of the layers or major effect on <60% of the floral strata. Large thickets interspersed with other vegetation	MH
	Major effect on all layers. Able to form monocultures; virtually no other intact strata/layers present.	H
9. To what extent could riparian areas (in-stream, margins, banks, floodplain, wetlands) be impacted by this willow?	Coexists with other vegetation in any of the riparian niches and is not dominant OR does not grow in riparian environments.	L
	Occurs as the dominant species in any one of the riparian niches.	ML
	Occurs as the dominant species in any two of the riparian niches.	MH
	Occurs as the dominant species in any three of the riparian niches, and/or is capable of invading wetlands.	H
10. To what extent could this willow affect other invasive species (flora and fauna)?	Suppresses (e.g. *Glyceria*). No associations formed with other invasive species	L
	May occur in association with minor pests, such as blackbirds or non-declared weeds	ML
	n/a	MH
	May occur in association with serious (declared) pests, such as rabbits, foxes or blackberry	H

Appendix 2. Criteria used to determine confidence scores for the literature used to answer each question.

Document type or information source	Rating
Peer-reviewed scientific papers	H
High quality science or plant specific books (e.g. floras), non-peer reviewed scientific papers (e.g. conference proceedings), personal communications from expert on species being assessed, unpublished reports from highly reliable source (e.g. commercial reports or honours theses, etc.), internet information from herbaria or internet information that cites sources.	MH
Personal communications from people with experience with the species under assessment, information from general plant books, (e.g. *Encyclopaedia Botanica, Gardening Flora*, etc.), unpublished reports from uncertain sources, internet information from government or university websites that does not cite sources.	M
Anecdotal data from non-experts, internet information from uncertain/uncited sources, or horticultural, nursery notes or general web pages.	ML
No data or reference material available.	L

Appendix 3. Victorian Pest Plant Prioritisation Process impacts criteria.

Social values

1. How could the weed restrict human access?
2. How could this weed reduce the tourism /recreational use of the land?
3. Is the plant injurious, toxic, or spines affect people?
4. How much damage is done to indigenous or European cultural sites?

Natural resources

5. How could this weed impact on water quality
6. How could this weed impact on quantity?
7. How could the weed increase soil erosion?
8. How could this weed reduce the biomass of the community?
9. How could the weed change the frequency or intensity of fires?

Fauna and Flora/Vegetation

10. How could this weed impact on the vegetation composition on the following:

a. High value vegetation?

b. Medium value vegetation?

c. Low value vegetation?

11. How could this weed effect the structure of a vegetation community?
12. How could the weed have on threatened flora spp.?

Threatened Flora and Fauna

13. How could the weed impact threatened fauna spp.
14. How could the weed impact non-threatened fauna spp.
15. How could this weed provide benefits or facilitate the establishment of indigenous fauna?
16. How is the plant toxic, its burrs or spines affect indigenous fauna?

Pest animal

17. How could this weed provide a food source to assist in success of pest animals?
18. How could this weed provide habitat to assist in success of pest animals?

Agriculture

19. How could this weed impact on the quantity of agricultural produce?
20. How could this weed impact on the quality of agricultural produce?
21. How could this weed affect land value?
22. How could this weed cause a change in priority of land use?
23. How does the weed increase the cost of harvest?
24. Does this weed act as an alternative disease host or vector?

Appendix 4. Scores from the willows impacts risk assessment.

Taxon name	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
S. subgenus *Chamaetia*	M	ML	L	L	L	L	L	L	L	ML
S. subgenus *Salix*	H	MH	H	H	H	MH	H	H	H	H
S. subgenus *Vetrix*	MH	MH	L	H	H	MH	H	MH	H	H
S. aegyptiaca	MH	MH	L	ML	L	ML	MH	M	M	M
S. alba	H	MH	H	H	MH	MH	H	H	H	H
S. alba var. *caerulea*	L	L	L	L	L	L	L	L	L	H
S. babylonica	H	MH	M	H	H	MH	H	H	H	H
S. caprea	MH	MH	L	ML	L	ML	MH	H	H	M
S. cinerea	MH	H	L	H	H	MH	H	H	H	H
S. daphnoides	ML	M	L	MH	L	H	MH	H	H	H
S. elaeagnos	MH	ML	L	ML	MH	M	MH	ML	L	L
S. eriocephala	MH	MH	L	MH	ML	ML	MH	MH	MH	H
S. exigua	MH	M	L	H	H	MH	H	MH	H	H
S. fragilis	H	H	H	H	H	MH	H	H	MH	H
S. glauca	M	M	L	MH	M	H	MH	MH	H	H
S. glaucophylloides	L	H	L	ML	M	M	MH	M	M	M
S. gracilistyla	MH	M	L	MH	ML	H	ML	MH	ML	H
S . humboldtiana 'Pyramidalis'	MH	MH	L	L	ML	L	L	L	L	M
S. integra 'Hakuro-nishiki'	L	M	L	L	L	L	L	L	L	M
S. matsudana	H	MH	H	ML	ML	ML	H	ML	L	H
S. myrsinifolia	L	M	L	M	L	M	L	M	M	M
S. nigra	H	H	H	H	MH	MH	H	H	H	H
S. pentandra	M	M	M	M	L	M	MH	M	H	H
S. purpurea	MH	MH	L	H	H	MH	H	MH	H	H
S. triandra	MH	MH	L	H	H	MH	H	H	H	H
S. viminalis	MH	H	L	H	MH	MH	MH	H	H	H
S. alba × *matsudana*	H	MH	H	M	MH	M	MH	H	M	H
S. × 'Boydii'	L	L	L	L	L	L	L	L	L	L
S. × *calodendron.*	MH	H	L	M	M	M	MH	M	H	M
S. × *mollissima*	MH	H	L	M	M	M	MH	MH	M	H
S. × *pendulina*	H	MH	H	MH	M	H	H	M	M	M
S. × *reichardtii*	MH	M	L	M	H	MH	MH	M	M	H
S. × *rubens*	H	H	H	H	H	MH	H	H	H	H
S. × *sepulcralis*	H	MH	H	H	H	MH	H	H	MH	H
S. × *sericans*	M	H	L	M	M	M	MH	M	M	M

Community based quality assurance scheme

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Introduction

Managing weeds on private and public land is problematic; with some land managers being very diligent and others no so. Where weeds are not being managed can cause weed incursion on to adjacent land. Legislation is targeting those who do not manage weeds in accordance to the regulations set down by Government and their representative bodies. This can tie up a lot of resources with little positive outcomes in the field. The Dookie Land Management Group (DLMG) decided to turn the table on this process and recognise those in the district that do a good job of managing their weeds as part of their Weed Management Implementation Strategy.

In 2002, the Dookie Land Management Group started the Recognised High Level Weed Managed Property Quality Assurance Scheme. The Scheme is supported by the State Department of Primary Industries, the City of Greater Shepparton and the University of Melbourne. This support is both through agreement of the principle aims of the scheme and allocating time for staff to be involved in the inspection regime set up by the scheme.

DLMG Weed Management Implementation Strategy

Aims of the strategy are to:

- Implement actions in accordance with the Goulburn Broken River Catchment Weed Action Plans,
- Prevent the incursion of new weeds within the DMLG area, and
- Reduce the weed levels within the DMLG area.

The initial objects set out in 2002, where:

- In 2002–2003, have weeds managed along roadsides in the area bounded by South Boundary Rd, Dookie – Nalinga Rd, Cashels Rd, and
- Have landholders involved in a co-ordinated roadside weed management programme by 2006.
- Management of all weeds listed in the book 'Weeds of the Goulburn Broken' within five years.
- Recognise property owners who have successfully implemented a high-level weed management programme through an inspectorial accreditation scheme.

Recognised high level weed managed property

In order for a property to be included as a Recognised High Level Weed Managed Property, the landholder or their agent must:

- Nominate a defined area boundary to be inspected.
- Give authorisation of DLMG representatives to inspect the land referred to above and to erect or remove the Recognised High Level Weed Managed Property Sign in accordance to the inspections.
- Give approval for Inspectors appointed by DLMG to enter this portion of land at least three times of year, and
- Have less than five plants of any one species and no more than 20 plants of combined species that are nominated within the Goulburn Broken Catchment Authorities declared weed list, observed by the inspectors.

How the scheme operates

The property is inspected at least twice a year, after the autumn break and again in spring.

The inspectors travel over the whole property and look for any of the weeds listed within the Goulburn Broken Catchment Authorities declared weed list. A formal report is written (see form at end of paper) and any recommended actions are also noted within the report. The report is signed off by a member of the DLMG and a DPI officer. Weeds that are not on the list are in great numbers are also be noted on the inspection report.

If the property has some recommended actions listed during the inspection a follow up inspection is conducted within six weeks of the inspection. If the recommended actions are have not been done the property losses it status.

If the property meets the criteria of having less than five plants of any one species and a total of lees than 20 combined species the property can have access to the signage 'Recognised High Level Weed Managed Property'. The cost to the grower is an annual fee of $50.00 as well as maintaining their high level weed managed properties.

Why are growers using the scheme?

There are two main reasons why growers are using the scheme. The first is to get acknowledgement that their property is managing weeds well. This gives the land manager a status within the district and puts pressure on neighbouring properties to improve weed management on their properties. This recognised status also aids land managers in discussions on weed management with Government authorities, whether this be on weed management issues on adjacent land or on policy matters to do with land management. Some of the topics within this policy area have included a rate incentive scheme for properties recognised under the DLMG 'Recognised High Level Weed Managed Property' scheme.

The second reason why growers have taken up the scheme and stayed with the scheme is in marketing their own produce. When the scheme was first initiated, several of the properties that joined the scheme were growing crops for seed production, others had hay production as a major component of their farm enterprise. The scheme gave them a quality assurance programme for their customers.

Effectiveness and uptake of the scheme

Since its inception in 2002, the DLMG 'Recognised High Level Weed Managed Property' scheme has had five to six properties listed. In its inaugural year, there where seven properties that requested to join the schemes but only five achieved the level required by the scheme. While there is presently only six properties recognised under the scheme, the level of weed infestations both on these properties (as noted on the inspection reports with little follow up actions required) and on adjacent land has been reduced since the start of the scheme. The scheme has had no formal publicity other than the signage on the respective properties and word of mouth. Several of the surrounding councils are keeping a watching brief on the scheme to see if it fits within their weed management implementation plans.

Recognised high level Weed Managed Property Inspection Report

Date: .... Property: ....

Owner/ Manager: .... Phone No.: ....

Property Boundary References (either Grid Ref form CFA map or GS readings)

....

....

I authorise DLMG representatives to inspect the land referred to above and to erect or remove the Recognised High Level Weed Managed Property Sign in accordance to the inspections.

Name:... Signature:...

Weeds Observed

Weed	*<5 plants*	*>5 plants*		*<5 plants*	*>5 plants*		*<5 plants*	*>5 plants*
Alligator Weed	☐	☐	Wild Garlic	☐	☐	Great Mullein	☐	☐
Black Knapweed	☐	☐	Kyllinga	☐	☐	Hardheads	☐	☐
Ivy-leaf Sida	☐	☐	Parramatta Grass	☐	☐	Hoary Cress	☐	☐
Mesquite	☐	☐	Arrowhead	☐	☐	Horehound	☐	☐
Water Hyacinth	☐	☐	Carpet grass	☐	☐	Noogoora Burr	☐	☐
Chilean Needle Grass	☐	☐	Amsinckia	☐	☐	Parrot's Feather	☐	☐
Ragwort	☐	☐	Artichoke Thistle	☐	☐	Parthenium Weed	☐	☐
Serrated Tussock	☐	☐	Bathurst Burr	☐	☐	Saffron Thistle	☐	☐
Sliverleaf Nightshade	☐	☐	Boxthorn	☐	☐	Salvinia	☐	☐
African Lovegrass	☐	☐	Caltrop	☐	☐	Slender/Shore Thistle	☐	☐
Blackberry	☐	☐	Camelthorn	☐	☐	Spear Thistle	☐	☐
English Broom	☐	☐	Cape Broom	☐	☐	Spiny Burr Grass	☐	☐
Furze	☐	☐	Cape Tulip	☐	☐	Star Thistle	☐	☐
Paterson's Curse	☐	☐	Devils Claw	☐	☐	Stemless Thistle	☐	☐
Prairie Ground Cherry	☐	☐	Dodder	☐	☐	Thorn Apple	☐	☐
St John's Wort	☐	☐	Golden Thistle	☐	☐	Variegated Thistle	☐	☐
Sweet Briar	☐	☐				Viper's Bugloss	☐	☐

Inspectors

Name:.. Signature:...

Name:.. Signature:...

Name:.. Signature:...

Name:.. Signature:...

Property Approved........Yes ☐ ....No ☐

Recommended Actions:

....

....

....

....

....

President of the Dookie Land Management Group DPI Representative

Signatures:... ....

An investigation of application techniques for the control of various noxious and environmental weeds with picloram gel based herbicides

Geoffrey G. Keech, Macspred Australia, 714 Duri-Dungowan Road, Timbumburi, New South Wales 2340, Australia.

Abstract Over 2500 species of introduced plants are now established in the wild in Australia, and many threaten the integrity of some of our most valued places. For many of these environmental weeds, there is no registered herbicide. Are we winning the battle, do we have the tools to win and is research keeping up with the spread?

In an effort to facilitate better control methods, trials using a picloram based gel herbicide, were set up in conjunction with several Local Government Weed Control Authorities. The aim was to investigate the application techniques for the most efficient control of the following species: African olive (*Olea europaea* ssp. *africana* (P.Mill.) P.Green), arum lily (*Zantedeschia aethiopica* (L.) Sprengel), broad-leafed pepper tree (*Schinus terebinthifolia* Raddi), cat's claw creeper (*Macfadyena unguis-cati* (L.) A.Gentry), Formosan lily (*Lilium formosanum* Wallace), glory lily (*Gloriosa superba* (L.), Madeira vine (*Anredera cordifolia* (Ten.) Steenis), prickly pear or common pest pear (*Opuntia stricta* var. *stricta* (Haw.) Haw.), smooth tree pear (*Opuntia vulgaris* Miller) and senna (*Senna pendula* var. *glabrata* (Vogel)).

Application techniques investigated included: cut stump, scrape and paint, stem injection, basal bark and foliar smearing, not all techniques were trialled on each species.

All species treated according to label directions for cut stump application were satisfactorily controlled. The exceptions were for African olive and golden rain tree where one multi stemmed plant for each species was cut and treated at a height of 30 to 40 cm above ground level. These plants re-shot and may survive. Long term observation of the re-shot plants indicate that there is still herbicide activity occurring. As picloram may take up to two seasons to fully control some species, further observation will take place. It should be noted that all plants cut at 2 to 5 cm were satisfactorily controlled indicating the need to follow label directions.

Scrape and paint and basal bark techniques were employed for Madeira vine, cat's claw creeper and senna. Madeira vine was successfully controlled and also a very high percentage of the aerial tubers. The cat's claw creeper trial was compromised, however early indications showed defoliation. The Senna trial was established in October 06 and needs to be monitored until Spring 07 for meaningful results.

Foliar and stem injection shows a great deal of promise on the *Opuntia* species and the results may lead to an inclusion on the label. Basal bark treatments on thin and green barked species have proven to be effective to date and offer a significant saving in time.

Introduction

In an ideal world we could have grown what we liked in our gardens, and retained unspoiled forests and beaches to be enjoyed on holidays. According to McFadyen (2003), 'The arrival of Europeans in Australia has been followed in the last 200 years by over 28,000 foreign plants. Some introductions were accidental, but most were imported for pasture, horticulture or for ornamental reasons. Of the nearly 300 plants known to have established themselves as weeds in the wild between 1971 and 1995, for example, two-thirds were introduced as ornamentals. Of the 460 pasture and legume species trialled in northern Australia 1947–85, 60 became weeds and 13 of these are now serious crop weeds. Only four proved useful without also causing weed problems. One plant introduced for pasture became a major weed within a decade'. 'Over 2500 species of introduced plants are now established in the wild in Australia, and many threaten the integrity of some of our most valued places'. Introduced plants have found their way into nooks and crannies where some have become so firmly established that it's been close to impossible to remove them. They are now posing a significant threat to our native species and our biodiversity. We need to ask ourselves are we winning the battle, do we have the tools to win and is research keeping up with the spread?

In recent times there has been an upsurge in the concern over environmental weeds, in particular those weeds which have escaped from garden situations. Many of these species which threaten native vegetation areas are of the woody weed variety and are well known to bushland regenerators. Until recently, the control of these weeds has been hampered due to the lack of a registered herbicide for this specific purpose. Vigilant® herbicide gel containing 43 g kg^{-1} picloram as the potassium salt has provided a solution to this problem and offers a low-impact way to control woody and rhizomatous plants.

Vigilant is registered for application by cut stump, blazing (stem injection), drilling and foliar application (on wandering Jew with a paint roller). There remains however some species and growth stages which are not suited to these techniques.

To overcome this anomaly and to develop a more efficient means of control, trials in conjunction with several Local Government Weed Control Authorities were set up to investigate both species susceptibility and application techniques for the most efficient control of: African olive (*Olea europaea* ssp. *africana*), arum lily (*Zantedeschia aethiopica*), broad-leafed pepper tree (*Schinus terebinthifolia*), cat's claw creeper (*Macfadyena unguis-cati*), Formosan lily (*Lilium formosanum*), glory lily (*Gloriosa superba*), Madeira vine (*Anredera cordifolia*), prickly pear or common pest pear (*Opuntia stricta*), smooth tree pear (*Opuntia vulgaris*), senna (*Senna pendula* var. *glabrata*).

Techniques and methodology

Those methods chosen for investigation were standard label claims and some commonly used methods in bushland regeneration which included cut stump, stem injection by cutting blazes and wedges and by drilling and filling (Ward and Henzell 2002, 2004). Other methods considered were foliar, basal bark and scrape and paint methods. The treatment methods for each species are shown in Table 1.

Cut stump

Stems treated by this method were cut horizontally (Figure 1) so as to leave a flat non-sloping surface to receive the gel. Stems were cut at 20 mm to 50 mm above the ground (except for one multi-stemmed plant each of African olive and golden rain tree). A further trial was conducted on senna, cutting the stems of dense juvenile stands at about knee to waist height. This was done in an attempt to achieve easier application for elderly volunteers. The stems at each site were cut with either secateurs, loppers or a pruning saw, depending on stem diameter. Vigilant gel was applied to the cut surface in a layer 3–5 mm thick within five minutes of cutting.

Foliar/stem smear

For *Opuntia* spp. Vigilant gel was applied as a thin smear covering 75–80% of the leaf surface. One side of the stem/leaf was treated using a stiff bristled brush, ensuring treatment to below or on the lowest leaf. For the lily group, treatment of the stems and/or leaves or midrib of the leaf was achieved with the Vigilant brush bottle (see species trial results below).

Table 1. Treatment methods and species trialled.

Species	Cut stump	Stem injection	Leaf and stem smear	Basal bark	Scrape and paint
African olive	X				
Arum lily	X		X		
Broad-leafed pepper tree	X	X			
Cat's claw creeper	X	X		X	X
Formosan lily	X				
Glory lily			X		
Madeira vine				X	X
Prickly pear		X	X		
Smooth tree pear		X	X		
Senna	X			X	X

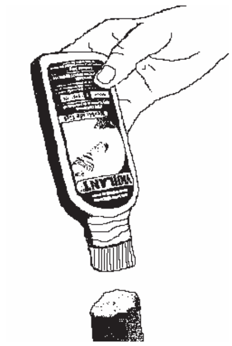

Figure 1. Cut stump.

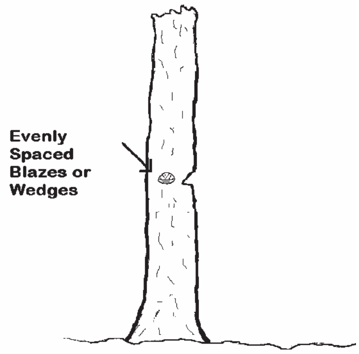

Figure 3. Stem injection

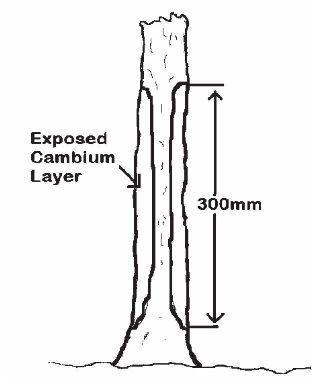

Figure 2. Scrape and paint.

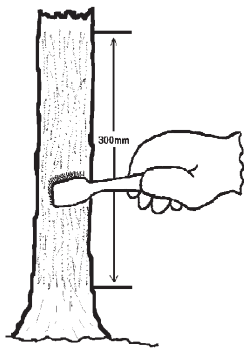

Figure 4. Basal bark.

Scrape and paint

Stems were scraped on 2 sides (Figure 2) to expose the outer cambium layer for a combined area of approximately one third to half the circumference of the stem from a height beginning at approximately 20–50 mm and for a distance of 300 mm up the stem. Vigilant gel was applied as a smear over the stem using a stiff bristled brush, sold in supermarkets as a dishwashing brush, dispensing the gel from the 1.8 kg tub. For single plant treatments, the Vigilant brush bottle was used (not recommended because of possible damage to the soft bristles on the brush).

Stem injection

The technique for stem injection varied according to the species trialled. For soft tissue plants, a hole was cut in the base of the plant stem with a narrow bladed knife or a specially developed lance. Vigilant gel was placed into the hole with a squeeze bottle fitted with a long nozzle. Woody stemmed species were treated by cutting blazes with a tomahawk or wedges with a pruning saw (Figure 3). Vigilant was applied from either the brush bottle, a squeeze bottle or with a stiff bristled brush from the 1.8 kg tub. Further work is anticipated with both drilling and frilling techniques.

Basal bark

Vigilant gel was applied by direct application to the stem of the target plant (Figure 4) using a stiff bristled brush. The stems were treated from 20 mm above ground level for a distance of approximately 300 mm up the stem.

Results

African olive (Olea europaea ssp. africana) (Cessnock City Council)
Established: 8/3/05
Treatment method: cut stump
Stems treated: 11, Control (untreated):3
Results Assessments made on 5/7/05 and 1/9/05 showed the untreated controls were already re-shooting and all treated stems appeared to be controlled. One of the treated stems was a multi stemmed plant and was cut at about 300 mm from ground level. Initially it appeared that this plant along with those cut at 20–50 mm, was controlled. On 2/11/05 this plant had shoots approx 300 mm long growing from the base and a smaller deformed shoot from further up the stem. All other stems were still controlled and showed signs of decay. On 16/2/06 the multi stemmed plant showed evidence of some dead shoots but also had several healthy shoots while the plants cut close to the ground were still controlled and showed more evidence of decay. Further investigation on 21/10/06 showed that the majority of re-shooting on the multi-stemmed plant had died however there was still one shoot with fresh green leaves at the very base of the plant. These leaves still exhibited symptoms of herbicide activity. This is in agreement with the known data that indicates activity for up to two seasons in plant tissue. A final assessment on 3/4/07 showed no green shoots and it would appear that control has been achieved.

The trial was compromised by an overspray with Grazon® DS in June 05. The untreated controls recovered from this application and are all actively growing.

Arum lily (Zantedeschia aethiopica) (Gosford City Council)
Established: 2/11/05
Treatment method: cut stump, leaf/stem smear.
Stems treated: 10 each method
Results Assessed 22/2/06 and December 06 showing death and desiccation of all treatments. The site was inspected by Eddie Lanting, Weeds Officer with Gosford City Council on 12/12/06 and all treatments show 100% control.

Cats claw creeper (Macfadyena unguis-cati) (NSW DPI)
Established: 18/5/05 (in conjunction with DPI as part of a larger trial)
Treatment method: cut stump, stem injection, scrape and paint, basal bark.
Stems treated: 3–5 each treatment.
Results Initial assessments on 23/6/05 indicate excellent control with cut stump applications. Basal bark applications on larger stems had defoliated the canopy but it was too early to ascertain the level

of control. Small diameter (<10 mm) were controlled above ground level. Stem injection treatments on large diameter stems had defoliated the canopy, assessment at a later date indicated that the control was effective. All uncut stems including the stem injection plants were compromised by the 'Vine Weeds Work Team', cutting and treating the trial plots with a glyphosate solution, at approximately nine weeks after the original Vigilant treatments had been applied. The only valid data available from the site was for the cut stump method which yielded 100% control after 12 months. Small diameter stems (<5 mm), which were treated by the basal bark method but were lost due to cattle movement, also appeared to be satisfactorily controlled. The major problem in achieving control of cat's claw creeper is the seedling regeneration and ground cover creepers re infesting the trees. Inspection at two years shows all material below ground level for the cut stump treatments had rotted away.

Formosan lily (Lilium formosanum) (Port Macquarie-Hastings Council)
Established: 22/2/05
Treatment method: cut stump.
Stems treated: 10
Results Assessments in March 05 and April 05 indicated no regrowth from the bulbs. Treated and untreated plants were dug up on 25/5/05 for comparison. The treated plants showed fragmentation and separation of the bulb from the stem/root system while the untreated controls were still intact. Several samples of both treated and untreated bulbs were collected and planted in a garden for observation. The untreated bulbs sprouted and grew the next season while there was no growth exhibited by the treated samples.

Glory lily (Gloriosa superba) (Bellingen Shire Council and Bellingen Landcare)
Established: 25/11/04
Treatment method: Foliar and stem smear.
Stems/area treated: Plot size 2 m × 2 m. #1–310 plants, #2–265 plants, approx 50% treated. #3–untreated 195 plants.
Results Plot 1. The top 100 mm every stem was treated by holding in a gloved hand and smearing with Vigilant gel. Severe burning of all plants was evident at seven days with the exception of some untreated plants, an indication of overdosing which may have reduced translocation of the herbicide. Reassessed 22/2/05 and counted 20 plants with severe phytotoxicity, 51 slight to nil effect, some of these had obviously not been treated. 77% reduction. 124 plants present 9/12/05, mostly fresh germinations. Plot 2. Only the treated plants were burnt at seven days, 152 plants present 22/2/05, 438 plants 9/12/05. Plot 3 had increased to approx 640 plants.

The trial was duplicated on a smaller scale and Vigilant gel applied with a paint brush wiped across the top of the plot. Some phytotoxicity resulted and some plants were controlled but insufficient product was applied to be totally effective. This trial may need to be re-established using a paint roller technique as for wandering Jew. Vigilant has proved effective as a treatment for isolated patches and individual plants shown by in field use, but would prove to be uneconomic for large infestations. For best results use only a thin smear on the stem and leaves, foliar application with a paint roller may be an option but at this time is unproven.

Madeira vine (Anredera cordifolia) (Coffs Harbour City and Port Macquarie-Hastings Council)
A trial was established by Tony Cook, DPI NSW at Ellenborough, using several different herbicides. At the initial assessment all Vigilant treatments were deemed to be controlling the plants. Unfortunately the site was flooded and most of the data was lost and no conclusions were drawn.

Madeira vine was treated at Coffs Harbour on 28/9/04 as part of the demonstration site on Coffs Creek. Only two plants were treated by scrape and paint method. Both were successfully controlled. Aerial tubers were collected on 25/11/04 and examined internally. There was significant evidence that the tubers were controlled. Other plants have been treated as a basal bark treatment and anecdotal evidence indicates good control of plants and tubers. A large vine was treated by DEC staff and total control was achieved. The tubers on this plant also appeared to be controlled. Basal bark treatments will always work better when applied to green bark as penetration of mature bark on older plants is shown to be variable.

Plants were also treated at Hornsby on 14/9/04 with similar results.

Prickly pear (Opuntia stricta) (Port Macquarie-Hastings and Clarence Valley Councils)
Established: 8/11/05 – Yamba, 23/11/05 – Port Macquarie.
Treatment method: (a) Stem injection by cutting a plug out of the base of the stem or placing slits in leaves, and (b) Foliar smear.
Plants treated: Yamba – 15 stem injection, 10 leaf smear. Port Macquarie – 40+ leaf smear, 3 stem injection.
Results Yamba 7/12/05. All treatments showed low to moderate phytotoxicity in the main leaves at first assessment. However the flowers and small fruit and some of the outer leaves showed severe phytotoxicity and burning, severe site burning was noted at stem injection sites which may have reduced translocation. Port Macquarie was not assessed in December.

The second assessment for Yamba and first for Pt. Macquarie 9–10/2/06 showed severe damage to the smaller plants and significant damage to large plants. Except one large plant which had been treated as a basal bark only, this plant has not been fully controlled due to insufficient coverage; only the treated leaves have died.

The assessment of 21–23/3/06 showed severe damage and death of smaller plants and further evidence of increased damage to large plants. Coverage of at least 75–80% of the surface of one side of all of the main leaves and stem is needed for optimum control as plants only partially treated have survived. All plants treated by leaf smear have been controlled and it is the preferred option. Stem injection is slower and all main stems of large plants need to be treated. Complete control is attainable with follow up treatments on leaves which drop off or are broken off due to the rapid collapse of the main stems. No root production from the majority (>95%) of collapsing plants has been observed. The fallen leaves/stems in most cases have eventually desiccated and are no longer viable.

Smooth tree pear (Opuntia vulgaris) (Greater Taree City Council)
Established: 23/11/05
Treatment method: Stem injection, leaf smear
Plants treated: 10 each method
Results Assessments were made 22/12/05, 22/2/06 and 21/3/06. The initial assessment was made by George Wisemantle, Weeds Officer at Greater Taree City Council. Significant phytotoxicity was observed in both treatments with the stem injection treatments burning the injection site so severely that the plants had snapped of at this point. Some concern was held that translocation of the product would be reduced because of this effect. Subsequent assessments have shown that this is not the case, continued monitoring has resulted in the observation of complete tissue desiccation and satisfactory control has occurred.

The foliar treatment has shown excellent control as long as all of the main stems and leaves receive treatment on at least one side of the leaf. Where a large leaf was not treated on one plant, there seems to have been little translocation of the product from the stem to the leaf. The reason for this is may be that there was insufficient product applied to the stem below the junction with the leaf.

Picloram moves both in the xylem and phloem tissues but does not translocate between these tissues. In other words, it moves up and it moves down but not down from higher applications and back up the stem beneath this application.

Senna (Senna pendula var. glabrata) (Port Macquarie-Hastings Council and Dept. Conservation and Climate Change NSW–Parks and Wildlife Division)
Several trials on this species were established as listed below.

1. Established 9/02/06 A small scale trial was established on 9/2/06 using cut stump both high and low cuts and basal bark applications. Insufficient numbers of plants were treated to derive meaningful data although all treated plants appeared to have been controlled. A second site was established on senna with stem diameters <10 mm diameter in conjunction with Dept. of Conservation and Climate Change NSW, National Parks division, cutting at above knee height to trial an easier method for elderly volunteers, assessment in June 06 showed re-shooting of the majority of these stems however all shoots were showing typical Vigilant damage. An assessment on 14/3/07 showed that two plants >10 mm diameter were controlled and eight plants which were <10 mm in diameter had regrowth. This indicates that it is difficult to apply sufficient product to small diameter stems to achieve control by the cut stump method.

2. Established: 27/9/06
Treatment method: Scrape and paint, basal bark
Plants treated: 80+ plants from 5 mm to 20 mm diameter at two sites were treated as scrape and paint and two plants (multi-stemmed) to 20 mm diameter were treated by basal bark application.
Results Rainfall was experienced shortly after application however early results observed on 24/10/06 were encouraging with all plants showing signs of defoliation. On 29/11/06 all small diameter plants treated by the scrape and paint method were completely defoliated and the stems above ground were dry and brittle. The larger plants had also completely defoliated and the smaller branches were dry and brittle. The larger multi-stemmed plant treated with the basal bark method had defoliated except for one stem which may not have been sufficiently covered. The fresh leaves on this stem were showing signs of herbicide activity. There were green stems at the canopy of the plant showing severe tip burning, indicating ongoing herbicide activity. The smaller plant treated in this manner had defoliated and there was no sign of any green stems.

An inspection of both sites on 21/2/07 and 10/5/07 revealed all treated plants (both methods) were dry and brittle, indicating a control. The plants were all loose in the soil and were easily puled up, indicating that the root systems were also dead. There was no regrowth from any treated plant from either method. One area has been mulched and replanted; the treated plants show no evidence of re-shooting while untreated plants have vigorous regrowth.

3. Established: 14/12/06
Treatment method: basal bark
Plants treated: 53 plants up to 15–20 mm in diameter were treated on one side of the stem from 20 mm above ground level for a length of 300 mm.
Results The site was inspected on 21/2/07 and 10/5/07; 52 plants were dry and brittle and easily removed from the soil. Adjacent live plants were not able to be removed by hand pulling. One double stemmed plant which had been treated above the fork showed half the plant still alive on 21/2/07. This is typical of the mode of action of picloram. All stems of multi stemmed plants need to be treated or treatment should be below the lowest branch.

Small scale trials and demonstrations

Other small scale trials (look and see type demonstrations) have also been conducted during 04/05. Some of the results are surprising and reveal the need to understand not only the botanical structure of the plant but also the activity and mode of action of the active ingredient. The African olive and smooth tree pear experiences have been described above. Other instances have also been discovered where application technique needs to be fine tuned and adapted to suit the species.

Golden rain tree One multi-stemmed plant which was cut at about 300 mm resprouted from the base, while others cut low, as in the Cessnock/African olive experience were effectively controlled. **Follow label instructions, cut at about 20 mm above ground and certainly no more than 100 mm.**

Camphor laurel Cutting blazes in the trunk of the tree and applying product to the flat part of the cut (bottom) does not allow product to move up the plant and control the top, whereas saw cuts with product contacting both top and bottom of the cut appeared to give better control. A better method for stem injection of camphor laurel may prove to be the frilling technique with axe cuts close together and penetrating the cambium layer so that the product is in contact with both upper and lower portions of the cut. One plant each at Gosford 2/11/05 and Port Macquarie 27/9/06 were treated by scrape and paint method. The stem diameters were approximately 20 to 30 mm. The plant at Gosford remains controlled as at 12/12/06 and the Port Macquarie plant had completely defoliated on 29/11/06 and is dry and brittle at 14/3/07. Cut stump application was effective on this species.

Broad-leaved pepper tree Stem injection by blazing carried out on a large tree in Taree has proved to be ineffective to date and a smaller tree treated similarly was not completely controlled initially but eventually died, however cut stump applications on other plants of the same species have proved to be effective. Observation of the stem injection technique indicates that cuts should be made at distances of no greater than 50 mm apart and should be located so that a cut is made directly below each branch. This species may require further refining of the stem injection technique with a complete frill being preferred as the next option.

Conclusions

The gel formulation of picloram (Vigilant) has shown to be effective on a range of invasive plant species. The most effective application technique for all woody species with stem diameter larger than 10 mm is the cut stump method. For smaller stem diameters, scrape and paint application or for thin or green bark species, basal bark application has proved effective. Basal bark treatment offers the added benefit of time saving along with reduced bending down time for elderly volunteers. Cut stump application is best suited to manage larger trees and shrubs and those plants with thick bark, application should be within 100 mm of the ground for a faster and more effective kill. The experience for senna, African olive and golden rain tree, where stems were cut at a height of 300–400 mm and higher; which is outside label claims, indicates that plants treated in such a manner may re-shoot and survive or take longer for complete control to be effected. This problem is likely to be species related as according to Ward *et al*. (2002) there was little difference in efficacy against grey willow (*Salix cinerea*) between stems cut at 300 mm and those cut at 0.5 to 1 metre. Long term observation of the reshot olive and senna plants indicate that there is still herbicide activity occurring with stems greater than 10 mm for Senna now being controlled. This indicates that insufficient product can be applied to the smaller surface area for control to be effective. As picloram may take up to two seasons to fully control some species, further observation will take place. It should be noted that all plants cut at 20–50 mm were controlled. The olive at Cessnock is now controlled as at April 07.

Foliar smear and stem injection shows a great deal of promise on the *Opuntia* species and the results may lead to an inclusion on the label. The ease of control of small pear plants by foliar application will enhance the activities of all land management groups. There is no longer a need for these people to physically remove all plant material to prevent dispersal by fragmentation. *Optunia* species are best treated using the leaf smear method while the scrape and paint and basal bark techniques for Madeira vine also successfully controlled a very high percentage of the aerial tubers. Anecdotal evidence from New Zealand indicates that good control of wild tobacco can also be achieved with basal bark applications as long as the bark is green at application. A trial of this method on wild tobacco has been established at Pacific Palms on 8/3/07 on 50+ plants and will be monitored by Great Lakes Shire Council. The use of these techniques on any species should be trialled on small areas before attempting a large scale operation and should initially be restricted to green or thin barked species. Operators will also need to be more alert to weather conditions, as these methods leave a larger surface area of gel exposed and rainfall soon after application may reduce the effectiveness of the product and/or increase the risk of off target damage.

For a list of species known to be susceptible to Vigilant, see Appendix A. As with all pesticides, extensive research has been carried out, the results of which impact directly on the wording of the label. In all cases therefore, read and follow the instructions on the label and you will ensure quality results.

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- Ian Turnbull, Bellingen Shire Council.
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- Reece Luxton and Darrin Heron, Clarence Valley Council.
- Terry Inkson, Great Lakes Shire Council.
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Appendix A. Species known to be susceptible to Vigilant Herbicide Gel at 1/5/07.

Known susceptible species		Application method				
Common name	Botanical name	Cut stump	Basal bark	Scrape paint	Foliar	Blaze inject
African olive	*Olea africana*	X		cut close to ground		
Agapanthus	*Agapanthus orientalis*	X		drill tubers		
Arum lily	*Zantedeschia aethiopica*	X			X	
Balloon vine	*Cardiospermum grandiflorum*	X	X			
Bitou/boneseed	*Chrysanthemoides monilifera*	X				
Blackberry	*Rubus fruticosus*	X				
Broadleafed pepper	*Schinus terebinthifolia*	X				X
Camphor laurel	*Cinnamomum camphora*	X		X		X
Canna lily	*Canna indica*	X				
Cassia	*Senna pendula* var. *glabrata*	X				
Castor oil plant	*Ricinus communis*	X				
Cat's claw creeper	*Macfadyena unguis-cati*	X				
Chinee apple	*Ziziphus mauritiana*	X				
Chinese celtis	*Celtis sinensis*	X				
Coastal morning glory	*Ipomea cairica*	X	X			
Cockspur	*Maclura cochinchinensis*	X				
Coral tree (smooth and rough bark)	*Erythrina* spp.	X				X
Cotoneaster	*Cotoneaster* spp.	X				
Formosan lily	*Lilium formosanum*	X				
Glory lily	*Gloriosa superba*		isolated plants only		X	
Golden rain tree	*Koelreuteria paniculata*	X		cut close to ground		
Gorse	*Ulex europaeus*	X				
Grafted apricot	Unknown	X				
Green cestrum	*Cestrum parqui*	X				
Groundsel bush	*Baccharis halimifolia*	X				
Hiptage	*Hiptage benghalensis*	X				
Honey locust	*Gleditsia triacanthos*	X				
Hybrid pine	*Pinus elliottii* × *carribea*	X				
Japanese honeysuckle	*Lonicera japonica*	X				
Kahili ginger	*Hedychium gardnerianum*	X				X
Lantana	*Lantana camara*	X				
Lemon tree	*Citrus limon*	X				
Madeira vine	*Anredera cordifolia*		X	X		
Mesquite	*Prosopis* spp.	X				
Monsterio	*Monstera deliciosa*	X				
Moth vine	*Araujia sericifera*		X			
Mysore thorn	*Caesalpinia decapetala*	X				
Night scented cestrum	*Cestrum nocturnum*	X				
Ochna	*Ochna serrulata*	X				
Ornamental fruit tree	Unknown					X
Paddy's lucerne	*Sida* spp.	X				
Prickly pear	*Opuntia stricta*				X	X
Privet (broad and narrow leaf)	*Ligustrum* spp.	X				
Rubber vine	*Cryptostegia grandiflora*	X				
Senna	*Senna floribunda*	X	X	X		
Siam weed	*Chromolaena odorata*	X				
Smooth tree pear	*Opuntia vulgaris*				X	X
Sweet briar	*Rosa rubignosa*	X				
Umbrella tree	*Schefflera actinophylla*	X				
Wild tobacco tree	*Solanum*	X	X			
Willow	*Salix babylonica*	X				
Yellow bells	*Tecoma stans*	X				
Yellow oleander	*Nerium oleander* ssp.	X				

Empowering gardeners to make informed choices when buying garden plants

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Summary This paper highlights the risk posed by the garden plant invasion pathway, particularly the on-going sale of around 40 per cent of naturalised garden plants that have been declared noxious in one or more Australian states or territories. This risk is compounded by an existing backlog of around 4,065 non-naturalised referenced weeds identified by the Weeds CRC that have already been imported into Australia for cultivation as garden plants many of which have yet to be screened by governments to determine whether they should declared as noxious weeds. The causes of this problem include the limitation of existing government regulatory systems and public information systems as well as the scale and increasingly complex structure of the Australian garden plant retail industry.

WWF-Australia proposes a two-tiered policy response to reduce the weed spread risk associated with invasive garden plants. High-risk invasive garden plants need to be identified as matter of urgency and banned from sale before they naturalise, while medium-risk invasive garden plants should be carefully managed – retailers and consumers need to be alerted to their invasive potential and how they can responsibly care for them to reduce weed spread risk. This paper focuses on the role of a labelling standard and scheme in reducing the weed spread risk associated with medium-risk invasive plants.

A national labelling scheme is proposed for Australia that is regionally flexible (a plant may be high-risk in one State and low-risk in another); mandatory (to create a level playing field in a fragmented and dispersed industry); and provides a range of benefits for the nursery industry at minimal cost and disturbance. The scheme would incur minimal costs to industry and protect it a potential future costly civil liability risk.

Introduction

This paper examines the issue of the garden plant invasion pathway in Australia as a major source of agricultural and environmental weeds in Australia. In particular, it recommends policy measures to tackle the risk posed by the on-going sale of garden plants that have been declared by one or more state/territory as a noxious weed. This risk is compounded by a backlog of potentially invasive garden plants that can be legally sold in Australia many of which have yet to be screened by governments to determine whether they are likely to develop into weeds of agriculture or the environment.

The source of this problem is a combination of the inadequacies of existing regulatory control measures and public information systems and the scale of the Australian garden plant retail industry. The factors that pose a challenge to addressing this problem will be considered including a heterogenous and dispersed industry which is itself poorly informed about risk posed by invasive species and the potential legal liability that this infers.

It proposes a way forward for industry and government that, in addition to better-resourcing existing systems to remove backlogs before they become an uncontrollable problem and centres around mitigating the risk posed by the garden plant invasion pathway at the point of sale.

Background

Weeds cost Australian agriculture $4 billion a year (Sinden *et al.* 2004), and degrade tens of millions of hectares of Australia's environment (CRC for Australian Weed Management 2003). While there are many weeds, there are relatively few invasion pathways; the garden plant invasion pathway has been identified by the CSIRO, the Weeds CRC, Meat and Livestock Australia, and WWF-Australia as Australia's dominant weed spread pathway (Groves *et al.* 2005, Glanznig 2005, Barker *et al.* 2006, Randall unpublished). About 70 per cent of Australia's agricultural and environmental weeds are escaped invasive garden plants (Virtue *et al.* 2004). Studies suggest that introduced garden plants will comprise an even greater portion of the total of future naturalised species (Groves *et al.* 2005). Figure 2 provides an illustration of the garden plant invasion pathway.

Agricultural and environmental weeds that are present in Australia are generally identified and regulated on the State/Territory level (with the exception of the 20 nationally-agreed Weeds of National Significance and regional/local government lists). Each State/Territory has its own list of declared weeds which it has assessed to determine its 'weediness' (a process often referred to 'weed risk assessment') and then listed under the relevant state/territory legislation under a given control category.

Each state/territory law has different control categories which indicate different management requirements depending on the level of risk that the species poses of developing into a weed of primary industry or the environment and the level of opportunity that exists to get it under control. These categories typically range between plants that are banned outright in the entire state to prevent them from establishing, to those that are already well-established in the state but are damaging enough to warrant legislative control to prevent its further spread (Australian Weeds Committee 2006).

In some states/territories, the legislation includes weed categories that declare a species in a given region or local management area of the state (Victoria, Western Australia, South Australia, New South Wales), while other State's weed declaration categories apply throughout the state regardless of the regional or local management areas (Tasmania, ACT, Queensland, Northern Territory). The categories also vary in terms of management responsibility, the higher-risk categories typically place responsibility on the state/territory departments to enforce, the medium-risk categories place responsibility on local or regional governments, some categories place responsibility on land-owners to manage the weed on their land, other categories place responsibility on traders to remove them from trade.

Some 430 weeds are declared under the different pieces of state/territory legislation. However, due to the different categories, a declaration does not automatically ban a plant from being traded, and places no obligation on other states/territories to do so in their jurisdictions. As more and more potentially invasive garden plants emerge, the ongoing spread of declared weeds between jurisdictions via the garden plant trade will become an increasingly significant invasion pathway.

This situation has arisen due to the generally narrow and reactive nature of State and Territory laws to prevent and control weeds which exposes these jurisdictions to the risk of continued and sustained import of many new weeds (Glanznig 2005). It is important to note at the outset of this paper that the garden industry has generally operated within the bounds of the law. The importation of hundreds of invasive garden plant species was entirely legal – as such, responsibility for the historical weeds problem squarely rests with governments. This policy failure is being progressively addressed – the introduction of 'guilty until proven innocent' import protocols at the borders of both Australia and Western Australia are two of the outstanding policy innovations that have occurred in the late 1990s.

Issues

Many weedy garden plants are still advertised for sale

Due to the poor harmonisation between State and Territory declared weed lists, noxious weeds declared in one jurisdiction can still be sold in another. Table 1 presents the results of analysis conducted by Groves *et al.* (2005) that compared a list of invasive garden plants declared under State and Territory legislation with a published catalogue of garden plants available for sale from nurseries in Australia (Hibbert 2002). The catalogue lists about 30,000 garden plant taxa (including varieties) derived from the catalogues of 280 individual nurseries and 31 seed suppliers spread across all states and mainland territories. It is important to note that Hibbert (2002) does not include many of the other retail sources for garden plants illustrated in Figure 1, including e-commerce and non-specialised retail outlets such as discount department stores. It also important to note that this audit was based on 2002 data on plant availability. There is clearly an urgent need to conduct a national audit of garden plants currently in trade.

Nationally over 40% of the invasive garden plants that are declared noxious in one or more jurisdictions were still available for sale in 2002 (Table 1), with all states and territories significantly exposed to the sale of declared plants in other jurisdictions. The most exposed states were Western Australia with 40 per cent of the plants declared noxious in WA being available for sale in at least one other Australian state or territory, NSW with 37% and Queensland with 35%.

This situation creates a significant risk of 'leakage' from one jurisdiction to the State where the weed is declared. This leakage could take the form of movement of a pot plant when people move inter-State or purchase seeds over the internet.

Table 1. Naturalised invasive and potentially invasive garden plants and their noxious status and availability for sale in 2002, both nationally and by jurisdiction (source: Groves *et al.* 2005).

Jurisdiction	Naturalised invasive garden plants[A]	Declared Noxious[B]		Declared Noxious in jurisdiction and available for sale in at least one other state or territory jurisdiction	
	No.	No.	%	No.	%
Australia	720	178	24.7	72	40.4
NSW	205	99	13.8	36	36.7
QLD	158	57	7.9	20	35.1
SA	161	66	9.7	19	28.8
TAS	152	51	7.1	16	31.4
VIC	409	60	8.3	18	30.0
WA	314	171[C]	23.8	69	40.4
ACT	104	23	3.2	6	26.1
NT	63	42	5.8	13	31.0

Notes

[A] Number naturalised includes all listed taxa (genera, species, sub-species) that are recorded as naturalised in jurisdiction (Randall and Kessal 2004).

[B] Declared noxious refers to taxa that are declared noxious under relevant State/Territory government legislation in respective jurisdiction. The Australian total refers to the number of taxa that are declared noxious in at least one State or Territory jurisdiction. Percentage is portion of total naturalised invasive plants that are declared noxious in respective jurisdiction (AWC January 2004). The NSW figure includes regional declarations, and these listed species may be available for sale in non-control regions.

[C] This includes those species that are both declared noxious or unassigned. Unassigned species are subject to a weed risk assessment if importation into the State is sought. Sources: Randall and Kessal (2004), Australian Weeds Committee (2004), Hibbert (2002) cited in Groves, Boden and Lonsdale (2005).

Backlog of unscreened potentially invasive garden plants

Data complied by the Weeds CRC indicates that the lists of noxious weeds declared in each state/territory should grow substantially in the future. The CRC has estimated that there are about 4065 plant species that have already been imported into Australia for cultivation as garden plants which are referenced weeds yet to naturalise in the Australian environment[1] (Randall unpublished). While it is important to note that not all of these species will become future weeds, the probability that they will is significantly higher than for species with no overseas weed history. This list of species indicates that there is a large pool of plants already in Australia imported as garden plants that have not yet established themselves and that pose a significant risk of becoming weeds of agriculture and/or the environment.

Two reports recently released by the CRC for Weed Management have further highlighted the risk posed by invasive garden plant species that are still advertised for sale but have yet to naturalise:

- A report commissioned by Meat and Livestock Australia identified 281 introduced garden plants and 800 lower priority species that are likely to develop into significant grazing weeds should they naturalise in Australia. Of the 281 potential high risk grazing weeds, over two thirds (70%) were still available for sale from Australian nurseries in 2004 (Barker *et al.* 2006).
- A report commissioned by the NSW Department of Environment and Conservation found that weeds threaten 419 NSW plant and animal species listed as threatened under the State's legislation. The report estimated that around 93% of these threatened species were directly threatened by weeds that are escaped garden plants. The report found that 44% of the 127 weed species identified by the report were still available for sale in 2004 (Coutts-Smith *et al.* 2006).

These figures give an indication of sheer scale of the threat posed by the garden plant trade invasion pathway and highlight the need for better control measures as these plants inevitability spread from state to state/territory. As governments risk assess more of these plants the numbers of declared weeds should theoretically swell from the hundreds to the thousands.

A fragmented and dispersed industry

The risk posed by potentially invasive garden plants is worsened by the dispersed and fragmented nature of the plant retail industry – plants can be bought from a wide range of outlets including over the counter at hardware stores, supermarkets and large discount store chains, as well as via mail order and over the Internet. The 'Australian Garden Market Monitor 2005' shows that for retail channels, retail nurseries make up 26.3% of the market share, while the combined market share of hardware, supermarkets and discount department stores is 40.3% (Figure 1).

The peak body, Nursery and Garden Industry Australia (NGIA), covers roughly one third of the production businesses recorded by the Australian Bureau of Statistics in 2001 (Martin *et al.* 2005). This is

Footnote

[1] A referenced weed is a plant species that has been identified as a weed of any type overseas which is listed in the *Australian Exotic Species Database* which is maintained by the West Australia Department of Agriculture.

an important consideration when looking at tackling the issue of invasive garden plants, as any effort to influence growing and purchasing practices that is run through the peak body will only target a portion of the sector.

Potential civil liability for plant traders

In recent years, many industries have encountered civil liabilities that had long been dormant. Suppliers of goods and services that have or are facing civil actions include: the tobacco industry; 'fast-food' outlets; liquor companies; asbestos suppliers; and local governments. The common feature in all such claims is the argument that the industry was aware of the harm-causing potential of its product, and chose not to take the responsibility for either warning of the risks and required controls, or to directly control that risk (Martin *et al.* 2005).

A study by the University of New England's Australian Centre for Agriculture and Law identified that the practice of knowingly selling invasive plants with no consumer disclosure presents a civil liability risk for the garden industry (Martin *et al.* 2005). The report demonstrated the grounds for future claims against garden plant growers and sellers to pay for the 'clean up' costs of invasive plants that they have sold. Under Section 52 of the *Trade Practices Act (1974)*, a failure to disclose a relevant fact of which a supplier is aware could be interpreted as a misleading offence. The report notes that, from a legal perspective, adopting a preventative approach may be in the best interests of the suppliers of potentially invasive plant species.

Dependence on industry knowledge

As most invasive garden plants tend not to be banned outright, so responsible use of them depends on effective communications. The current system relies on attending staff at plant retail outlets to be informed and conscientious in warning customers about plants that are declared as invasive in other jurisdictions or plants that are not prohibited but are known to be invasive in certain local environments. Qualifications are not required for a person to work in the Australian nursery industry (Adler *et al.* 2000).

A casual survey by the lead author of four Sydney garden centres in January this year revealed that even well-informed, conscientious garden centre staff only provided a warning in relation to a maximum of three plants from a list of over 40 invasive plant species that were requested and, in some cases purchased. This indication of nursery staff ability to identify plants and warn consumers of their properties was reflected in a more comprehensive American study that conclusively found that American plant nurseries were not a reliable source for plant identification (Savage and Rondeau 1992).

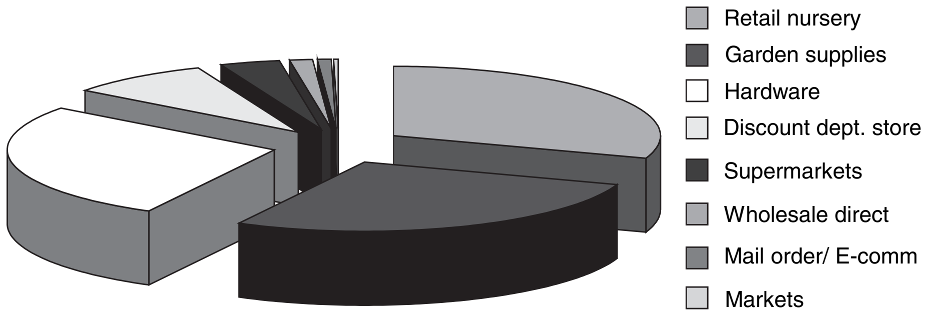

Figure 1. Summary of the Garden Retail Market Share, year ending June 2006 (Freshlogic 2006).

Poor information systems

The Weeds CRC attempted to measure public awareness about weeds through a national survey conducted in 2003. The survey revealed that the urban public is still largely uninformed and unaware of invasive plants as an issue (Martin 2006).

Current information sources include state lists of declared weeds which plant retailers within the state are legally obliged to comply with. Nurseries may also have to comply with weed lists generated by their local government which may or may not have a legal status. In the case of invasive plants that have not been listed, various government and non-governmental bodies have produced communication materials such as websites, booklets and posters aimed at consumers to encourage them to avoid selecting plants that can be legally traded but are invasive or potentially invasive in the their areas, notable examples include the Nursery and Garden Industry Association's 'Grow me Instead' campaign which presents safe alternatives to around 17 invasive garden plants that are in trade in NSW and ACT.

The low level of public awareness combined with the widespread availability of declared invasive plants through the garden trade illustrates the ineffectiveness of current consumer awareness-raising efforts. Current systems rely on nurseries taking the initiative to supply the information materials in their outlets and refer to them at the point of sale, or they rely on consumers taking an active interest in the issue, seeking out the information and applying it when choosing what plant to buy.

A major fault of the existing system is that the information is not well coupled to the activity it is trying to influence, i.e. consumer purchasing behaviour. For consumers to be able to make wise choices about which plants to choose and where to plant them they need to be provided with information about the plants properties at the point of sale. Martin *et al.* (2005) note that 'purchase transactions' are an important intervention point in the garden plant invasion pathway (refer Figure 1) because this intervention point can be used to:

- Encourage consumer purchasing preferences toward plants…that are benign or positive in their impacts,
- Stimulate action to reduce the risk of future invasions, such as retro-fitting gardens…, and
- Provide information to enable purchasers to implement actions that prevent the spread of any invasive species they have purchased (Martin *et al.* 2005, p.5).

A rare example of this approach in Australia is the pioneering efforts of a large Australian national mail-order garden plant and seed retailer: 'Diggers'. 'Diggers' has voluntarily introduced regionally-specific invasiveness warnings in their catalogues. Along with the standard plant characteristics and care information, each catalogue entry indicates if the plant has been listed as a weed in State legislation and flags that it is unavailable for sale these jurisdictions. 'Diggers' also goes one step further by warning consumers about plants that have not been listed as a weed by any states/territories but are potentially invasive in certain areas. These plants are indicated in their catalogues with an icon that denotes plants that can be invasive and the climate zones where this risk exists. 'Diggers' independently identifies these weedy species through their own research including international weeds databases. In the words of a 'Diggers' representative 'This information is not required by law, but we feel that by providing these notes we can help gardeners to make informed decisions about what to plant (or what not to plant)' (Sansom 2005).

Consumer demand for warnings at point of sale

The increase in awareness about the large impacts of weeds and where they are coming from over the next several years will lead to strong community expectations for governments and the garden industry to implement effective solutions to the invasive plant problem. Urban Australian have low awareness about weed issues. However, market research shows they have strong latent demand to adopt behaviours that reduce weed spread risk if it is easy and convenient (Martin 2006).

This latent demand was affirmed by a recent national galaxy poll commissioned by WWF Australia that surveying 1100 Australians by telephone. The poll demonstrated that a very low level of Australians have knowingly brought invasive plants for their gardens (5%). It also demonstrated very strong consumer demand for warnings on plant labels:

> *'Almost all Australians (96% of respondents) believe that plants which can become harmful agricultural or environmental weeds should be clearly labelled with a warning. This belief is consistently held by all types of Australians, regardless of factors such as gender, age, or [where they live],*
>
> *…Australians believe the warning label should contain plant care information to reduce the risk of weed spread (93%), the parts of Australia where the plant can become a weed (89%) and how to get more information about which plants are invasive (88%)' (Galaxy Research 2007, p. 4).*

Virtually all garden plants are sold with a label which varies from basic and often inadequate or incorrect descriptive information to elaborate marketing devices. Plant labels are unusual in the commercial world in not addressing the range of community expectations that apply in most other consumer product categories such as food, clothing, and most household products. As a Senior Horticultural Botanist at the Melbourne Royal Botanic Gardens recently asserted;

> *'consumers expect to be provided with accurate labelling…we have every right to expect that a plant label faithfully indicates what is in the pot…Accuracy and truthfulness in labelling may not always suit the marketing objectives of plant producers, but consumers have the right to know if the plant they are purchasing is an environmental weed' (Spencer 2007, p. 1).*

A way forward – policy solutions

Stop the supply of high-risk plants

It is clear that there is an urgent need for states and territories to tackle the reservoir of potential future Australian weeds that have been identified by the Weeds CRC before they 'jump the garden fence' and move beyond affordable control. Better resourcing of weed risk assessment systems will enable governments to process the backlog of non-naturalised garden plants in the country that pose a risk of developing into weeds. It is also clear that the declaration and control of weeds requires better national coordination, particularly due to the national nature of the garden plant industry and the lack of existing coordination between states/territories on weed identification and control. Non-naturalised plants that are determined to be high-risk through weed risk assessment should be nationally banned as a matter of urgency.

Influence demand for medium-risk plants

The focus of this paper is on finding a solution to those plants that are identified as 'medium risk'. For the purposes of this paper, medium-risk plants are those that have been listed in state/territory legislation as noxious weeds but are not banned from trade[2].

Rather than being banned outright, these species need to be contained to areas and uses that will prevent them from becoming a problem. This containment will require a range of measures that together target each stage of the garden plant invasion pathway (Figure 2). As this paper has demonstrated, a critical intervention point in the garden plant invasion pathway is at the point of sale. Consumers have a right to know if they are buying a potentially invasive plant. They also need to know how to reduce their weed spread risk by knowing if the plant is suitable for the proposed location, how to maintain it, and how to dispose of green waste responsibly. Furthermore, plant sale staff require better clarity about which plants to warn consumers about and what to advise - particularly as more invasive plants are identified and as the garden plant retail sector becomes more diverse.

WWF recommends a number of measures to bring industry practice up to speed, these are:

- An industry code of practice that sets a standard of responsible conduct to ensure compliance with legislation and to prevent the spread of invasive garden plants into the environment. International models of best practice are available including the UK's horticultural code titled 'Helping to prevent the spread of invasive non-native species' (UK DEFRA 2005).
- An awareness-raising campaign that targets garden plant consumers and garden industry operators to encourage both parties to proactively preference low-risk weeds.

These on-going 'soft' measures need to be accompanied by a focused effort to provide the key information at the point-of-sale so that consumers start to factor the invasive plant threat into their purchasing decisions. Hence WWF-Australia also recommends that:

- The Nursery and Garden Industry Association (NGIA) in conjunction with the Australian Weeds Committee (under the Natural Resource Management Ministerial Committee) introduce a national mandatory plant labelling standard and scheme. Such a scheme would enable garden plant retailers and consumers to identify at the point of sale species that have been determined as medium-risk on a national level and in what areas these species pose a risk of becoming invasive.

A labelling standard and scheme

While the NGIA is the appropriate peak body to lead the development of a labelling scheme, responsible plant labelling should not be the sole responsibility of the NGIA, particularly as its membership only covers a small proportion of the plant retail industry. The plant labelling standard would need to apply to the whole industry; hence, once it had been developed it would need to be established as a national mandatory code possibly under the *Trade Practices Act 1974*.

Models of best practice in labelling have begun to emerge in Australia and overseas. The example of industry-leadership by 'Diggers', an Australian national mail-order retailer, was profiled in this paper. The United Kingdom's peak horticultural industry body adopted a national plant retail labelling code and a specific labelling code for hazardous plants in 1994 (HTA 2000). Based on these existing models and on the experiences of other labelling schemes in Australia, WWF has identified a number of key characteristics that the scheme would need to adopt. These include:

Nationally structured but regionally flexible The labelling scheme would need to be nationally coordinated so as to overcome the lack of inter-jurisdictional coordination that has contributed to the weed problem that exists today. However, the label should be designed in a way to show regional differences in invasiveness, for example one option would be a map of Australia showing suitable growing area where the plant is not known to be invasive in one colour, with areas where it is invasive highlighted in another colour. This would enable consumers and retailers to quickly identify which medium-risk

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Footnote

[2] By this definition, in any given state or territory, a medium-risk plant would be a plant that has been declared as a noxious weed in the jurisdiction under a legal category that does not ban trade, and/or, a plant that has been declared as noxious in another state/territory (hence can be traded but poses a risk of 'leaking' into the area where it is banned).

plants are appropriate for which areas. It would also enable a simple system where the same symbol and warning would apply to a given plant regardless of where it is being sold in Australia. Beyond specifying the presentation of the warning, the standard would not need to place any restrictions on creativity or innovation in the label design.

Mandatory There is strong evidence to suggest that a labelling scheme that seeks to enable consumers to compare between products needs to be mandatory. In the case of the retail grocery industry's code of conduct and Australia's water efficiency labelling code, both were scheduled to be converted from voluntary to mandatory due to the failure of an initial voluntary approach (Buck and Associates 2003, Wilkenfield and Associates 2003, Campbell 2006). A University of New England report, 'Costs and Benefits of a Proposed Mandatory Invasive Species Labelling Scheme' (Martin *et al.* 2005), looked at the issues associated with a national labelling scheme for invasive garden plants. It concluded that unless such a scheme was mandatory it was unlikely to be universally adopted which would result in an unfair financial load being borne by the most responsible members of the industry and 'free-riding' by others.

Supported by awareness-raising As recommended by Martin *et. al.* (2005) the labelling code would need to be promoted to retailers and the public and supported by education materials such as: a user-friendly booklet and posters and/or a website. The code could also be factored into existing awareness-raising and educational efforts such as horticultural training programmes and nursery industry accreditation schemes.

Complementary to industry interests The labelling scheme would reinforce the direction the nursery industry has already taken in with its 'Grow me Instead' campaign which encourages consumers to preference low-risk plants. A labelling scheme could incorporate and support the 'Grow me Instead' campaign and brand, for example by indicating on labels if a plant has been identified as a recommended non-invasive alternative plant.

A likely result of a national labelling scheme would be increasing consumer recognition of invasive plants that have already made it into their gardens. Encouraging home owners to participate in schemes that audit their gardens and help them replace high-risk plants with those that are environmentally safe is the logical next step in tackling the reservoir of medium-risk invasive plants that have yet to naturalise in Australia (refer Figure 2). This 'retro-fitting' of gardens is analogous to homes installing more efficient lights or showerheads to save energy and water respectively. This second phase would present an obvious opportunity for the nursery industry to develop a new market for low-risk plants.

In terms of costs to industry, implementation of the scheme would be timed to work with the normal replacement cycle for labels allowing for existing stocks to be used and then replaced, with an appropriate sunset clause. This approach would keep transition costs to a minimum. A mandatory labelling scheme would also enable the garden industry to move to contain future civil liability risk which presents the risk of massive costs to the industry in future years.

Conclusion

This paper demonstrates the risk to Australia's environment and agricultural industry posed by invasive plants available through the Australian garden plant trade. The source of the problem is partly government weed regulation systems which have been slow to catch up with the evolving scale and complexity of the garden plant invasion pathway, and partly the industry itself which has also not been proactive in tackling the threat posed by its products. The nursery industry now faces a potential civil liability for failing to disclose a plant's invasive properties.

The problem is made more complicated by the fragmented and dispersed nature of Australia's garden industry which includes internet sales, supermarkets and discount department stores. Garden plant retailers are not required to have any plant-related qualifications or knowledge. A recent national poll demonstrated strong consumer demand for plant labelling to enable consumers to choose plants that are not invasive.

This paper recommends that governments prioritise processing the backlog of thousands of potentially invasive garden plants that can be legally sold in Australia and before these plants develop into Australia's next generation of agricultural and environmental weeds. Plants identified as high-risk need to be immediately banned from sale. Plant determined to be medium-risk (hence allowable for sale in certain parts of Australia) need to be brought under more thorough control by government and industry so that they are confined to areas and uses in which they will not develop into weeds. A key tool in this effort will be a national mandatory labelling standard supported by an industry code of practice. The code would result in consumers being consistently informed of a plant's properties in a way that enables them to choose the right plant for the right purpose.

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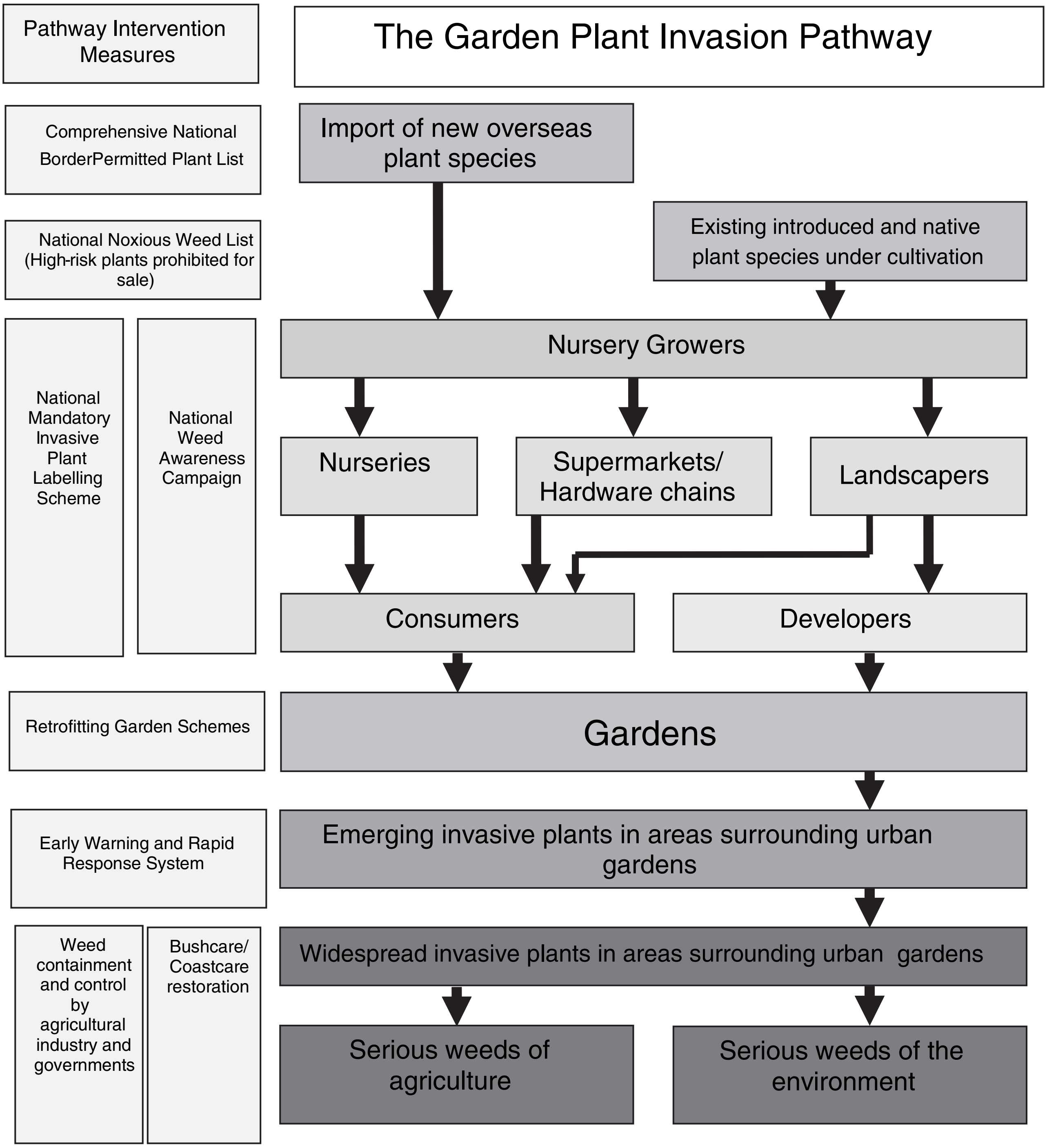

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The use of radiation wavelengths to manage weeds

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Introduction

Light exists as quantum states of electromagnetic fields (Dirac 1927), simultaneously exhibiting both particle and wave behaviour. These quantum states, or photons, transport energy and information over vast distances. Information is modulated onto light by variations in intensity (number of photons) and energy. The energy associated with a photon is frequency dependent, such that $E = h\upsilon$; where h is Planck's constant (6.626×10^{-34} J s) (Einstein 1951). It is these differences in photon energy that differentiate the behaviour of photons.

Some photons provide energy that stimulates biological activity, while others in different parts of the spectrum can severely damage organic tissues. Examples that highlight the favourable interactions of photons with organic molecules in living things include:

1. The absorption of photon energy by chlorophyll to start the complex sequence of reactions known as photosynthesis (Ladiges *et al*. 2001),
2. The absorption of blue light to modulate phototropism, slowing of hypocotyl expansion and stomatal opening (Ladiges *et al*. 2001),
3. The absorption of red and far-red photons by phytochrome molecules in plants, that regulate plant development including seed germination, flowering, branching or apical dominance, (Oh *et al.* 2006), and
4. The transformation of retinal molecules ($C_{20}H_{28}O$), found in the light receptor cells of the eye, from the hooked 11-cis isomer to the straight all-trans isomer. This transformation disentangling the retinal molecule from its encapsulating opsin protein and triggers a synaptic signal along the optic nerves to the brain, which results in vision (Chang 1998).

Examples that highlight the damaging effect of photons on organic molecules include:

1. The ionisation of organic molecules by very high energy photons such as X-rays and gamma radiation, which leads to radiation poisoning and tissue death; and
2. The over-heating of organic tissue by low energy photons, such as microwaves and radio waves, which leads to permanent protein denaturation and tissue death.

This paper summarise recent research in to the effect of photons that either regulate plant development (i.e. light wavelengths) or provide heating of organic tissues (i.e. microwaves and solarisation).

Plant regulating photons

Photons that are visible to humans (wavelengths between 400 nm and 900 nm) affect plants in various ways. The main photons that affect plants are the red and blue parts of the spectrum. Plants have three types of receptors that respond to blue light: a) crytpochromes which regulate hypocotyl expansion; b) phototropin which regulates phototropism and c) zeaxanthin which regualtes stomatal opening (Campbell and Reece 2006). In the red wavelengths (700–900 nm), the plant responses are governed by phytochromes which exist in several states – an active (P_{fr}) and an inactive state (P_r). The phytochrome converts between the two states depending on the type of light it receives. If P_{fr} receives far red light it will convert to P_r. If P_r receives red light it will convert to P_{fr}. P_{fr} is also unstable and converts slowly back to P_r in darkness (Campbell and Reece 2006).

The requirement for light after seed burial has been observed in many species (Wesson and Wareing 1968, Woolley and Stoller 1978, Froud-Williams *et al*. 1984, Scopel *et al*. 1991, Baskin and Baskin 1992, Corbineau *et al*. 1992, Milberg and Andersson 1997, Botto *et al*. 1998, López-Granados and Lutman 1998, Milberg and Andersson 1998), the seasonal loss of a light requirement has only been reported in a few species such as in *Bromus rubens* L. (Corbineau *et al*. 1992), *Datura ferox* L. (Botto *et al*. 1998) and *Lolium rigidum* (Steadman 2003).

Is it possible to use this switching mechanism to trigger or stop germination? Previous researchers have tried to use night tillage as a mechanism to stop germination. This has been successful in some experiments but not in others. In an experiment at Dookie (James 2000) showed that night tillage did not decrease weed germination. More recently, Watts (2006) and preliminary results from 2007 (Johansen) have indicated utilising light filters can alter weed emergence. Light filters are used extensively in the horticultural industry to promote or delay flowering (Pearson and Khattak 2006).

Heat generating photons (microwaves)

Over the past 40 years, microwave heating has frequently been proposed as an alternative method of controlling soil-borne pests such as weed seeds, insects, nematodes and pathogens (Nelson 1996). In particular, treatment of soils as a method of weed control (i.e. killing the weed seed bank) has been proposed for some time (Nelson 2003).

Barker and Craker (1991) demonstrated that treatment of soil, containing 'Ogle' Oats (*Avena sativa*) and an undefined number of naturalised weed seeds, in a microwave oven prevented seed germination when the soil temperature rose above 80°C. Other experiments (Brodie *et al.* 2007a) have demonstrated that microwave treatment of soil significantly reduced wheat seed germination when the soil temperature rose above 65°C. These trials also demonstrated that microwaves interact with the soil rather than with the seeds and that heat must transfer from the soil to the seeds if germination is to be suppressed.

Horn antennas can project microwave energy into open space (Connor 1989). Heating equations, developed in earlier studies (Brodie 2006, Brodie 2007a, Brodie 2007b), can forecast the heating patterns in the soil. The temperature distribution can be described by Equation 1.

Figure 1 shows these patterns. The hottest place in the heating pattern was along the centre line of the antenna and between 2 cm and 5 cm below the surface, depending on the soil type and moisture content.

Soil type, which depends on the distribution of particle sizes in the soil mixture, determines how easily a soil will interact with microwave photons. Table 1 shows that dry clay heats more rapidly than dry loam, which in turn heats more rapidly than dry sand.

Photons in the microwave energy range interact strongly with polar molecules, such as water (Metaxas and Meredith 1983); therefore the most likely explanation for this differentiation in soil heating between clay, loam and sand probably involves bound water on the soil particles. Usually bound water layers are a few molecules thick, even when the soil is 'dry' (Tikhonov 1997). Microwaves

Equation 1.

$$T = \frac{s\pi f \varepsilon_o \varepsilon'' \tau^2}{4k\alpha^2} \cdot E_o^{\,2} \cdot \left(e^{4\gamma\alpha^2 t} - 1\right) \times \left[e^{-2\alpha z} + \left(\frac{h}{k} + 2\alpha\right) z \cdot e^{\frac{-z^2}{4\gamma t}} \right] \times Cos\left(\frac{\pi}{a} x\right)$$

interact with this bound water to create heat. Because clay has the smallest particles (followed by loam and then sand), the surface area per unit volume for clay is very high; therefore there will be more bound water in a given volume of dry clay, resulting in faster microwave heating.

Seed survival depends on the soil temperature (Nelson 1996), seed size and whether the seeds have imbibed water or not (Bebawi *et al.* 2007, Brodie *et al.* 2007c). Figure 2 shows that wheat seeds, with an average mass of 41.7 mg each, are more susceptible to microwave treatment than wild oats seeds, with an average mass of 7.2 mg. Wild oats are more susceptible than ryegrass seeds, which have an average mass of only 2.1 mg each.

Figure 3 shows the temperature response curve for ryegrass seeds in sandy soil. Clearly, dry seeds (dormant seeds in dry soil) are much less susceptible to microwave induced damage than imbibed seeds.

Microwave treatment will not be as cheap as chemical treatments; however its mechanism for killing weeds and their seeds is different to chemical treatments. This can deal with herbicide resistant individuals in the weed population; therefore microwave treatments should be considered as part of an integrated weed management plan.

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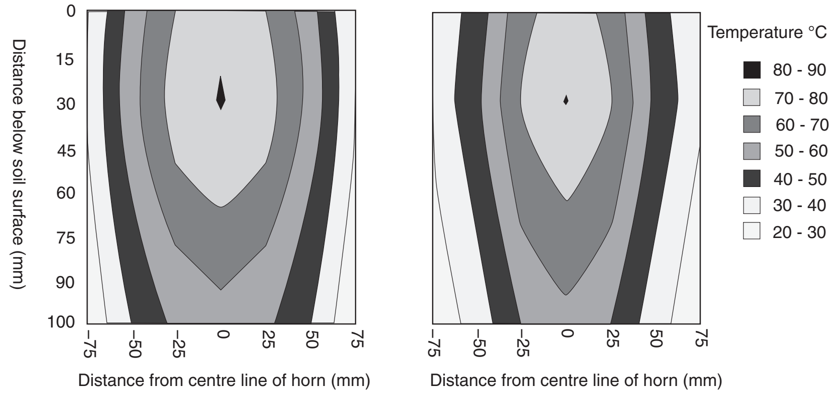

Figure 1. Comparison of expected heating patterns (left) with measured pattern (right) in clay/loam soil (Source: Brodie *et al.* 2007b)

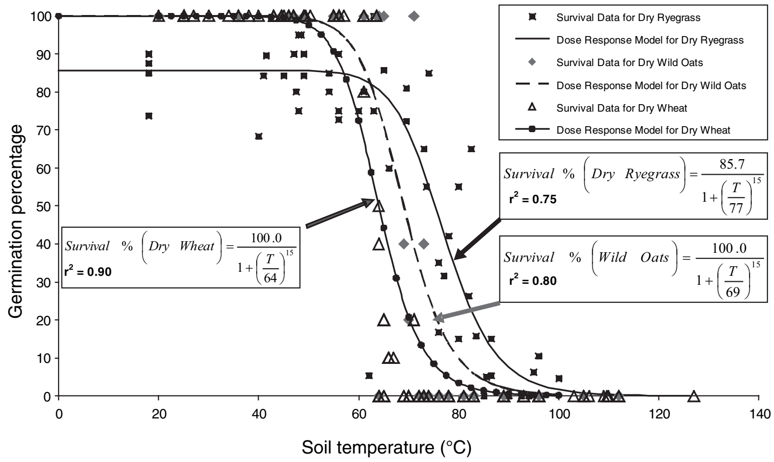

Figure 2. Dose response curve for soil temperature versus seed survival percentage for wheat, wild oats and perennial ryegrass seeds in dry soil.

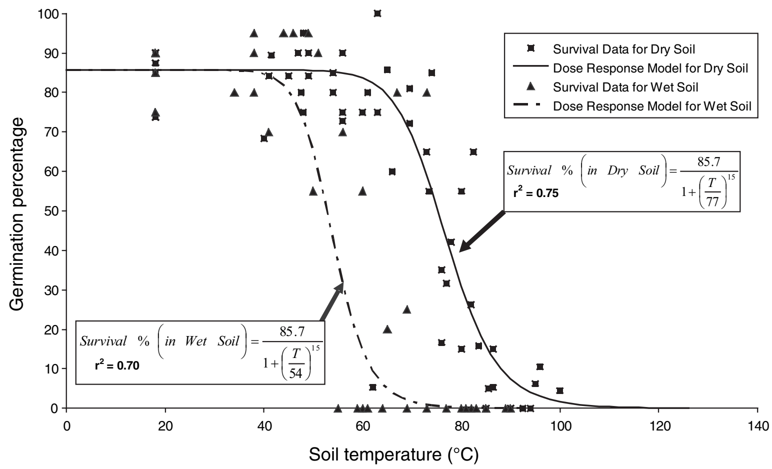

Figure 3. Dose response curve for soil temperature versus seed survival percentage for perennial ryegrass (*Lolium perenne*) seeds (Source: Brodie *et al.* 2007c)

Table 1. Soil heating data for two levels of microwave power.

Soil type	Average moisture content of air dry soil samples (% of dry soil mass)	Average heating rate for air dry soil samples at 2 kW of microwave power (°C per second)	Average heating rate for air dry soil samples at 4 kW of microwave power (°C per second)
Clay	6.92 a	0.66 a	1.33 d
Loam	3.08 b	0.53 b	0.80 e
Fine sand	0.38 c	0.30 c	0.68 a
LSD (P <0.05)	1.12	0.09	

Note: Means with different superscripts are significantly different to each other (Source: Brodie *et al.* 2007b).

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The impact of weeds on our roadside secrets

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I am here today to share my passion for roadsides and the challenges of inspiring people to get out and bond with their roadside before strapping on their spray pack. I use the word bond because that is what our roadsides need. People need to understand that roadside weed control is a journey, sometimes of many years, it is not a quick spray and the problem is fixed. Before I jump into the weed focus I would like to start at the beginning of the roadside journey, to give you an insight into how people understand roadsides and the weeds that grow on them.

Roadsides are often perceived as that forgotten strip of crown land located in that no mans land between private property and the road. Places where weeds grow in their own merry way, unaware the anxiety and stress they are causing.

Working for Victorian local government has given me the ability to realise that roadsides are not forgotten, if anything they are the most thought about crown land in Victoria, possibly Australia. More importantly I have learnt to listen and appreciate that everybody has a view point about roadsides and in relation to weed management their comments are very rarely positive.

The focus of a person's interest in roadside weed management closely reflects the passion and interests of that person. The more general comments relate to the fact that everybody drives past roadsides, we all spend too many hours of our lives watching them, zoning out on them and in some cases they are where we interact with our native wildlife – not always in a positive manner. This understanding of roadside management is what can be referred to as the 100 km per hour windscreen opinion.

To local government, VicRoads and roadside contractor staff our appreciation and interaction with roadsides can get bogged down in the fact there are more than 23 different legislations, strategies and requirements relating to roadside management. If you know of any other crown land that has as many rules and regulations I would like to know.

We are also dealing with staff coping with a huge 180 degree change in their work practices. We have engineers and grader drivers who, as recently as 15 years ago, were clearing chain widths of roadside native vegetation. Now they are having to dealing with young green things like me tapping them on the shoulder and ask them not to park their machines on tuffs of 'scrappy, crappy and grey' native grasses. No wonder they are left scratching their heads!!

Fire management personal also bring another angle to roadside management where, based on historic practices landholders spend hours and hours sitting on their tractors ploughing away their roadsides. If they take a step back they also scratch their heads wondering why they now have a weed invasion just in their plough lines (in some cases they now have a higher fuel load then the natives species they started with) and was it worth the expense of fuel and their time. There is also the fact that the behaviour and intensity of recent fires showed that the majority of fire breaks on roadsides were in-effective.

The adjoining landholder opinion usually is more sensitive because they try to take their paddock focused weed management knowledge and try to adapt it the linear roadside. The difference with a roadside and a paddock is that the roadside is usually long and linear in shape, there are a large number of uncontrollable external intrusions and the edge effect provides great stress on the native vegetation (making it much easier for weeds to dominate).

There are also the roadside firewood collection and grazing view points that need to be considered.

To the flora and fauna departmental people, naturalists, friends of groups and environmentalists, roadsides are seen as the saviour for our habitat future. Roadsides have been lovingly referred to as the window into our past, the source of genetic material on which the future of our bare-paddock revegetation projects depend on, as well being the Ned Kelly of the natural world. Why Ned Kelly?

Roadsides and Ned can be described as being famous for all the wrong reasons, yet both are an important part of what it means to be Australian. As well as the fact that many of our endangered ecological vegetation classes (EVCs) and endangered animals are only found on roadsides and like Ned, they are facing their last stand. This battle is seeing the armour of Mother Nature slowly being eroded away and we are seeing the diversity of roadside ecosystems being slowly disappearing. I have yet to see a low conservation roadside be upgraded to medium or a medium to high but many of us could name examples where we see them going the other way.

So what can we do?

Well, as all local government staff know, the solution needs to be done on the sniff of an oily rag, a juggling act of view points needs to be preformed (preferable in a suit of lycra) and you need to think outside the square, especially since roadsides are linear reserves not blocks of land. The lycra is a good start to get you out of your comfort zone and it gets you thinking as you have not thought before.

So where did Wangaratta start with our thought process? Well, we started with how lucky local government staff are. Unusual thought you say? But if you think outside the square we have people coming to us, to tell us, what they think about roadsides. How lucky is this! Other land mangers spend huge amounts of money seeking community input. If there is something local government does well – we attract community input. Obviously, I would love the community input to be about celebrating the first flowering of their roadside orchids or the nesting of the grey crowned babbler but realistically we settle for the fact they will be telling us they have the best crop of roadside Patterson's curse in the district!!

Once digesting the fact of how lucky we are, we then moved on to try and understand what are the weed messages people have heard and what do they understand. The positive is that the message is clearly out there that weeds are bad and therefore they must be controlled. Department staff and the Landcare movement have done a great job on weed education – landholders know Patto is bad, they know blackberries are the enemy and if you want an interesting discussion ask them about willows!

What we found is that the understanding as to why roadside weeds are bad was lacking. There is great understanding of weed control in a cropping paddock, a vineyard or alpaca farm but when it comes to weeds growing within a native area this is a different story. If you think about it, this knowledge does exist but usually within departmental staff, for example Parks Victoria Rangers or weed contractors, not individual land holders. This is a broad generalisation and I acknowledge that there are many friends of people and Landcare people that will have more knowledge of weed control in native areas that I ever will.

Continuing the thought process – we worked out that these bushland land mangers and staff have been taught to look at all elements of the bush not just the element of weed management.

So, by taking a step back we discovered why the message of weed control on roadsides has been missing the mark. So the challenge Wangaratta accepted was to find a way to assist landholders to see roadsides through a range of different eyes.

We discovered the solution existed in the fact that people come to local government with their knowledge of roadsides – again, how luck are we! Another angle included in the solution came from a presentation I heard at a Landcare conference where the speaker challenged us as to why images of salinity and bushfires always get the funding over weeds? The answer related to the images – salinity and bushfires evoke emotion from people as they highlight the devastation. Now think about weed images. Generally they have been taken to help people identify the weed not to stir emotion or open the purse strings. On more than one occasion at a weed information stall, a person looking at the weed in a pot has ask me how much would I like for it as they would like to plant it in their garden!! I would not think I am the only one to experience this request!!

There is so much jargon and terminology in the natural resource management industry that it does not take long for people to feel overwhelmed and you notice their eyes glazing over. Therefore we needed something to engage them.

We were also conscious that there are many landholders with the attitude that they know enough about weed control, or that they do not seek out information as they are embarrassed by the fact they are suppose to know about weeds but in reality they do not.

Now if I was to lean closer to the microphone and ask you 'Can I tell you a secret?' Would you be interested? Would you not want to know more? Even better, once I tell you the secret, many of you will think of someone else you would like to tell the secret to.

Well the secret I would like to share with you, is this roadside film, 'Keeping Roadside Secrets Safe'.

We took many local people out onto their roadsides and captured their knowledge. Over 30 hours of interviews, roadside footage and car cam have been condensed into a 25 minute film which captures the wide range of secrets found on our roadsides.

This film has been distributed for free to all relevant local community groups, the other 78 Victorian local Councils, NE NRM agencies, local schools and to interested persons. We have even been fortunate that the community television station, Channel 31, viewed it to its Melbourne viewers. Never did I think there would be so many Melbournites interested in rural roadsides!

There is a twist to this secret and that is we want the secret to get out. The message has been spreading far and wide and I now receive many phone calls from people wanting to know what else is on their roadside before they spray. This is a huge change in behaviour especially in areas where Chilean needle grass grows in amongst native grasses and historic accidental kill rates of the native grasses has been high. There have also been phone calls from as far a field as NSW, SA and WA. I am always fascinated how networking spreads the message! I have also had calls from many environment officers from other Victorian local governments where a member of their community has seen the film and are now putting pressure on their Council!

Running in the background of this education process is the debate of who is actually responsible for roadside weed control. Personally I do not want to wade into this debate without a nice sunset to watch and bottle of red to share. The outcome of this debate, if it ever comes, will be decided by solicitors and the powers-to-be in Melbourne, not by me. With guidance from the Municipal Association of Victoria (MAV) mention is given to this issue in the film without distracting from the key messages we want people to hear.

It is with these key roadside messages I would like to conclude my presentation. To date, roadside weed management messages have focused from the road and looked toward the property. We have tried to turn this around and looked at them from the property through the roadside to the road. By understanding the secrets of your own roadside and by looking at the activities undertaken on your roadside a landholder will start to understand why weeds grow where they do. For the first time in seven years I have had a landholder approach council wanting to know how to restore a high conservation roadside he has meandered through with a plough for his long life time. His enquiry came after watching our film. While I do not have the pulling power of Al Gore it is still a start in the right direction. For those interested in a copy of the roadside film, please come and take your free copy. Please limit it to one copy each but if you would like more please let me know. Thank you very much for your time and I welcome any questions.

Containing orange hawkweed (*Hieracium aurantiacum*) infestations in the Ballarat area

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Summary The Victorian Department of Primary Industries (DPI) has successfully contained and is working towards the eradication of orange hawkweed (*Hieracium aurantiacum*) in the Ballarat area in western Victoria. Orange hawkweed is a declared State Prohibited Weed in Victoria and is a significant threat to the State's agricultural industries and natural environment. Several garden and nursery infestations have been located around Ballarat. These have been treated and are regularly monitored.

Introduction

Ballarat

Ballarat is described as 'Victoria's largest inland city'. It is located at 441 metres above sea level with a population of approximately 88,000 people. Major industries include tourism, retail, manufacturing and community services (City of Ballarat 2007).

The Ballarat area is described in this paper as the area of land consisting of the statistical local areas of 'Ballarat Central', 'Ballarat Inner North' and 'Ballarat South' (Figure 1). The total area containing agricultural activity is described as being 6369 hectares in size. Of the agricultural land 2753 hectares of land was sown to pasture, and there were 14,036 sheep and lambs produced during 1996/7 (Australian Natural Resource Atlas 2007).

There is a high attraction and influx of tourists to Ballarat during festivals and events throughout the year, with one estimate suggesting that there are 1.8 million domestic day trips per year (City of Ballarat 2007). This has interesting implications for the spread of weeds through the vector of human transport and this will be explored further.

Orange hawkweed in Victoria

Orange hawkweed *Hieracium aurantiacum* (F.W.Schultz & Sch.Bip.) was lodged for the first time with the National Herbarium of Victoria in 1999, from a Falls Creek site (Williams and Holland 2007).

After an assessment of the potential invasiveness of *Hieracium* species and the history of the plant in other countries, all species of *Hieracium* were declared as State Prohibited Weeds in the State of Victoria, on the 22nd of May 2003 (Victorian Government 2003), under the *Catchment and Land Protection Act 1994*.

In particular, hawkweeds were considered to be a potential threat to 'pastures and to the wool, meat and dairy industries' (DPI 2003 p. 2). The extent of the area of potential distribution of orange hawkweed was determined during Phase 1 of the Noxious Weed Review process and was created using CLIMATE® modelling (DPI 2007). The modelling placed the Ballarat area within a 'high' category of potential orange hawkweed distribution.

Orange hawkweed was first recorded, outside of the high country, by DPI in 2002 at a nursery near Geelong, and in 2003 in a small 'collectable plant' nursery on the outskirts of Ballarat. It has since been found in West Gippsland at Yallourn in 2004, and again in Ballarat in 2006.

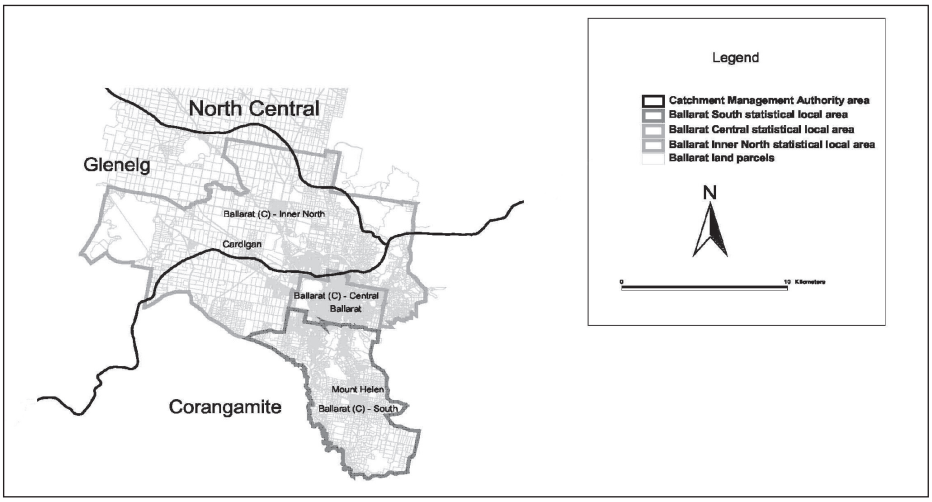

Figure 1. Statistical local areas of Ballarat.

Assessment of orange hawkweed in Ballarat

Assessing an infestation of a weed can be described as including the process of determining the identity, size, location and density or distribution of a particular species. The process of assessment is usually undertaken during a site inspection and can be assisted by the use of photographs and field reporting sheets to record the particulars of the site, including land tenure, date and specific location coordinates.

The following is an assessment description of known in-ground infestation sites of orange hawkweed, found within the Ballarat area and recorded by the DPI Weed Alert program. These infestations have been recorded on the DPI Integrated Pest Management System (IPMS) database and are described in Figure 4 using site numbers.

Site 1

An infested site found in the Ballarat area was at a property that was initially developed as a nursery and display garden. The property which is around two hectares in size was once described as being 'along the lines of the great gardens of Europe and England… [with] hidden gardens, dry stone walls, waterfalls, bridges, manicured hedges and much much more' (City of Ballarat 2007).

Pots of orange hawkweed were removed from the display garden in which a 0.005 hectare in-ground infestation was recorded on IPMS. The in-ground infestation occurred along a walking path. Non-selective herbicide was used to spot spray areas of infested lawn on the 17th of November 2005. After the initial inspection by Departmental officers it was discovered that the nursery was to be sold and the new owners were to take over the property from early July 2006.

The next inspection on the 29th of September 2006 resulted in the discovery of eight orange hawkweed infested pots within a disused glasshouse (Figure 2). The neglected and run down glasshouse contained a large number of orange hawkweed infested pots within which the original nursery plants had died (Figure 3). Discussions with managers at the site revealed that the pots within the glasshouse had been offered to those associated with the property. This led to the creation of a warning notice attached to the glasshouse asking that anyone who had removed pots from the site contact the Department. The eight pots were voluntarily surrendered and taken to the State Government Offices for storage prior to disposal.

After the initial pot surrender it was considered that the remaining pots within the glasshouse had the potential to contain viable seeds, seedlings or stolons of orange hawkweed. Two officers returned to the site on the 18th of October 2006 and worked to manually remove the pot material including potting mix and plant matter in a hygienic manner. Two hundred and forty litre garbage bags were used to contain the material. Two bags, one inside the other, were used to contain the material and bags were tied at the top. Bagged material was stacked into a tandem trailer and transported to the local land fill site with which an arrangement to bury the material had been made. A total of 1.18 tonnes of material was buried in an asbestos trench at the land fill site. This site was then recorded on IPMS.

Site 2
The second infested site of orange hawkweed was on a property that formerly traded as a nursery. The infestation was recorded on IPMS in the 18th of May 2005. Several garden beds around the nursery site contained plants that were subsequently treated with non-selective herbicide on 17th of November 2005. Due to the diligence of the new manager of the site, no longer trading as a nursery, the infested areas were later staked and marked with flagging tape to allow them to be easily identified. A Departmental officer returned to the site on the 23rd of May 2006 and treated the infested areas with non-selective herbicide. No further germinations of the weed were found during an inspection on the 12th of February 2007.

Site 3
An orange hawkweed infestation recorded on a nature strip in the Ballarat suburb of Wendouree was reported to DPI by a local resident, a student of Ballarat University. The reporter observed an unusual orange flower and took it to the University to consult a lecturer. Upon receiving advice that the flower was most likely that of orange hawkweed the reporter contacted the Department. An inspection found that small rosettes of the plant were present in November 2006. These rosettes were treated by being spot sprayed with selective herbicide. No further rosettes were found upon inspection on the 2nd of February 2007.

Site 4
A fourth site found to be infested with orange hawkweed was a private residence on the south side of Ballarat within a suburb with a larger than average property size on the border of State Forest. This property contained a very well maintained garden that has been open to the public under the Australian Open Garden Scheme. The plant was described by the owner as having been deliberately planted within a driveway garden bed between 1998 and 2000. Although the original plant had been treated, seedlings of orange hawkweed were later found within lawn areas adjoining the original site. Treatment during May 2006 and September 2006 was conducted using non-selective and selective herbicides within lawn areas. A follow up inspection in February 2007 revealed no further plants were present.

Site 5
An orange hawkweed infestation, first recorded on IPMS on the 12th of May 2005, was discovered at the Ballarat Botanic Gardens. The infestation in a lawn area adjoining garden beds was treated with a non-selective herbicide on the 17th of November 2005. The infestation was said to have spread to this location from an unknown source some years before (Peter Marquand personal communication 2nd of February 2007). A subsequent inspection on the 1st of May 2006, determined that a repeat treatment was required with spot spraying of non-selective herbicide.

Further inspections on the 23rd of November 2006 identified orange hawkweed within two separate garden beds to the east of the initial infestation as well as around the garden beds previously treated. Spot spraying with selective herbicide was used on garden paths and rock borders as well as within the newly identified infested garden beds. The aim was to treat rosette foliage as well as stolons, which may have regenerated if missed by manual treatment. An inspection of the gardens on the 2nd of February 2007 led to the discovery of several rosettes within the same gardens, on the soil surface above Iris plants. Hand pulling was used to remove the rosettes and as much of the root material as possible with the material being bagged and stored prior to hygienic disposal by incineration.

Mapping orange hawkweed
Maps of weed infestations can be created from the data recorded within IPMS. The collection of data is usually done as part of the assessment process and is enhanced with the use of accurate spatial coordinates. From the points created to indicate an infestation patterns of infestation can be interpreted. Maps can help to define the Catchment Management Authority Area in which the infestation falls and may help to identify those responsible for managing the land. This leads to benefits in planning infestation treatment and may also be used as a tool to plan the validation or further searching for the location of the same weed within the area.

Due to seed dispersal by wind as well as the possibility of stolons of orange hawkweed being distributed by machinery such as lawn mowers, accurate maps may help to identify areas in which a weed has the potential to infest. For example, areas to the west and south east of all known inground infestations have the potential to become infested by wind dispersed seed if any orange hawkweed plants are able to flower and set seed. These areas would therefore from a priority area for monitoring and surveillance.

Treatment of orange hawkweed
The treatment of orange hawkweed in the Ballarat area has mostly been confined to the expected flowering period of the species between January and March (CRC Weed Management 2003) but has also included the period between September and November. The use of non-selective herbicide by spot spraying has been shown to be an effective treatment method, however it does have the disadvantage of creating large patches of bare ground and effecting non target species within lawn areas and garden beds. A shift to spot spraying of selective herbicide in more recent times has shown to be advantageous.

An area surrounding a known infestation within a lawn area can be treated using a selective herbicide resulting in the destruction of numerous species of flat weeds including orange hawkweed without leaving bare soil prone to further weed infestation. The hand pulling of plants within infested sites such as those at the Ballarat Botanic Gardens, where rosettes were found within structured garden beds amongst a variety of other annual and perennial plants, was used. This treatment method is limited by the fact that not all of the plant rosette and root system may be accessible, especially within heavily mulched garden beds, and the network of stolons leading from a rosette may not be identified and therefore left intact. Any remaining stolons may have the capacity to re-shoot and therefore require further treatment.

The human aspect of orange hawkweed spread
A large number of human activities have been important to the spread of the weed. These activities have included the sale and distribution of the plant as a garden plant, anecdotally reported throughout various nurseries in the Ballarat area. Two of the known infested sites described earlier (sites 2 and 4), have been involved in the sale of the plant and it is suspected that the plant was also placed within garden beds at both sites. It may have been planted as a garden specimen and used to promote sales as a display plant.

The flowering period of the plant may also help to create demand for the plant as it flowers during a period when there is limited colour within the garden. There may also be accidental distribution of the plant through infested potting material.

There are a large number of visitors to Ballarat throughout the year for several very popular festivals and special events. The special interest events, such as the 'Begonia Festival' are conducted within the expected flowering period of orange hawkweed. With the assumption that

Figure 2. Nursery pot infested with orange hawkweed. Source: Simon Martin, Department of Primary Industries.

Figure 3. Glasshouse pots at former display garden Ballarat Source: Andrew Staley, Department of Primary Industries.

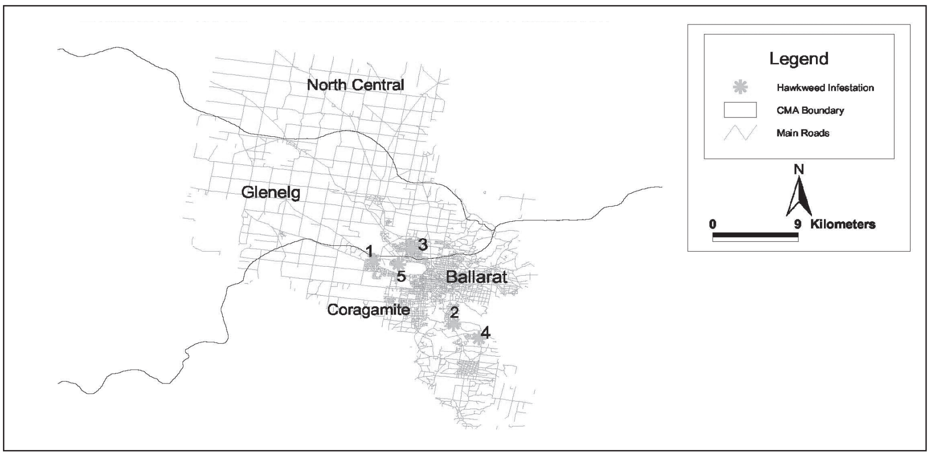

Figure 4. A map of the known in-ground infestations of orange hawkweed in the Ballarat area.

the best time to trade a plant is while it is flowering, this has implications for the export of orange hawkweed from the Ballarat area. With visitors potentially having observed orange hawkweed within the Ballarat area during festivals prior to the sites being treated in the past, any number of trades may have occurred resulting in imports and exports of the species.

Conclusion

After declaration of orange hawkweed in Victoria as a State Prohibited Weed, five sites have been identified with in-ground infestations within the Ballarat area. The human vector can be considered as being very important to the spread of the weed and continued work with the community will be needed to highlight the potential threat that this weed presents.

Continued assessments, monitoring, mapping and treatments by DPI have been required to ensure containment to date. These efforts which involve working towards eradication of the weed are necessary in Ballarat where the potential distribution has been assessed as being high. Of greatest threat are the very important agricultural enterprises of the Ballarat region, the surrounding area and Victoria.

Continued successful containment and eradication of the weed will depend upon successful negotiation with land owners and managers from a range of land tenures. The timing of assessments and treatments will be critical to ensuring that all in-ground infestations of orange hawkweed do not spread.

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Alert and action on *Nassella charruana* and a range of other National Alert List species in Victoria

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Summary Six National Environmental Alert List weed species were targeted for follow-up surveys and treatment for eradication in Victoria. The species were: *Nassella charruana*, *Acacia karroo*, *Hieracium aurantiacum*, *Trianoptiles solitaria*, *Piptochaetium montevidense*, and *Cytisus multiflorus.* New infestation sites were discovered for *Nassella charruana*, *Hieracium aurantiacum* and *Cytisus multiflorus*. To facilitate prompt reporting and effective treatment of new infestations of *Nassella charruana* the Department of Primary Industries (DPI) developed networks with affected landowners and local governments. Neither *Trianoptiles solitaria* nor *Piptochaetium montevidense* were detected during the project period. *Acacia karroo* is a species restricted to a small number of sites and is considered very close to being eradicated from Victoria. Negotiations with landowners will progress to ensure the removal of the last remaining *Acacia karroo* trees. However, much work is predicted in the future with *Nassella charruana*, as it occurs in the midst of a land development area on the northern outskirts of Melbourne. Caution will need to be taken to ensure that weeds are not spread through the land development process. DPI will need to continue working with land developers to make certain that suitable hygiene protocols are adopted.

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

Introduction

The National Environmental Alert List (Alert List of Environmental Weeds) was developed in 2001. It consists of 28 weed species currently in the early stages of establishment that have potential to become a significant threat to biodiversity if they are not managed (Department of Environment and Water Resources 2007). Six National Environmental Alert List weed species were targeted for follow-up surveys and treatment for eradication in Victoria. The species were: *Nassella charruana*, lobed needle grass; *Acacia karroo*, Karoo thorn; *Hieracium aurantiacum*, orange hawkweed; *Trianoptiles solitaria*, subterranean Cape sedge; *Piptochaetium montevidense*, Uruguayan rice grass; *Cytisus multiflorus*, white Spanish broom. This work was largely a continuation of the work achieved by a previous project targeting the same six species (Hansford 2005), except that the new project placed more emphasis on *Nassella charruana* (lobed needle grass), a species which had shown a marked increase in the number of known infestation sites due to recent detection efforts (Hansford 2006). The latest project, which ran from July 2006 to June 2007 was called 'Alert and action on *Nassella charruana* and a range of other National Alert List species in Victoria' and was funded by the 'Defeating the Weed Menace Programme'. The project worked with many key stakeholders to enable early detection and treatment of infestations and to raise awareness amongst the general public of these species. Three of the targeted species, *N. charruana*, *A. karroo*, and *H. aurantiacum* are declared State Prohibited Weeds in Victoria under the *Catchment and Land Protection Act 1994*. This status requires their eradication from the State.

Materials and methods

1. Framework

The 'Weed Alert Plan Victoria 2006/2007' describes how the surveillance and response to potential, new and emerging weeds, including the six species targeted in this project, is managed in Victoria. Weed Alert is a State Government program developed to prevent the introduction of serious new weeds to Victoria, and to eradicate the most serious incursions that have naturalised. The program focuses on State Prohibited Weeds and Victorian Alert Weeds by overseeing the surveillance, collection, identification, assessment of and response to these species. Weed Spotters are enlisted to assist with the surveillance part of the process. They assist the Weed Alert team by keeping an eye open for these species (McInerney and Robinson 2007).

2. Surveillance

Without ongoing detection new weeds can establish in areas making it difficult to eradicate or even contain the incursions. Awareness of characteristics and pathways in which weeds can be introduced into Victoria improves the chance of catching the incursion in its infancy, greatly improving the chances of eradication. All existing properties that contain or once contained incursions of these species have been surveyed. Follow-up monitoring takes place to ensure all necessary incursion treatments occur seasonally to achieve an eventual eradication of incursion sites. As well as knowing the existing sites of the weeds, it is also necessary to have a good knowledge of the growth patterns of a species. The times of year and forms of a plant that make identification possible must be known before a surveillance program can be run. The potential vectors of spread and the habitat in which the species will grow are also very important to be able to locate outlying populations.

3. Control

The control methods used to treat the weeds in this project were based on those used in the previous project targeting these species, as described in Hansford (2005). These methods are outlined below:

Physical/mechanical *A. karroo* trees were physically removed as follows:

- All branches were chipped on-site in enclosed chippers. Large limbs and trunks were cut to smaller size for ease of handling and loaded with the chipped material.
- All tree stumps were cut close to the ground and swabbed with herbicide.
- The truck that transported the plant material to landfill was covered and secured to avoid any plant material escaping en route.
- All of the plant material was then deposited to an excavated hole at a landfill site, and then the hole was covered with soil and other rubbish as part of the landfill operation.
- Site revegetation was undertaken using non-invasive species.

Chemical The strategy to control *N. charruana* was to 'spot spray' individual plants to kill these plants before they set seed. This enables the germination of soil stored seed which can then be followed-up continuously with 'spot spraying' when growth conditions are suitable. This method will exhaust the seed bank over time. A non-selective chemical is used which may promote the appearance of bare ground in the dense infestations sprayed. This will encourage further germination from the seed bank. It is expected that once the seed bank is exhausted natural regeneration of native or introduced pasture grasses will occur, providing sufficient ground cover in the future.

The strategy to control *H. aurantiacum* involves spot spraying individual plants or dense patches before they set seed. This enables the germination of seed stored in the soil, which will be followed up with more, spot spraying. In most instances a selective chemical is used.

For *C. multiflorus*, all plants were sprayed during flowering before seed set. *C. multiflorus* is best targeted during its spring flowering as it can be difficult to detect it amongst other vegetation when it is not flowering.

4. Site monitoring

All sites were monitored after treatment to make sure treatment was effective and to assess whether more treatment was required that season. All landowners were made aware of the need for follow up monitoring by DPI officers. All treatment and monitoring were recorded on DPI's Integrated Pest Management System (IPMS).

5. Machinery hygiene procedures

There are many vectors of spread for weeds, including wind, water, animals and machinery used for both farming and land development. While working with land owners to eradicate a species it is also important to make sure they are not perpetuating the problem by spreading the weeds to other areas of the property or to other properties. Machinery hygiene is import to stop weed spread. It involves washing down any part of a vehicle that may be harbouring any part of a weed that may grow. Mapping the infestation on the property and having knowledge of times of year that the weed is seeding are also important in the management of weed spread (Tyers *et al.* 2004). At known infestation sites for *N. charruana*, DPI has informed land developers about weed spread and the importance of machinery hygiene and will continue to work closely with them to ensure seed-infested soil is disposed of appropriately.

Results and discussion

Nassella charruana – lobed needle grass

Even within its native range in South America, *N. charruana* is reported to be a weed due to its competitiveness, unpalatability and very sharp, needle like seeds. Once thought to only infest a small number of properties on the northern outskirts of Melbourne (CRC for Australian Weed Management 2003a), *N. charruana* has now been found on many more properties in the Whittlesea council region. The increase in number of properties infested from 15 (reported in 2004) to 53 (see Table 1) has been due to more surveillance in the region by both Whittlesea City Council employees and DPI employees. With more surveillance planned for the 2007/08 season it is expected that more new sites will be found.

Historically this land was predominantly open grasslands with some scattered tree cover. After settlement this area was used for grazing and there has also been some quarrying in the area. Now this area lies right on the edge of the urban fringe, with many new housing developments under way. As the increase in properties to be treated continually by contractors has increased there is need for coordination of both spraying and surveying. In addition to the IPMS database, the Project Officer maintains a spreadsheet and landowner file system that encompasses land owner details, size and density of the infestation, times of treatments occurring in the year, maps, photographs and other relevant information. As more properties will be developed in the future it is imperative that good records are kept and relationships are maintained with developers.

All known *N. charruana* sites were surveyed at least once during the project period to assess how effective the spraying program has been. While assessing existing properties, neighbouring properties were surveyed to look for new *N. charruana* incursions. If new incursions were found, landowner information was obtained and the landowner was contacted. During the infestation surveys the following information was recorded:

- Global Positioning System (GPS) points of patches of the weed over the property
- The area the infestation covered
- The percentage density of the coverage
- If the plant had been sprayed how much had died off from the last treatment.

All of this information was then recorded in the IPMS. If a known infestation cannot be located, it is followed up each year until DPI is confident that the weed has been eradicated from the site. By carrying out field surveys, DPI can maintain up to date records and also keep up to date on other avenues in which the weed may be moved onto other land (i.e. soil removal, slashing etc.). DPI works closely with property owners to minimise the spread of weeds.

The success of the *N. charruana* eradication program relies on catching new infestations in their early stages. By working with local councils new infestations have been found and treated during the project period. The City of Whittlesea (where most of the infestations occur) has officers that are trained in the identification of *N. charruana.* Once found the officers report the incursion to DPI who follow up the report. Some incursions have been found outside the boundaries of Whittlesea, therefore the councils surrounding have been contacted and made aware of the weed. An information and identification session was run at Hume City Council in February 2007. Items covered were what the weed looks like, its growth habit, how to report an incursion and what to tell land owners if it

Table 1. The number of known infestations in 2004 (as reported in Hansford (2005)) compared to 2007.

Species	Number of properties with infestations reported by 2004	Locations of infestations	Additional number of infestations detected by June 2007	Total number of infestations detected by June 2007	Number of infestations treated by June 2007
Nassella charruana	15	Whittlesea, Hume, Darebin Council regions	38	53	51
Acacia karroo	10	Werribee, Bendigo, Williamstown	0	No new infestations, only 2 trees left in Victoria	1 site 7 trees treated or removed
Hieracium aurantiacum	27	Falls Creek, Ballarat, Gippsland	24	51 (33 in Village at Fall Creek)	51
Trianoptiles solitaria	1	Balwyn North	0	1	0
Piptochaetium montevidense	0	Altona	0	0	0
Cytisus multiflorus	2	Creswick, Ballarat	1	3	3

is found on private land. Around 20 council officers attended the training. Training events in the other councils surrounding Whittlesea are planned for 2007. DPI is also working with councils to ensure that strict machinery hygiene protocols are put in place for land developers and their contractors (particularly in the Whittlesea region).

DPI is also working with developers to minimise the spread of *N. charruana* through the movement of soil on the property and to other land. It has been proposed that developers scrape seed contaminated soil and use as fill or for landscaping and cap with clean soil and top soil. Burying the seed deep in the soil profile will limit the growth of germinates and eventually the seed will loose its viability. Other avenues that developers could engage in is to take the scraped soil to landfill and have it buried deep beneath other layers of waste.

Acacia karroo – Karroo thorn

There have been no new discoveries of *A. karroo* found within Victoria (see Table 1). The known infestations that still exist today were all planted many years ago, prior to the 2003 declaration of *A. karroo* as a State Prohibited Weed. Originating in South Africa the *A. karroo* is a large growing acacia with large thorns (CRC for Australian Weed Management 2003b). At the start of this project, there were only three known sites: Werribee Open Range Zoo (seven trees in enclosures), Bendigo and Williamstown. During this project period the seven trees at the Werribee Open Range Zoo were treated by DPI contractors. There were issues with timing the extraction of the trees due to the inconvenience to the zoo and having to re-design the Meerkat enclosure once the trees were removed. The Zoo also wanted to leave one dead *A. karroo* tree standing in the Cheetah enclosure as a feature. After some negotiation, the outcome was successful, with six trees being removed from the zoo, the remaining tree being poisoned and left standing dead in the Cheetah enclosure (as requested by the Zoo). The zoo also received assistance from the project in the revegetation of the affected Meerkat enclosure.

In May 2007, an arborist was engaged to remove the trees from the Werribee Open Range Zoo. All trees were de-limbed and taken to the chipper that was parked close by. Extra large limbs and trunks were placed in the truck with the woodchips. All material was taken to a quarantine landfill site, and was deposited in a hole at the landfill site to be buried under several meters of landfill. The cut stumps of *A. karroo* were treated with chemical to ensure that re-shooting did not occur. The tree that was left standing in the Cheetah enclosure was drilled and filled with chemical and left standing to die. This tree had started showing signs of die-off within a few weeks and will be closely monitored over the next few months to ensure that the tree dies.

The Williamstown and Bendigo trees are now the only two known trees of *A. karroo* left in the State. It is hoped these trees will be able to be removed in the near future. This would effectively mean the eradication of all known trees of *A. karroo* from Victoria. However, issues such as their Heritage listing add complexity to the situation. The next step will be for DPI to undertake more liaison with a range of stakeholders concerning these trees.

Piptochaetium montevidense – Uruguayan rice grass

In its native range in South America, *P. montevidense* forms dense tussocks to about 0.5 m high and its growth is stimulated by fire. *P. montevidense* may compete well against native species because it is resistant to grazing. In its native range it is the most prevalent species of its genus (CRC for Australian Weed Management 2003c). The original infestation of *P. montevidense* at Cherry Lake Altona had been inadvertently completely buried by earthworks at some time in the past. The burial of the original infestation was noted at the previous inspection of this site in 2004 (Hansford 2005), where *P. montevidense* was not detected. The purpose of the visit to the site in the current project was to conduct a further follow-up inspection. The site was checked twice during the spring/summer of 2006, and both times there was no sign of the plant. Given that the species has not been detected during several previous surveys, it seems very likely that the species has been eradicated from this site.

Trianoptiles solitaria – subterranean Cape sedge

Trianoptiles solitaria is a small leafy annual herb that can grow to 200 mm high and has the ability to out compete more desirable indigenous plants. *T. solitaria* has only been reported from Winfield Park, a small park in the centre of Balwyn North (CRC for Australian Weed Management 2003d). The park was surveyed twice during spring/summer 2006. No plants were found during the inspection and it was concluded that the plant might not have come up this year due to the severe drought conditions experienced in the spring of 2006. The site will be inspected again in the spring of 2007 in an attempt to detect it.

Cytisus multiflorus – white Spanish broom

Cytisus multiflorus is a large shrub that grows to 3 m high. It has distinctive white flowers with a pink streak and the foliage is a green grey colour. *C. multiflorus*, like other brooms, is very invasive and forms dense stands. It can invade in many different habitats and soil types (CRC for Australian Weed Management 2003e). The existing site, Creswick Regional Park, where *C. multiflorus* has been treated in previous years, was surveyed during spring when the plant was most identifiable. Some sites within the park that had been treated were mostly clear of the weed; however, probably due to treatment being missed in 2005/06, some sites had grown back or spread to other areas. A school camp that borders the park was found to have a medium stand of *C. multiflorus* within its boundary. Another site in Ballarat (15 km away from Creswick) was also discovered this season. A possible source of the infestations on this new site is garden refuse being dumped on the edge of parkland. All of the new infestations were part of the Ballarat Cemetery property in Invermay. A contractor was engaged to treat all of the known infestations of *C. multiflorus*. All plants were sprayed before they set seed, which greatly reduced the chance of spreading. A very large specimen was found while surveying in the Creswick Regional Park this season. This plant had not been found in earlier years and is thought to be at least 15–20 years old.

Hieracium aurantiacum – orange hawkweed

Hieracium aurantiacum is a perennial plant that can grow up to 400 mm high. It has bright orange flowers and dark green hairy steams and leaves. It potentially threatens alpine regions and temperate tablelands. Hawkweeds have been found to be extremely invasive in areas overseas (CRC for Australian Weed Management 2003f). There has also been an increase in the number of known infestations of *H. aurantiacum* since the 2004 report. This result could be due to the greater time spent in surveying for the weed. The main outbreaks of *H. aurantiacum* have been in the Alpine region and the Ballarat area. Both outbreaks are believed to have occurred due to escape from previous garden plantings. Snow machinery has probably also contributed to the spread in the Alpine region. The incursions in Ballarat have mostly been found in gardens or old nurseries.

In late 2006, Parks Victoria (PV) employed a field officer to survey and treat all *H. aurantiacum* sites in the Falls Creek area. Due to bushfires in late 2006, this program did not run for the expected timeframe, however all located *H. aurantiacum* plants were treated. New arrangements are now in place for the next detection season, and stakeholder meetings on *H. aurantiacum* detection and management are held each year, with operational participants including PV, DPI, Falls Creek Resort Management Board, Mt Buller Resort Management, and the local Falls Creek water authority and ski-lift company. Information on *H. aurantiacum* identification has also been sent to a number of stakeholders and businesses, including ski lodges and residents at Falls Creek. This will ensure that key messages and identification techniques are circulated in the public domain. PV and DPI are also working closely together on data exchange and management techniques for *H. aurantiacum*.

In the Ballarat area, DPI coordinated all surveys and treatments of *H. aurantiacum*. DPI also held two information days featuring *H. aurantiacum.* These information days were run at a market in Ballarat during December 2006 and February 2007. The sessions were to alert the public to the presence of the weed in the area, and to help find any new incursions of this weed.

Conclusion

The project was successful. There were new detections of several of the targeted species during the project period, namely *N. charruana*, *C. multiflorus*, and *H. aurantiacum* which were subsequently treated and the data entered on database. One infestation site of *A. karroo*, was treated for eradication during the project period, bringing this species very close to being eradicated in Victoria (there now being only two single tree infestation sites left in Victoria). *P. montevidense* was not detected during the project period, suggesting that this species (combined with the results of past surveys) has most likely been eradicated from its only known site of occurrence in Australia. Similarly, *T. solitaria* was not detected at its only previously known site of occurrence during the project period. However, this result may have been attributed to the drought, and a further search will be conducted in the spring of 2007. There will be a need for continued detection and eradication work for *N. charruana* for some time, and DPI will coordinate this process with affected land owners, land developers and others through the Weed Alert program.

Acknowledgements

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The Victorian Weed Spotter network

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Abstract The Weed Spotter network is a weed surveillance program where individuals are trained to look for and report high priority Weed Alert species in Victoria. They assist in validating the distribution of these weeds which pose a serious threat to the State's assets and values. Reports are made through Weed Alert Contact Officers (WACOs) in the Victorian Department of Primary Industries (DPI) Weed Alert program. Weed Spotters are individuals recruited from the community, government or industry with an interest in reporting these priority weeds.

The network was officially launched and activated in October 2006 and has been expanding since this time. WACOs are now employed across the State and have been actively engaging with Weed Spotters, holding training and other events regularly. The network is now supported centrally by a Weed Spotter coordinator. The first year of network data can now be examined to inform future recruitment activities and to determine the effectiveness of Weed Spotters to look out for and report Weed Alert species.

Introduction

Weed Alert species

Weed Spotters are asked to look for and report Weed Alert species which are:

State Prohibited Weeds Are declared under the *Catchment and Land Protection Act 1994* (CaLP) and are illegal to buy, sell, display, propagate, possess for sale, deposit onto land, bring into or transport around Victoria. They either do not occur in Victoria or are already present but it is reasonable to expect that they can be eradicated. Their listing reflects the very serious harm these plants cause. Currently there are 25 declared State Prohibited Weeds.

Victorian Alert Weeds Are weeds that potentially pose a serious threat to Victoria's agricultural and natural assets or could affect human health. They may be naturalised in small numbers but are still eradicable or have not yet reached Victoria, but are believed to present a high risk. Each species will be targeted for surveillance by Weed Spotters to determine their distribution throughout Victoria.

Role of the Weed Spotter Coordinator

The Weed Spotter Coordinator works with the WACOs to ensure consistent engagement across the Weed Spotter network. This primarily occurs through the Weed Spotter Engagement Plan (McInerney and Robinson 2007) which outlines a strategic approach to recruiting new volunteers and maintaining the interest and effectiveness of existing Weed Spotters across Victoria.

Role of the Weed Alert Contact Officers (WACOs)

The role of a WACO within the Weed Spotter network is to strategically recruit new volunteers from their region and to provide a local contact point for existing Weed Spotters to make reports and receive training and information.

Weed Spotter network information

Location and recruitment trends

The Weed Spotter network rapidly expanded during the 2006/07 financial year. Weed Spotter numbers almost doubled from 595 in July 2006 to 1187 at the end of June 2007, as indicated by the sharp incline in Figure 1.

The distribution of Weed Spotters has been represented in Figure 2. Locations marked with a square indicate gaps where there were previously no Weed Spotters in the network and the locations marked with a triangle represent where numbers have increased. The number of Weed Spotters varies due to a variety of factors including the population of a catchment, the length of time a WACO has been present and the time dedicated to active recruitment. For example, during 2006/07 WACOs were

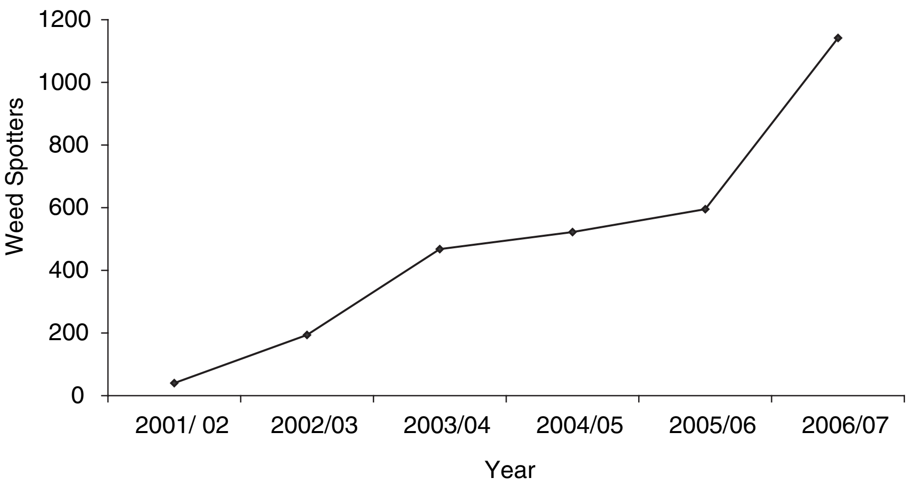

Figure 1. Increase in registered Weed Spotter numbers. Note that there are 28 registered Weed Spotters not included in this graph as no recruitment date is available.

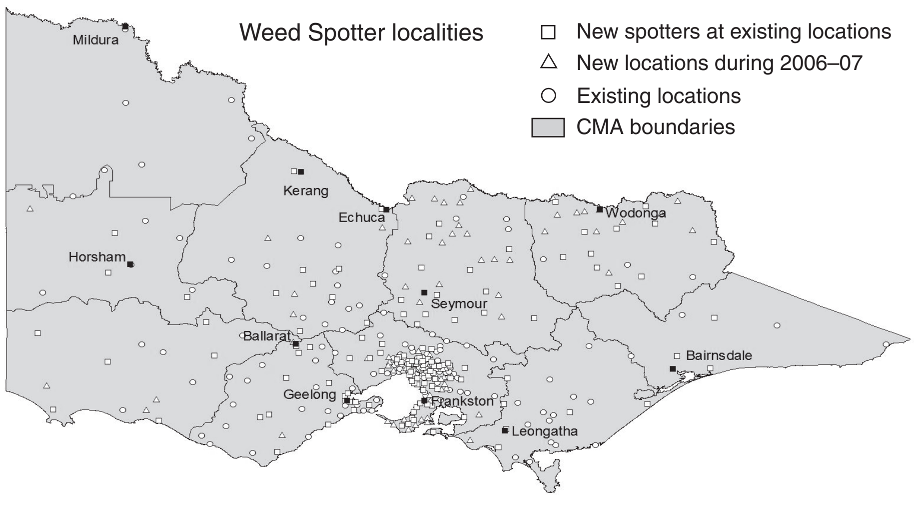

Figure 2. Distribution of registered Weed Spotters across Victoria.

recruited later in the year in East and West Gippsland and therefore Weed Spotter numbers are lower in these regions.

Recruitment methods
Information has been gathered on the methods used to recruit Weed Spotters during 2006/07. The most frequently used methods were introductory Weed Spotter training sessions, Weed Alert presentations, Weed Alert displays and secondary Weed Spotter training sessions.

Introductory Weed Spotter training sessions are planned, organised and promoted by WACOs for potential and newly registered Weed Spotters within each catchment. This is an effective method of recruiting new Weed Spotters with the largest number of Weed Spotters recruited through this approach (Figure 3). Weed Spotters who attend introductory training sessions learn about the purpose of the network, how it operates, what their commitment involves and are given the initial skills to become an active Weed Spotter. Attendees are also given a Weed Spotter handbook and a WEEDeck at introductory training sessions.

The second most effective method of recruiting Weed Spotters during 2006/07 was Weed Alert presentations. These are often similar to introductory Weed Spotter training in the content presented, however the difference is that a Weed Alert speaker is invited to present to a pre-existing group that is usually meeting for a purpose other than Weed Spotters. For example, Landcare meetings or University/TAFE lectures. The topic of the presentation is related to an aspect regarding weeds and contains some Weed Alert and Weed Spotter material. This method is similar in effectiveness to formal introductory training in terms of numbers recruited; however these recruits may not be as committed to the network, as those that have intentionally given their time to a session specifically designed for Weed Spotters.

Weed Alert displays are usually held at field days, markets or shows and include displaying live weed species and printed material. Weed Spotters who register in this way are not exposed to as much information as those who attend dedicated training or a presentation, and therefore may not be fully aware of their commitment and may not be effective Weed Spotters until they attend training.

Secondary Weed Spotter training sessions are subsequent training modules that occur after the introductory session to improve the skills of existing Weed Spotters. The purpose is not necessarily to recruit new Weed Spotters, which is consistent with the trend presented in Figure 3.

The 'other' category is made up of recruitment via personal communications (19), newspaper articles (nine), meetings (nine), the DPI Customer Service Centre (eight), garden club presentations (two) and letters (one). There is also a significant number that are unknown which may have been recruited through a combination of all methods. This data will be collected more accurately in the future through a recently developed Weed Spotter brochure.

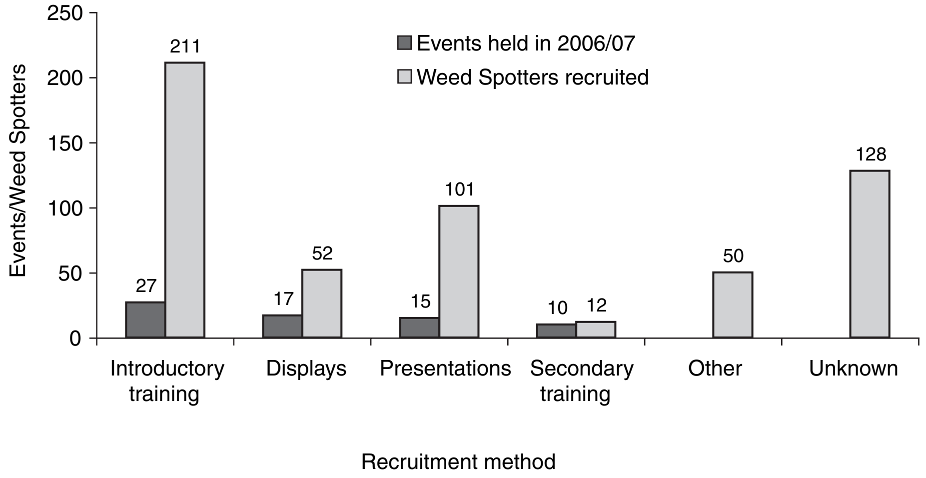

Figure 3. Weed Spotters by method of recruitment for 2006/07.

Weed Spotter training
Weed Spotters have been trained to various levels as illustrated in Figure 4. Those who have attended both an introductory and secondary training session are more highly trained in how to identify and report weeds than those who have only attended a Weed Alert presentation or registered their details without receiving any training. It is important to encourage all Weed Spotters to attend training so that they can be as effective as possible.

Weed Spotter skills
The Weed Spotter engagement plan (McInerney and Robinson, 2007) suggests that recruitment efforts can be focused on targeted groups to strategically expand Weed Spotters based on requirements from the network. For example, if there is a need for more Weed Spotters with skills to locate aquatic Weed Alert species then it is worth recruiting from water authorities, Catchment Management Authorities (CMAs) and the WaterWatch program. Table 1 shows the breakdown of Weed Spotters by affiliation category which is an indication of their weeds interest and skills.

Weed Spotter surveillance and reporting activities
Weed Spotter reports from across the State and all other Weed Alert species reports received by WACOs and other Weed Alert team members during 2006/07 have been compiled. Figure 5 shows the number of reports received and indicates the breakdown according to class.

Information collected suggests that more reports were made by registered Weed Spotters (39) than other individuals (26), and only two of these have since registered as Weed Spotters. Discussions with WACOs indicate that this is partly due to some individuals preferring to keep their contact details confidential and to not formally register with the network. Others have a good relationship with the WACO and do not feel that registration is necessary. This issue has been addressed with the development of a Weed Spotter brochure that includes a registration form. It is important that individuals who are already reporting Weed Alert species register as a Weed Spotter, so that they receive network information to become as effective as possible.

State Prohibited Weeds (39) have been reported more often than Victorian Alert Weeds (14) and other species (14). This may be due to more readily available information on State Prohibited Weeds in comparison to Victorian Alert Weeds. For example, many of the fact sheets and the WEEDeck which are made available to Weed Spotters mainly cover State Prohibited Weeds. It is expected that as Weed Spotters receive more training, improve their identification skills and more materials on Victorian Alert Weeds are produced, the pattern shown in Figure 5 may change.

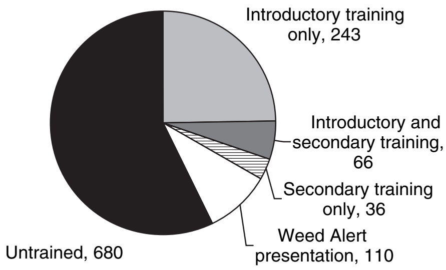

Figure 4. Number of trained Weed Spotters.

Table 1. The breakdown of Weed Spotters by affiliation category.

Affiliation	Number of Weed Spotters 30 June 07
Department of Primary Industries	151
Farming (including Landcare)	93
Education	87
Conservation Group	69
Local Government	68
Department of Sustainability and Environment	53
Waterwatch	43
Horticulture	35
Botanic Gardens	24
Consultant/Contractor	24
Catchment Management Authority	21
Parks Victoria	19
Water Authority	17
Other	16
Unknown	454
Total	1174

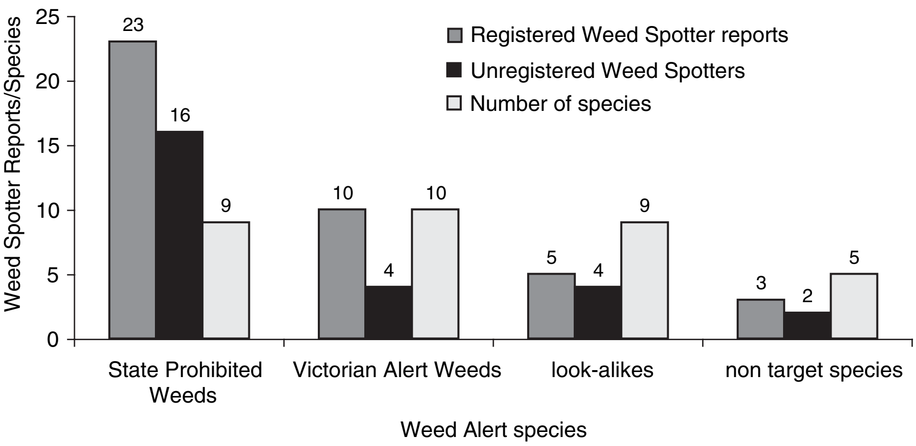

Figure 5. Weed Alert species reports made by registered versus unregistered Weed Spotters including the number of different species reported.

The number of look-alikes (Figure 5) reported is interesting and indicates a need to ensure information on similar looking plants is available for both State Prohibited and Victorian Alert Weeds.

Conclusion

The consistent collection and storage of all Weed Spotter network data is essential for accurately determining whether Weed Spotters are being recruited strategically and whether registered Weed Spotters are reliably monitoring and reporting Weed Alert species. The results from the first year of network data collection are promising, indicating that recruitment is well underway and that accurate Weed Alert reports are being submitted through the WACOs. The information will be useful as a benchmark for tracking the Weed Spotter network into the future.

It is recommended that the Weed Alert program should:

- Implement the Weed Spotter Engagement Plan (McInerney and Robinson 2007),
- Encourage all new Weed Spotters to complete the questionnaire in the Weed Spotter brochure,
- Encourage all Weed Spotters to formally register,
- Make information available to Weed Spotters on Victorian Alert Weeds,
- Make information available to Weed Spotters on Weed Alert species look-alikes, and
- Collect evaluation information at all Weed Spotter training events via the evaluation survey and incorporate results into program development and improvement.

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Water hyacinth illegal trade in Victoria: the trace back and forward of a State Prohibited Weed

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Summary A Victorian Weed Spotter reported the sale of several water hyacinth plants (*Eichhornia crassipes*) on the internet auction house eBay. Compliance staff from the Department of Primary Industries' Weed Alert team alerted eBay of the plants, as the seller was located in Victoria.

Officers visited the seller's residence prior to the end of the auction and seized all the water hyacinth plants. Through questioning, the officers traced the plants back to a previous online auction, where the seller was once again registered in Victoria. Officers then visited the initial seller and seized additional water hyacinth plants and discovered that plants had been sold to 11 other people from around Australia; one from Queensland, two from New South Wales, two from South Australia, one from Tasmania and five from Victoria.

Officers followed-up by visiting the residence of each purchaser in Victoria. Agencies in other states were alerted and provided with purchaser information. Two court matters relating to the offences detected under the *Catchment and Land Protection Act 1994* where heard against the two sellers, both resulting in fines.

Keywords: *Catchment and Land Protection Act 1994*, water hyacinth, *Eichhornia crassipes*, eBay, Weed Alert, State prohibited weeds.

Introduction

Within the state of Victoria the regulation of noxious weeds is administered by the Department of Primary Industries' (DPI) Landscape Protection branch. The *Catchment and Land Protection Act 1994* (CaLP Act 1994) provides guidance on prohibited activities regarding noxious weeds. Prohibited activities include the planting or propagation, display, movement, spread and sale of noxious weeds or any part that is capable of growing which includes the seeds.

Within the Landscape Protection branch of DPI, the Weed Alert program focuses on preventing the introduction of serious new weeds into Victoria and eradicating the highest risk incursions. The Weed Alert program has established a voluntary surveillance network in the community known as the Weed Spotters network. Weeds Spotters provide information and intelligence to DPI regarding unusual plants in the community, particularly State Prohibited Weeds and Victorian Alert Weeds.

Background

Under the CaLP Act 1994 a 'noxious weed' is defined as any of the following; a State prohibited weed, a regionally prohibited weed, a regionally controlled weed or a restricted weed. The definition of a noxious weed is important because under the CaLP Act 1994 it states in section 71 that 'A person must not without a permit from the Secretary sell or offer to sell in Victoria a noxious weed'. An offence against this section of the Act carries a maximum penalty of $12,000 per offence (State of Victoria 2006).

Of the four categories of noxious weeds in Victoria, the highest classification is State prohibited, which is classified for the entire state of Victoria. A species can only be considered for classification as a State prohibited weed if it is either not present in Victoria, or present in such low numbers that it can be eradicated from the state (State of Victoria 2006). At present Victoria only has 25 State Prohibited Weeds, one of which is water hyacinth *Eichhornia crassipes* (Martius) Solms-Laub.

Water hyacinth was one of the very few species that was declared a noxious weed in every state prior to the inception of Weeds of National Significance (Sainty and Jacobs 2003), and is recognised as one of the worlds worst water weeds (Hussey *et al.* 2007). Water hyacinth is a major weed world wide, having originated from South America, and is primarily spread as an ornamental plant because of its showy lilac flowers (Parsons and Cuthbertson 2001). This species has been known to multiply from a few plants to covering a 30 meter dam in one season (Sainty and Jacobs 2003).

Water hyacinth was first introduced into Australia in the 1890s, with introductions into Victoria were prior to the 1900s, however no long term naturalised infestations have persisted in Victoria (Parsons and Cuthbertson 2001). Over the last 20 years, most Victorian water hyacinth infestations have either been found in residential garden ponds or at nurseries and pet stores. There have only been a small number of naturalised infestations discovered, including one infestation detected in 1987 at Lochend and another at Brodribb in 1992, both of which are located close to Orbost in Gippsland. Another two sites were identified in dams in the Port Phillip region in 1994 and 2000. In more recent times, water hyacinth has been found in the Botanical Gardens in Williamstown (2002), Darebin Creek (2003), an urban pond system in Blackburn (2005) and Euroa (late 2006). All infestations are continually monitored by Weed Alert staff. Most locations have shown no signs of water hyacinth following initial or secondary treatment (DPI 2007). Historically water hyacinth has been associated with the plant trade, either at nurseries or the aquatic fish trade, although in recent years the nursery industry has shown leadership in removing these and other State prohibited weeds from sale.

Discussion

During January 2007, whilst searching for items on the internet auction house eBay, a Weed Spotter noticed a Victoria resident auctioning water hyacinths. The Weed Spotter was aware that water hyacinth was a State prohibited weed and referred the matter to a Weed Alert Officer based at Frankston.

After preliminary investigations the Departmental Officers contacted eBay to alert them of a possible offence and to gather intelligence. The following day, officers visited the sellers Edithvale property to ascertain whether the plants were in fact water hyacinth and begin the process of tracing the origin of the plants. It was evident upon inspection that the plants were water hyacinths. The seller was a private individual seller and not a commercial enterprise, who had bought the plants on eBay the previous year. DPI's inspection occurred prior to the conclusion of the auction, and any plants being sold.

The Edithvale seller had purchased one water hyacinth plant, less than a year prior to detection and possessed 41 mature water hyacinths on the day of inspection, not including plantlets attached to parent plants. All of these plants were seized by Departmental Officers.

Further investigations into the origin of the water hyacinth plants revealed that the original seller was from Seaford, Victoria. Officers contacted the Seaford seller and on inspection of the residence seized a further 60 plants. The Seaford seller had previously sold 39 plants to 12 people around Australia during four Dutch auctions. Buyers included one from Queensland, two from New South Wales, two from South Australia, one from Tasmania and six from Victoria (including the Edithvale seller). The Seaford seller was also a private seller and not a commercial business.

The description of the plants on the Seaford seller's auction page stated that the plants could not be traded to Western Australia or Northern Territory and that 'It is not recommended for dams and waterways, as it can get out of control, but for your pond or water feature it looks fantastic, and can be easily divided'.

Following this inspection, each of the Victorian purchasers were inspected by Departmental Officers. Of the remaining five purchasers, two no longer had plants, due to the plants being disposed of or dying. A Mornington purchaser who bought three plants still had two remaining, a Hastings purchaser had 27 plants from two original plants purchased and a Geelong purchaser had 67 plants after buying 12 plants less than 12 months prior.

Agencies in other states were alerted to the detection of water hyacinth being imported into their states and were provided with purchaser information. Investigators in Queensland also found water lettuce (*Pistia stratiotes* L.) and salvinia (*Salvinia molesta* D.S.Mitchell) which are declared plants in that state, at the same residence of the water hyacinth purchaser.

Following these investigations, the two Victorian sellers were both charged under the CaLP Act 1994 for 'without a permit from the Secretary sell or offer to sell in Victoria a noxious weed' (State of Victoria 2006). The Edithvale seller pleaded guilty in Melbourne County Court and was fined with costs, whilst the Seaford seller pleaded guilty in the Frankston Magistrates Court and also received a fine with costs.

Comments

Following this case and other similar investigations in other states, eBay has since stated publicly that it has changed its policy on the sale of noxious weeds and that if a plant species is declared in any of the Australian states or territories, it will not be permitted to be listed.

Despite the best efforts of Weed Alert staff attempting to eradicate State prohibited weeds such as water hyacinth from Victoria, infestations are still being found. In the six months following the commencement of this investigation, three separate water hyacinth infestations have been discovered. Given the ornamental appeal of this species, its distribution through urban garden ponds may be much greater than original estimates.

Conclusion

This investigation into the trade of water hyacinth in Victoria may have alleviated significant potential for this plant to establish within waterways throughout Victoria and other states where plants were exported. There may still however, be many more plants floating in garden ponds in backyards around the state, waiting for someone to throw a plant over their fence into the adjoining drain, creek, dam or river that could potentially devastate Victoria's water resources. Further education, awareness and compliance programs are being delivered by the Department of Primary Industries to build awareness of the threat that these and other State prohibited weeds pose to the environment and agricultural industries. The Weed Spotter network will also provide an important early detection function enabling the Department to activate an early treatment to achieve eradication.

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Seed bank spatial dynamics and plant invasions in Victoria's western basalt plains grasslands

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Abstract
The soil seed banks of six linear native grasslands were studied to investigate the effects of landscape context on the spatial patterning of grassland seed banks. Study sites were located along a 200 km urban – rural gradient running west from Melbourne, Victoria. Exotic annual graminoids dominated the composition of the soil seed bank with native species contributing only 13% of the seeds present. In contrast to the patterns identified in the vegetation, analysis of the soil seed bank did not detect a discrete edge effect related to exotic species invasion. Instead, exotic species were abundant throughout the soil seed bank. Similarity between the seed bank and the above ground vegetation was subsequently low, and declined as sites became increasingly rural. The removal of fire as a disturbance mechanism from grasslands, along with a change in the species composition of the surrounding landscape matrix, is likely to lead to increased weediness and similarity of native grassland communities.

Practice change by Victorian linear reserve managers

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Linear reserves (rail and road reserves) can provide a pathway for weed spread potentially impacting on thousands of landholders in Victoria.

Through Victoria's Tackling Weeds on Private Land initiative's Weed Management Grants, Victoria's rail companies and VicRoads have been actively improving their capacity for long term, effective weed management. This has produced improved partnerships developed between Victorian Rail industry organisations to produce vegetation management guidelines for rail corridors, and various projects on weed mapping, weed hygiene, staff training and weed management trials by VicRoads and Municipal Councils.

This poster will share learnings from the initiative which can assist future practice change programs aiming to reduce the economic and environmental impacts of weeds on linear reserves.

Practice change within the Victorian fodder industry

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The Victorian fodder industry is a key stakeholder in the challenge to minimise the spread of weeds. Through the Victorian Tackling Weeds on Private Land initiative's incentive Weed Management grants Program, The Australian Fodder Industry Association (AFIA) and the Australian Agricultural Contractors Association (AACA) have worked collaboratively with the Department of Primary Industries on several projects to assist with minimising weed spread across the industry. These projects include development of an industry Code of Practice to minimise weed spread and a hay bale tagging device (AFIA), formal training of association members in weed hygiene procedures (AACA) and targeted distribution of weed spread risk information at times of wildfire and drought.

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