Weed Society of Victoria Inc.

PROCEEDINGS

FOURTH VICTORIAN WEED CONFERENCE

Plants Behaving Badly: in agriculture and the environment

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7–8 October 2009

Mercure Hotel, Geelong

Weed Society of Victoria Inc.

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PROGRAM

DAY 1 WEDNESDAY 7 OCTOBER 2009

07.15 – 08.50 **REGISTRATION**

08.50 – 09.00 **WELCOME President, Weed Society of Victoria**

SESSION 1 KEYNOTE SPEAKERS Chair: Michael Hansford

09.00 – 9.40 Where we going with weeds?
John Thorp, National Weeds Management Facilitator 1

9.40 – 10.20 A new look at environmental weeds in Victoria
Geoff Carr, Ecology Australia

10.20 – 10.45 MORNING TEA

SESSION 2 WEED IMPACTS Chair: David McLaren

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Ian Mansergh, Department of Sustainability and Environment, Melbourne 2

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12.45 – 13.45 **LUNCH AND POSTER SESSION**

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14.10 – 14.35	Policy framework for invasive plants and animals **Nigel Ainsworth**, Department of Primary Industries, Melbourne		14.10 – 14.35	Two new cereal crop herbicides **John Ashby**, Bayer CropScience Pty Ltd, Melbourne	36
14.35 – 15.00	The noxious weeds review **Ruth Myers**, Department of Primary Industries, Melbourne **Ryan Melville**, DPI, Geelong		14.35 – 15.00	The importance of managing spray drift **David Loschke**, APVMA, Canberra (presented by Dr Subbu Putcha)	41
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Mercure Hotel Geelong

DAY 2 THURSDAY 8 OCTOBER 2009

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Kerrie Howe, Department of Primary Industries, Wodonga

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Fran Hausmann, Department of Primary Industries, Frankston

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Tony Herwerth, Melton Council

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Where we going with weeds?

John R. Thorp, National Weeds Management Facilitator, 16 Flowers Court, Launceston, Tasmania 7250, Australia.

Summary

Predicting what will happen in the next 10 years is difficult especially when we talk about weeds. The approach taken here is to examine what we have achieved in the past few years and speculate where this might lead.

The Australian Weeds Committee (AWC), which is comprised of senior weeds policy official/s from each state, territory and Australian government, continues to play a vital role to ensure that relevant Ministers are well informed on weeds policy issues. In 2007, AWC successfully sought endorsement from the Natural Resource Management Ministerial Council for the Australian Weed Strategy.

The three goals from the Strategy clearly set out the challenges. Goal one focuses on preventing new weed problems, which is the most cost effective approach. We will never have the resources to tackle all weeds, so in the future there will be increasing emphasis in investing in those that pose the greatest threats. There will also need to be a greater understanding of pathways and involvement of a greater range of stakeholders. A significant pathway continues to be garden plants 'jumping the fence' and we must continue to work with the nursery and garden industries and gardeners to stop this flow.

The Strategy's second goal focuses on reducing the impact of existing priority weeds. An important element is the Weeds of National Significance (WoNS) program in which 20 icon weed species are being targeted. This program is supported by all states, territories and national governments and has resulted in greater cooperation across jurisdictions and changed the way we manage weeds across the country.

The AWC recognises that there are other weeds that would benefit from the WoNS program. It also recognises that resources are finite and if other weeds were to benefit it would have to be done within existing resources.

The AWC has agreed to a tiered approach that will allow WoNS species that have implemented their national strategy to move to a second phase with reduced co-ordination effort. A third phase recognises that the WoNS species will require on-going action for many years and that this will be achieved by AWC oversight and reporting at a jurisdictional level. The resources freed up through this review process will allow other weeds to benefit from national co-ordination.

All WoNS species are currently being reviewed by the AWC with a view to allocating them to phases by December 2009.

It is also clear that the global economic crisis will reduce the incomes of governments at all levels and that will make it very difficult to find increased funding for future weed management activities. There is also a significant focus by governments on positive returns on its investment and therefore an increased focus on monitoring, evaluation and reporting.

Goal three is to enhance Australia's capacity and commitment to solve weed problems. Over the next decade weeds will continue to have a significant impact on agriculture and the environment. With finite resources, we must ensure that more Australians are aware of the issues and committed to doing something about it.

Weeds must be an integrated part of any natural resource management activity and it is essential that partnerships between governments, the community, industry and key stakeholders are built and maintained to deliver on-going weed management.

We will continue to make significant progress through your committed efforts, but we will do more if we can convince others to become involved.

Weeds and landscapes under climate and land-use change – between wombats and wedgies

Ian Mansergh, Climate Change Adaptation, Department of Sustainability and Environment, PO Box 500, East Melbourne, Victoria 3002, Australia.

Abstract

Under global climate change, south-eastern Australia faces a warmer, drier, extreme-weather- event-punctuated (e.g. fire and flood) future, whilst inhabitants face a socio-ecological–economic future that is both water and carbon-constrained. The basic bio-physical environment (altering net primary productivity) and its processes (e.g. soil fluxes) are changing, and will continue to change, as will abundances and distributions of biota, including weeds. In the context of multiple uncertainties, including vulnerability management and resilience, adaptation to climate change is an increasing focus of society. That focus includes land use and management.

Weeds are plants perceived to be deleterious to either economic or aesthetic wellbeing of humans, or to other environmental components that humans value (Cheal and Coman 2003). Nevertheless, these requirements for ecosystem services change over time as society, or part thereof, imbue landscapes with different meanings and desire different 'products'. To perceive a weed is to ascribe meaning to the landscape where it occurs. In Australia, native vegetation has been transformed from something to be cleared to something of intrinsic value, and landscapes from bare palettes for new agronomy species to landscapes needing strict continental quarantine. We now conceive of environmental weeds. Amidst these trends, the effects of global warming provide novel, all pervasive, pressures of environmental change at the continental scale.

Socio-economic and environmental factors over vast areas of traditional agricultural eastern Australia suggest that post-agricultural landscapes can now be envisaged. Making these landscapes resilient to climate change for long-term sustainability and inter-generational landscape equity are critical adaptation challenges for environment and land agencies. Assets and ecosystem services that we value and obtain from landscapes will change the trajectory of this process (e.g. carbon-sequestration). Adaptation and mitigation (of CO_2 and other greenhouse gas emissions) actions may be complementary in some landscapes where society seeks increased resilience to climate change impacts.

Adaptation to climate change may hasten perceptions away from 'single-purpose' landscapes (production–conservation) to 'multi-purpose' landscapes where our perceptions of weeds may change. This contribution examines the interaction of these major fluxes in relation to our perceptions of land use and weeds. Responses to climate change and our capacity to measure landscape attributes will accelerate Australian society's on-going re-evaluation of landscapes and ecosystem goods and services they provide and may prompt some re-evaluation of 'weeds' and consequent management strategies.

Introduction

We must get serious about adaptation and we must do so now… Adaptation is both a practical need and a moral imperative.

UN Secretary-General Ban Ki-moon, 27 July 2009
http://en.cop15.dk/news/view+news?newsid=1782

Ecosystem-based approaches to mitigation and adaptation should be included as a third and essential pillar in national strategies to address climate change.

World Bank (2009)

Building resilience to climate impacts:
To successfully adapt to climate change, we need to understand that different systems are connected; natural systems… human systems… the infrastructure. All these systems are vulnerable to climate impacts and all are connected to each other.

Victorian Climate Change Green Paper (Victorian Government 2009): 66

Weeds are plants perceived to be deleterious to either economic or aesthetic well-being of humans, or to other environmental components that humans value (Cheal and Coman 2003). This implies that 'weeds' provide a disservice to the ecosystem services that society (or parts thereof) expects from a landscape. Humans imbue landscapes (and components) with meaning that connects the past with a projected future (Schama 1998, Mansergh *et al.* 2008). Populating *terra nullius* in the post-penal colony, through transformation of a seemingly endless supply of land to 'Europeanised' agricultural landscapes (pastoral, cropping), was foremost in the projected landscape meaning of policy makers and early white Australian settlers. This paradigm continued for over 150 years (Cook and Dias 2008). Exotic species were transported to Australia for utilitarian or aesthetic purposes, often becoming weeds and pests as they spread and affected other land uses (blackberries (*Rubus* spp.) for food, willows (*Salix* spp.) for fibre and stream protection, red foxes and rabbits for hunting) (Cheal and Coman 2003, Kloot 1983, Groves *et al.* 2005).

New landscape paradigms are evolving from the past colonial land use and management in Australia. Indicative of these trends, native vegetation has been transformed from something to be cleared to something of intrinsic value. Since the 1980s, we can now conceive of 'environmental weeds' rather than purely 'agricultural' weeds (Carr *et al.* 1992). From acclimatisation of the 19th century, the 20th century saw government-supported/sponsored systematic introduction of over 8200 plant species of potential agronomic, then later soil conservation value with scant regard to their 'weediness' – indeed many may have been selected for their fecundity and rate of spread (Cook and Dias 2008, Lonsdale 1994). There is now strict continental quarantine. Amidst these trends, the effects of global warming provide novel, all pervasive, pressures for environmental change at the continental scale. Broad land use and management are major determinants of people's perception of 'wrong place'.

Under global climate change, south-eastern Australia faces a warmer, drier, extreme-weather-event-punctuated (e.g. fire and flood) future whilst inhabitants face a socio-ecological-economic future that is both water and carbon constrained. The basic bio-physical environment (elevated atmospheric CO_2, net primary productivity change) and its processes (e.g. hydrological cycle, soil fluxes, fire) are changing and will continue to change, as will abundances and distributions of the biota – the subset of the biota called weeds being no exception (Nemani *et al.* 2003, Cheal *et al.* 2003, Steel *et al.* 2008). In examining responses to global climate change, the World Bank (2009) considered that ecosystem-based approaches to mitigation and adaptation should be included as a third and essential pillar in national strategies to address climate change. Major land-use changes have been proposed for eastern Australia, premised upon comprehensive emissions accounting (Garnaut 2008).

Socio-economic and environmental factors over vast areas of eastern Australia suggest that post-agricultural landscapes can now be envisaged that must be harmonised with adaptation to climate change for long-term sustainability and intergenerational landscape equity. The vulnerability and resilience of landscapes, indeed the socio-ecology of humans within landscapes, have been important concepts in debates around adaptation to climate change (e.g. Walker *et al.* 2009). Assets and ecosystem services[1] that we value and obtain from landscapes will change the trajectories of these processes (e.g. C-sequestration in biota, including soils) as may plant species that we classify as 'weeds'. The dichotomy between adaptation and mitigation (of CO_2 and other greenhouse gas emissions) may blur as society seeks to enhance the adaptive capacity (resilience) of the landscape, where the interconnected nature of ecosystem services becomes more apparent (e.g. in Victorian catchments, Jones *et al.* 2007, Walker *et al.* 2009). Adaptation measures that enhance C-sinks would be advantaged. Indeed, the way ahead may be away from 'single purpose' landscapes (production or conservation) to 'multi-purpose' landscapes where plants in the 'wrong place' may change. This is not to suggest the desirability or inevitability of climate change hastening the *homogeo-cene.* Rather, there will be increased value from the insights provided by science associated with weed management. This paper examines the interaction of these major fluxes (land use, sense of place and climate change) in relation to our perceptions of land use and weeds.

> Whilst travelling in NE Victoria, a European visitor commented on the beauty of the landscape enhanced by the prolific purple flowered *Echium plantagineum*, a Mediterranean-derived exotic. The species has various names including Paterson's curse (graziers) or salvation Jane (beekeepers), with the nomenclature dependent on the observer. The 'weediness' of the species depends in part on perceived 'services' required from the landscape, including 'sense of place'[2]. In the same part of the world, the 'pest' status of the dingo is related to the economic value of pastoralism (particularly sheep). (See the discussion in Cheal and Coman 2003.)

Climate science and climate change

The phenomenon of global climate change, due to anthropogenic release of greenhouse gases (e.g. CO_2, methane), and potential impacts have been well documented by the International Panel on Climate Change (2007). The science and scenarios are being constantly refined, including shortening the timeframe of arrival of dangerous climate change and emission tracking along the worst-case scenario (Steffen 2009, Smith *et al.* 2009). Although there remains uncertainty around the exact scenarios, there is consensus around the inevitability of global warming (IPCC 2007) and the urgent need for mitigation and, more recently, adaptation. From global models, regional changes for south-east Australia have been derived and are periodically updated (Victorian Government 2008a, www.climatechange.vic.gov.au). The trajectories of various climatic parameters indicate that this region will become warmer and drier over the course of the 21st century (Figure 1, Table 1). These changes will happen at an unprecedented rate of change and the drier warm future contrasts to the paleo-record where past drier conditions were associated with cold, and wetter conditions with warmer climates (Woodward and Rochefort 1991). The broad ambient temperature and rainfall (Table 1) and consequent changes, will elicit major environmental change. The lower or slower the global mitigation of greenhouse gases, the more imperative adaptation becomes.

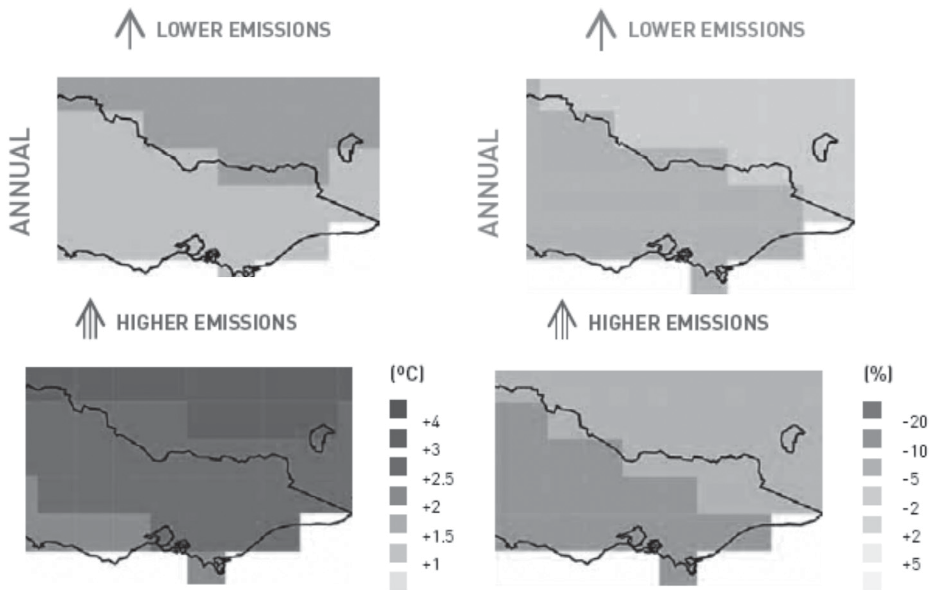


Figure 1. Temperature and rainfall changes under future climates (source: Victorian Government 2008a).

Table 1. Modelled temperature and rainfall changes under future climates in Victoria (Victorian Government 2008a).

Temperature	Rainfall
2030: +0.8°C (0.6 to 1.2°)	2030: −4% (−9 to +1%)
2070: +2.7°C (1.8 to 3.8°C) higher emissions:	2070: −11% (−25 to +3%) higher emissions:
• warming likely to be greatest in spring and summer	• greatest decreases in winter and spring
• greater increases in areas north of the Divide	• growing intensity of droughts since 1970s (warmer ambient temperatures)
• maximum temperatures likely to increase faster than minimum temperatures	• projections based on 1961 to 1990 mean
• increasing number of days over +35°C	• evaporation also expected to increase (~8% by 2070)
• decreasing likelihood of frost (in the medium to longer term)	• increasing rainfall intensity but decrease in the number of rainy days

Footnotes [1] Here we used ecosystem services sensu Millennium Ecosystem Assessment: Ecosystems and human well-being: Synthesis. Available at http://www.millenniumassessment.org/en/index.aspx.

[2] Note: Author believes it to be a very noxious weed in both agricultural and native vegetation causing erosion, replacement of nitrogen fixing plants, etc. However, a court case involving beekeepers was required prior to the release of a biological control by CSIRO in the late 1980s. http://www.ento.csiro.au/biocontrol/patcurse.html.

Climate change and the effects on terrestrial ecosystems and biota

By the end of the 21st century, climate change is expected to elicit alteration of Net Primary Productivity (NPP) and mass extinction of species (Thomas *et al.* 2002) with changes in the distribution, abundance and genetics of flora and fauna species under recent past climate warming already observed (e.g. Nemani *et al.* 2003, Root *et al.* 2003, Umina *et al.* 2005, Hughes 2003). Biota is already responding to climate change and experiments indicate significant phenological changes under induced *in situ* 2°C warming (e.g. www.australianitex.org). Further, plant species within communities may respond differently. Elevated CO_2 has been observed to favour grasses (C4) relative to forbs (C3) and in a CO_2 enriched atmosphere the floristic composition of groundcover and grasslands may change through differential competitive advantage. Changes in vegetation (including weeds), fire and soil nutrients have been observed to have cascading affects up the food chain to grazers and predators (Fisher *et al.* 2006, Radho-Toly 2001). Modelled potential trajectories of changes to the distribution of native biota and weeds under different climate warming scenarios show variability between species in SE Australia, e.g. bladder dock, *Acetosa vesicaria*, migrate south into Victoria where future climate becomes less suitable for ragwort, *Senecio jacobaea* (Steel *et al.* 2008). Range contractions and expansions have been indicated with general southward migration and risk of elimination of current high altitude bio-climates (Bennett *et al.* 1992, Brereton *et al.* 1995 – vertebrates, Newell *et al.* 2001 – vascular flora, Steel *et al.* 2008 – weeds, this conference). The distribution and abundance of species of Victoria's Central Highlands forests are expected to markedly change at their next regeneration event (fire or logging) around mid-century (Nitschke and Hickey 2008). Basic environmental drivers will change across Australia.

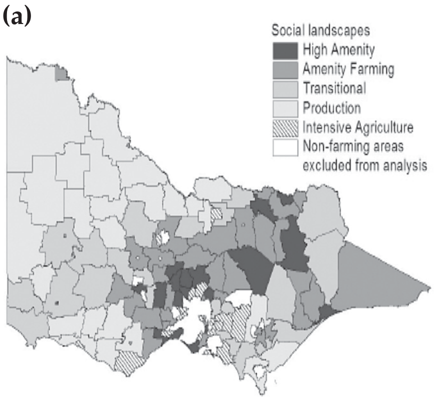
Modelling climatic scenarios for SE Australia indicate that high-risk fire days will increase, wildfire and fire regimes will change (ecological regeneration events), the area of snow fields will shrink and reduced run-off will affect the majority of Victorian rivers (Hennessy *et al.* 2003, Hennessy *et al.*2005, Jones and Durrack 2005). Thus increasing knowledge of the potential biotic and abiotic impacts and responses are now emerging. The biotic responses will include adaptation by basic evolutionary mechanisms devolving from reproduction, plasticity of genomes and re-colonisation. In the terrestrial environment, speed of change, land use, habitat fragmentation and discontinuities will be a large determinant of the capacity for the biota to adjust (Mansergh and Cheal 2007).

History of land use and driving paradigm has changed

Settlement of colonial Australia was based on populating *terra nullius* through pastoralism, agriculture and mining to supply goods to empire and capital to the continent (e.g. Wadham *et al.* 1957, Mansergh *et al.* 2006a, Cook and Dias 2007). However, the Mabo High Court case in 1992 and massive changes in socio-economics over the last 30 years have changed Australians' basic perceptions and their views of landscape. Despite the relative economic decline in the agricultural sector, agriculture in Australia (as in most developed OECD countries) still maintains a vastly disproportionate share of the land-use allocation – Hamblin (2009) calls this the current land-use paradox.[3] The flat, old, dry, nutrient deficient continent uses 3% of the world's farmland to produce food for 0.02% of the world's population and 80% of the produce and profit comes from 2% of the land area allocated to agriculture (Lindsay 1985, NLWA 2001, Hamblin 2009). In the case of rural Australia, the paradigm that produced the historical allocation of land predominantly for pastoralism and agriculture (and resultant land clearing and soil loss) now appears to have produced a dramatic 'overshoot' having profound environmental consequences (VCMC 2007, Hamblin 2009, McAlpine *et al.* 2007). Natural capital was transformed to economic capital with widespread environmental degradation in Victoria and elsewhere in temperate Australia where many terrestrial and freshwater environments are now degraded, especially in

[3] Indeed, Hamblin's persuasive analysis leads her to conclude Australia has a first-world lifestyle based on a third-world economy reliant on export of minerals and agricultural product.

(a)



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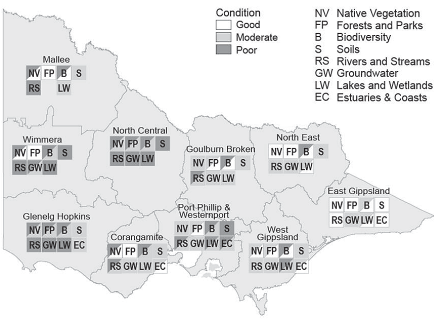

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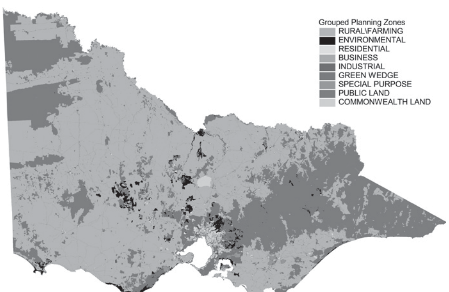

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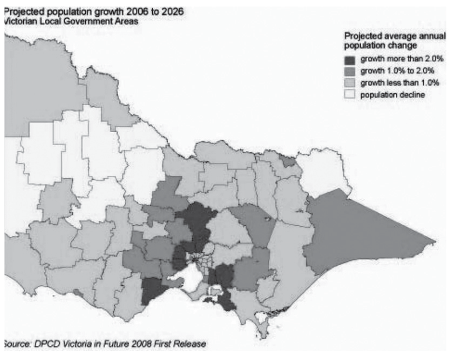

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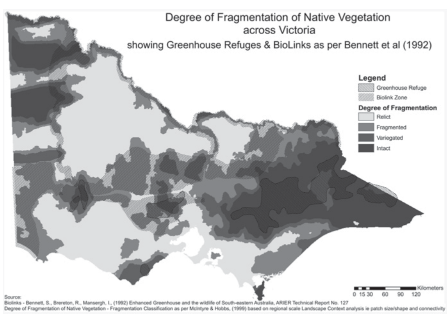

Figure 2. Victoria (a) social landscapes of Victoria (Barr 2008), (b) catchment condition (VCMC 2007), (c) planning zones in Victoria (mid grey agriculture/rural), (d) demography changes 2020 (source: DPCD 2008), and (e) biolinks and fragmented vegetation (Mansergh *et al.* 2008).

catchments currently or previously dominated by agriculture (SoE 1996, VCMC 2007, Mansergh *et al*. 2006, Cook and Dias 2007, Figure 2). Weeds and invasive species generally rank in the top two or three threatening processes of environmental degradation.

The underlying paradigm/perceptions that drove Australian environments to be 'Europeanised' derived from complementary views – the aesthetic (sense of making place) and the utilitarian (useful food and fibre products) (Wadham *et al*. 1957, Smith 2000, Mansergh *et al*. 2006). This promoted the introduction of exotic species with over 27 000 plant species introduced to the continent (Lonsdale 1994, McLaren 2008). Acclimatisation peaked in popularity late in the 19th century but continued on at an official level through the Commonwealth Plant Introduction service which brought in 8200 plant species (30% of total) – driven by the primary paradigm of Australian colonisation (Cook and Dias 2007). 'Arable' land was cleared of trees over massive areas, releasing CO_2 into the atmosphere with slower release of soil carbon over the subsequent decades with the loss of deep rooted perennials changing hydrology and causing salinisation and rainfall decline in some regions[4] (Attiwill and Leeper 1987, Pitman and Narisma 2004, McAlpine *et al*. 2007, VCMC 2008).

> Seeing a willow, scotch thistle or blackberry could well have given early Australian settlers warm memories of 'home' or tangible evidence of 'the progress of civilising the land'. The same species, as weeds, would elicit different feelings in modern Australians where home is here and nurturing the natural environment has social meaning.

This colonial view of landscape and new insights of science extended to changing the soils to become more productive for exotics (and 'weeds'). Native pastures were originally valued for establishing the wool staple until supplanted by the 'sub and super'[5] technique of the 1940s and the initial research into native pasturage was abandoned for generations as attention focussed on exotics (Smith 2000, Cook and Dias 2007, Table 2). The addition of phosphate (and other trace elements) and introduction of medics and clovers massively improved productivity and changed soil nutrient availability, cycling and pH levels. These processes also depleted the spatial extent of the natural vegetation and provided new areas for purposely-introduced exotics, including weeds (Wadham *et al*. 1957, Smith 2000, Cook and Dias 2007). Indeed, weeds themselves may change the nutrient levels in native vegetation to the detriment of native species (e.g. Ehrenfeld 2003, Fisher *et al*. 2006). Where affected, soils became relatively more favourable to exotic plants not adapted to a phosphorus-limited environment, and where used (or over used) they changed the biochemical soil environment with increasing

[4] Over clearing in Australia has been implicated in the rainfall decline in southern Western Australia with implications for Perth water supply (Pitman and Narisma 2004) and over the Murray–Darling Basin (McAlpine 2007). Conversely, evapotranspiration of the deep-rooted trees drawing water from deep in the water table is believed to promote a rain bearing local atmosphere relative to cleared areas (Pitman and Narisma 2004, Taylor 2009).

[5] The discovery that Australian soils could be made agriculturally more productive by the addition of phosphorus and of nitrogen-fixing plants (e.g. subterranean clover *Trifolium subterraneum* – the so-called sub and super technique).

Table 2. Perception of 'weeds' in eastern Australian landscapes over time. (Periods overlap temporally and spatially, generally southern states were earlier than northern states.)

Period	Perception of weeds	Attitude to exotics	Key drivers/social ideas
Penal – pioneer	• native vegetation (except native grasses as fodder, useful timbers)	Provide sense of 'home'?	• survival, avoid starvation, clearing, experiments with landscapes, food sources
Expansion of agriculture and settlement	• native vegetation • establishment of exotics	• inherently better • Europeanise the landscape • acclimatisation (random introductions)	• establishment of staples, wool, wheat – export capital • settlement through agriculture • acclimatise useful and aesthetic • recognition of periodic drought
Consolidation Intensification	• exotics important for increasing production • emerging recognition of costs agricultural weeds	• remain inherently better, but filter established. Official agronomy exotics seen as valuable systematic introductions	• agricultural intensification • soil conservation as national issue • systematic targeting of species • biological control, rise in weedicides
Recognition of new land uses	• environmental weeds as disservices in natural environment	• become inherent risky • higher quarantine bar for both production and environment	• end of wool boom • increased capitalisation – agribusiness • amenity landscapes • rise in area of national parks (Victoria 1–17%) • native vegetation retention (progressively SA, Vic, NSW, Qld) • recognition of environmental degradation • Victorian land management programs *LandCare*, *Land for Wildlife* evolve nationally
Under climate change	• effect on 'new' ecosystem services, land management and desired landscapes	• stricter quarantine • 'sense of place' • some may have new uses	• mitigate and adapt to climate change • agriculture where best suited • more holistic view of ecosystem services, including C-emissions and sequestration • new ecosystem services restore resilient landscapes for climate change

acidification attributed to the use and over use of P fertilisers (Dorrough *et al.* 2006, Livesley *et al.* 2008, Dalal *et al.* 2008, VCMC 2002). The dramatic increase in the use of nitrogenous fertilisers in Victoria since 1990 is a recent version of soil additives for increased agricultural production.[6]

Over 90% of Victorian private land has remained zoned rural–agriculture despite its relative decline in relative economic significance, since 1990 being 2–4 per cent of the Gross State Product (ABS 2008, Figure 2). Reflecting the latter, socio-economic trajectories have been changing since the height of the 'wool boom' (1950–70s) and now over 50% of private property has a trajectory towards amenity or transitional (post-traditional agricultural) landscapes with ownership and management changing (Barr and Karunarante 2002, Barr 2008, Figure 2).[7]

Over the same period, society sought new ecosystem services (previously presumed, or ignored) or improvement of those that had been degraded from landscapes. These services included biodiversity conservation, amenity, water quality and better soil conservation (Table 2). Indicators of this trend are:

- Victoria's area of national parks and reserves rose from 1% (1970) to about 17% (2009);
- clearing native vegetation controls were established in the late 1980s;
- Victorian land management innovations, such as *LandCare* and *Land for Wildlife* were established; and
- recognition of environmental weeds as producing major ecosystem disservices (Carr *et al.* 1992).

More recently, as a result of climate change, C-sequestration is evolving as a new societal ecosystem service as is the importance of water conservation and production (catchment protection). Land use, including soils and vegetation, has an important yet under-recognised part in both mitigation and adaptation under climate change (Garnaut 2009, Victorian Government 2009).

Soils as key ecosystem function

Soils vary in response to climate and biogeography but may store ≥ 50% of landscape carbon and are a vital part of the terrestrial–atmosphere gaseous exchange (Graetz *et al.* 1987, Lal 2004). The composition and configuration of the vegetation are inter-related to the services provided by the soils. Soils are complex interconnected bio-chemical self-organising ecosystems that vary across the landscape due to edaphic factors (geology, climate, topography, vegetation). Weeds in native vegetation may affect soils (Ehrenfeld 2003, Fisher *et al.* 2006). Soils provide fundamental natural ecosystem services: C-transformation, nutrient cycling, soil structure maintenance, biological population regulation and, of course, the substrate for terrestrial 'weeds' (Kibblewhite *et al.* 2009, Lehmann and Joseph 2009, Ehrenfeld 2003 (for weeds), Figure 3). Soil-based feedback mechanisms can accelerate or stabilise exotic invasions and are a predominant feature of such (Ehrenfeld 2003). Introduced exotics can extensively affect the storage and release of C/N of soil nutrient dynamics, which Ehrenfeld (2003) suggests may be more important than other, more frequently monitored impacts (e.g. plant diversity).

Fixed carbon is the major currency of the soil system and the C-transformation is implicated in climate regulation (IPCC 2007, Kibblewhite *et al.* 2009). The biological component of soils can be expected to adapt given responsiveness to changes in temperature, moisture and substrate. The quantum of services produced (including different GHG emissions), and opportunities for vegetation, including many weeds, depends on use and management of the soil (Livesley *et al.* 2008, Dalal *et al.* 2008, Turner *et al.* 2008).[8] If C-sequestration in soils is seen as socially desirable, then Kibblewhite *et al.* (2009) observed for European landscapes that some current 'weeds' might have an important role in restoring above ecological function of soils (see also Ehrenfeld 2003). In an extensive review of exotic plants and soil nutrient cycling, Ehrenfeld (2003) noted that the mechanisms by which plants alter nutrient dynamics have been rarely examined. However, he noted one study where the changes in the soil micro and mesobiota following invasion were widespread (Grayson *et al.* in Ehrenfeld 2003).

Agriculture, to provide food and fibre, involves clearance, tillage, fertiliser, pesticides, and modifies the natural energy pathways and quantum of soil services. C-sequestration is depleted following clearance of native vegetation and continues to be depleted over subsequent decades if subsequently cropped (Attiwill and Leeper 1987, Figure 3). These changes also modified the gaseous exchange. Uptake of methane (CH_4 a potent GHG) by soils in

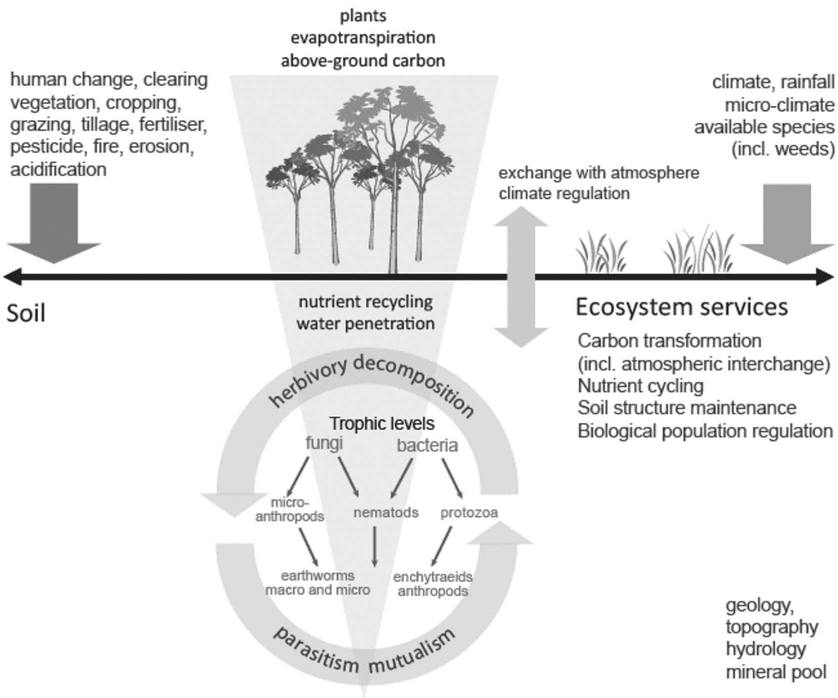

Figure 3. Idealised soil ecosystem services, function and trophic levels. These parameters are affected by land use and management (broadly from Kibblewhite *et al.* see text).

[6] Herbicides (for weeds) and insecticides were other additives to the soils post 1970s (see Herath 1998 in Mansergh *et al.* 2006, Figure 14).

[7] Small and medium size farms were caught in a trade squeeze (cost rise and prices decline), and over 80% of dryland farms in the Goulburn Broken Catchment were sub-economic by the mid 1990s (GBCLPB 1997, Barr 2002).

[8] Turner *et al.* (2008) references that although there are uncertainties around the estimates: agricultural soils are the main human-related source of N_2O globally, and in Australia N_2O contributes ~17.5% of agricultural emissions and ~4.5% of the nation's emissions. See Garnaut (2009) for discussion of methane (major agricultural emission) and ungulates and soil.

native forests is significantly greater compared to introduced pastures suggesting that land-use change has a significant impact on the total greenhouse gas exchange of these different ecosystems (Livesley *et al.* 2008, Dalal *et al.* 2008). Restoration of the GHG sequestration potential of soils may be an important part of a multi-faceted response to climate change (Victorian Government 2009, Garnaut 2008) and the quantification of GHG emissions has led to an increased scientific focus on sources, fluxes and land use.

Quantification (spatial and processes) of ecosystem services

The World Bank (2009) considers that ecosystem-based approaches to mitigation and adaptation should be included as an essential pillar in national strategies to address climate change yet environmental considerations have been difficult to include in the statistics of the national accounts in part because of quantification of changes (ABS 2002). Climate change has initiated increased efforts in the quantification of global carbon sinks and sources; e.g. GHG emission and carbon cycling in forests and agricultural land (Keenan 2002, Miehle *et al.* 2006, Dean *et al.* 2003, Dalal *et al.* 2008). Broadly these scientific studies quantify 'new' ecosystem services provided by landscapes, land use and management in a context of climate change. Climate change has elicited calls for comprehensive emissions accounting including land use (Garnaut 2008) which converges with a broader 'environmental' accounting, perhaps at the level of the national accounts (Stoneham *et al.* 2009). The Wentworth Group (2008) has called for ecosystem indicators to be included in the Australian national accounting framework and recent developments in quantification of ecosystem services, Geographic Information Systems (GIS), catchment modelling and economics have led to useable catchment models that make inclusion of data (rather than indicators) more feasible (e.g. EnSym – www.dse.vic.gov, Stoneham *et al.* 2009). Quantifying the ecosystem disservices of weeds and potential weeds in different bioregions/soil types into such systems remains a future challenge of research and management.

Potential new landscapes

Adapting Australian landscapes to climate change must be viewed over decades. If adaptation is combined with progressively expanding the national mitigation capacity over this century, multiple social, environmental and economic benefits can be envisaged (Garnaut 2008). As a response to climate change for mitigation and adaptation (and restoration of natural capital more broadly), large-scale restoration of native vegetation in landscapes has been proposed from various creditable perspectives: science, conservation and social and economic policy.[9] The capacity of this will vary bio-geographically (e.g. soils) and socio-ecologically, however, it is part of a broad national debate. The Garnaut Climate Change Review (Garnaut 2008, 2009) examined the economics (and responses) to climate change and saw alternative futures for large-scale soil C-sequestration and native vegetation regeneration, particularly from the perspective of emission mitigation. Garnaut (2009) indicated the importance of woodlands, and quoted Polglase *et al.* (2008) who, taking account of soils and climate, suggested 200 Mha of land were suitable for carbon plantings.[10] Garnaut considered this figure would not be achieved. However, it is significant that under Australia's second report to the Kyoto Protocol, Victoria and Western Australia turned the land-use change category from a carbon source in 1990 to a carbon sink in 2005, not so NSW or Queensland (Australian Government 2007). Thus our recent past suggests that land-use change to carbon sinks can be reasonably rapid (see also Mansergh *et al.* 2008). A longer-term view suggests that proposed changes for the 21st century are neither as large nor as radical as those that occurred over the last two centuries, many of which were accomplished by technologies based on human and animal labour.

In response to the interactions of habitat fragmentation and effects of climate change, Opdam and Wascher (2004) called for 'bold connectivity zones' as an adaptation model of land-use change in Europe (also Jones-Walters 2007). In a global review of corridor ecology Hilty *et al.* (2005) found it hard to imagine any realistic alternative to large-scale linkages that would be conducive to species' persistence, whilst Stern's (2007) economic analysis alluded to land use for increasing connectivity of biodiversity in his adaptation to climate change. Bennett *et al.* (1992) developed the concept of *biolinks* for SE Australia, where substantial areas of the landscape are to provide 'space' for native vegetation to regenerate and facilitate the self-adaptation of species to climate change. These were particularly vital across fragmented landscapes (for science, see Bennett *et al.* 1992, Brereton *et al.* 1995, Mansergh *et al.* 2006, 2008; for policy, Victorian Government 2008 b, Figure 2). Although ageing remnant eucalypts across many pastoral landscapes imply mass denudation (e.g. Vesk and McNally 2006), in many landscapes, such regeneration remains feasible (grazed, 'unimproved' woodlands) although the window of opportunity would be halved over the next 30 years (Dorrough and Moxham 2005).

The concepts of resilience and related ideas of thresholds and transformations are evolving in the global debates around adaptation of landscapes to climate change (Victorian Government 2008 a,b). Walker *et al.* (2009) analysed the socio-ecological resilience of the Goulburn Broken Catchment and suggested large-scale regeneration was certainly within the mix of the resilience options to preserve the viability of the highly productive (agricultural) land significant at the scale of the Victorian economy. Significantly, within this catchment, over 80% of the dryland farms were seen as uneconomic in the mid 1990s (GBCLPB 1997). In the adjacent North-Central Catchment modelling, combined adaptation and mitigation concluded that regeneration of riparian areas optimised C-sequestration, biodiversity and water quality outcomes (Jones *et al.* 2007).

Recuperative restoration of landscape differs from past, single paint on the palette land-use in that it is based upon a more holistic valuing of ecosystem services. Hallegate (2009) conceptualised strategic responses to adapt to the uncertainties of climate change and the new landscapes (above) have positive elements of no-regret, reversibility and incorporate safety margins. Such massive land-use changes (due to different valuation of ecosystem services provided from the landscape) will neither remove the exotic nature of introduced plants nor their inherent biological capacity but it will change the relativity of our perception of different species as weeds. How much does a species inhibit or promote the growth of the new ecosystem services desired from landscapes (soils and vegetation)?

New paradigms of land use and climate change

How humans treat the planet (and each other) is part of a moral–ethical imperative of climate change as asserted by Al Gore in *An Inconvenient Truth* and the UN Secretary-General (quotation at Introduction, von Bülow 2009). The ethical imperatives can be focussed on vulnerabilities of human societies to risks (food security, low-lying coastal populations) but also on how societies use natural resources, including land use. The growing recognition by Australians of 'own goals' in the depletion of natural capital *and* the debate over exacerbating effects of land-use changes on regional climates (e.g. Pitman and Narisma 2004) have both rational and ethical dimensions.

Compared to the colonial view, a new 'sense of place' has evolved within the

[9] Numerous businesses are emerging in the market-place that organise growing native species based on C-sequestration.
[10] Garnaut (2009) also noted the importance of a holistic emissions view – some of the methane-producing sheep and cattle could be replaced by low emission kangaroos.

growing respect for, and protection of, Australian landscapes and native and endemic species. This has supported the growth of national parks, changes in how we manage public land and also standards of expected stewardship of land and probably part of the recognition of environmental weeds (e.g. Landcare, Mansergh *et al.* 2006, Carr *et al.* 1992, Table 2). These social trends reflect an ethical position that could also be expected to support some form of large-scale restoration of landscapes as part of the 'morality' of climate change.

Natural regeneration

There are many ways for re-establishment of native vegetation: planting; direct seeding; natural regeneration; or, combinations of these. Here we discuss natural regeneration of eucalyptus. Where feasible, it appears to be the most cost effective, significant in re-establishment of microclimates and natural soil processes, increasing robustness to perturbations, as the dominant plant may inhibit some weed invasions; and, perhaps it is the most climate change sensitive methodology (Graetz *et al.* 1987, Ehrenfeld 2003, Greening Australia 2003, Mansergh and Cheal 2007). *Eucalyptus* species provide the major overstorey for the non-arid forest and woodlands of eastern Australia influencing microclimate (solar radiation, water penetration, wind speed) for lower strata and ground water hydrology. Many eucalypts have relatively broad climatic and latitudinal distributions. The agricultural and pastoral legacy has left landscapes with varying possibilities of resilience and resistance to natural regeneration. Dorrough and Moxham (2005) indicate that many pastoral landscapes of NE Victoria, some having as few as only 2.4% of remnant trees left, retain the capacity for about 40% of the land area to regenerate eucalypts, although this window of opportunity for resilience declines to only 18% of the land area over the next 30 years and is related to past land use including soil fertiliser use (Dorrough *et al.* 2006). Restoration of the eucalypt overstorey can be perceived as a stabilising parameter in the sense of landscape resilience (see Holling and Meffe 1995)

Over Victoria's history, native vegetation has occasionally re-established on abandoned farmland. Figure 4 shows the changing configuration of regenerating eucalypt canopy over an existing paddock in NE Victoria after removal of grazing. Many of these eucalypts have a broad climatic and geographic range and thus some plasticity and variation in their genetic memory (e.g. Mansergh *et al.* 2008). As a rule of thumb, good regeneration of eucalypts can be achieved from seed spread from the parent stock to a distance of about twice their height. Seedlings and saplings are naturally selected from the parental genotypes under the current climate, which puts the surviving phenotype on a trajectory of change relative to the parent stock (species with long generation times are at a disadvantage). Over 20 years, the second generation continues the trend by responding to local changing conditions as would remnant soil biota, e.g. fungi (Kasel *et al*. 2008). Full cover of eucalyptus (and faster C-sequestration) could be achieved by strategic direct seeding (Figure 4).[11] Other land management that may be compatible with hastening growth of eucalyptus may be biochar production from thinnings (for biochar, see Lehmann and Joseph 2009, Kiener 2009, Read 2009, Sohi *et al.* 2009).

Compared to the prior use (e.g. grazing), the emergent understorey provides multiple niches and seral stages for both native vegetation and weeds. Emerging from the present, vegetation communities would not be replicates of the past but through natural selection adapting to new environmental conditions. The new land use would increase the resilience of the landscape (biological inertia) and would require new management regimes and cognisance that new niches (for potential weeds?) will be created over time (Figure 4). This may be contrasted to a 'weed' that inhibits production of a specific agricultural or pastoral commodity over a relatively shorter time frame.

Sleepers and seral stages

Over 27 000 exotic plant species have been introduced to Australia, including more than 8200 species for agronomy and soil conservation work (McLaren 2008, Cook and Dias 2006). Many weed species, currently classified as major threats to the wider environment or to agriculture, spent many years, decades even, as 'sleepers', i.e. showing little potential for widespread establishment. Their widespread establishment may have only begun many decades after their introduction or after the first time they were recorded as adventive (Groves et al. 2005, Randall 2001). For example, bridal creeper (*Asparagus asparagoides*) persisted in very small populations in western Victoria for decades before a population explosion in the 1980s made it a virulent weed (Groves *et al.* 2005). Thus adaptation to climate change and potential land-use changes suggests management strategies that have an explicit, increasing vigilance to potential and emerging weeds.

Perception of some species currently regarded as weeds may change as society expects a different mix of ecosystem services from land management. Temporary invasion by plants that restore soil capacity

[11] Viable seed can be set from any eucalypt flower provided it is pollinated. Age of first flowering will vary between species, but any 'reasonable' quantities will not be produced until at least 10 years. Quantities will be dependent on size of the crown, which is of course age-related, and space available. Rule of thumb for forest species is about 20 years until they have enough seed for self-regeneration after fire, may be less time in drier areas. (P. Fagg DSE personal communication 2009, Florence 1996).

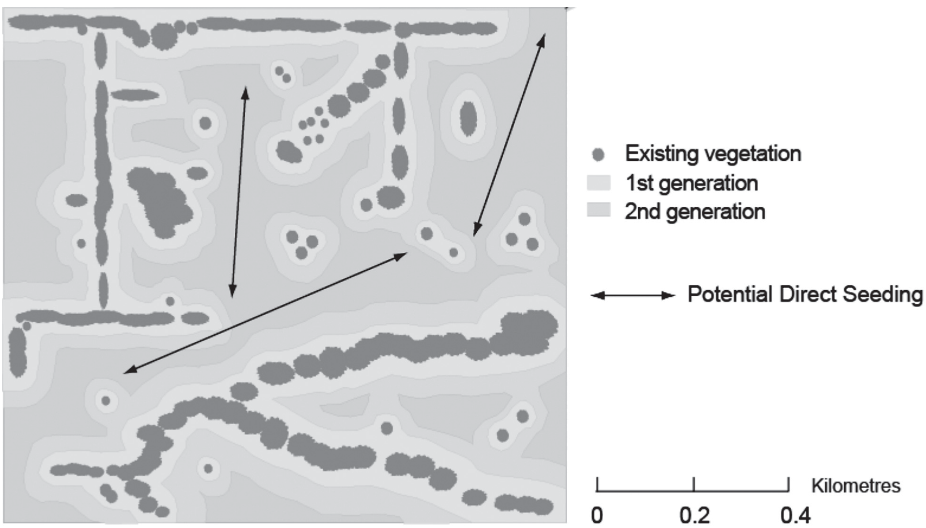

Figure 4. Idealised natural regeneration of eucalypt overstorey (grazing landscape in NE Victoria) relaxation of ungulate soil compaction and additives (fertiliser and biocides) would allow natural re-colonisation over time (see text). Natural selection determines seedling survival to 'current' environmental conditions, which successively move along a climate change trajectory. Note changes in niche availability for plants over time (see photographs in Mansergh *et al.* 2006).

as a prelude to longer-term regeneration of eucalypt woodlands may be seen as tolerable, if not desirable. However, a deeper understanding of the totality of effects of exotic invasions, including for instance soil C/N cycle, is required (Kibblewhite *et al.* 2009, Fisher *et al.* 2006, Ehrenfeld 2003). Weeds as 'nursery crops' is already well-established in the Mallee, where rye-corn *Secale* is a frequent cover crop planted onto bare sand dunes to enable seedlings of perennial and native species to establish in their cover.[12] When goods are produced on an annual basis, the disservices (and cost of control) of weeds can be quite clear, however, regeneration of landscapes to produce long-term decadal ecosystem services suggests a different context.

Climate change will change environmental perturbations (fire regimes, floods, increased intensity of extreme weather events) that will affect the abundance, distribution and rate of spread of 'weed' species (e.g. Radho-Toly *et al.* 2001, fire and spread of eastern eucalypts in WA). Weeds associated with fire (e.g. increased risk) would become relatively more important for management action. A water-stressed future (with increased flooding and extreme weather events) will increase the importance of riparian vegetation, and its restoration (as key part of water infrastructure) suggests a focus on weeds and vectors of distribution in these environments.

Under climate change, these perturbations may tip ecological thresholds leading to gradual or rapid long-term vegetation and/or changes to NPP (Nemani *et al.* 2003, Graetz *et al.* 1987). The interactions of climate, vegetation and soils may transform landscapes to another form of ecological community (e.g. woodland to shrub land) with the transition process following a regeneration event (fire or harvesting, Nitschke and Hickey 2007)[13] or a slower invasive evolution (e.g. change of understorey – heathy to grassy). Such events would be new phenomena and may offer large-scale opportunities for unwanted plants to establish.

[12] This technique is available on sandy substrate. However, exotic annual effects on soil nitrogen in finer textured soils in wetter areas are likely to lead to feedback mechanisms that perpetuate weeds rather than native species (L. Bennett, Melbourne University, personal communication).

[13] Nitschke and Hickey modelled dominant species in the forests of the Victorian Central highlands. Warming and drying may not kill existing Mountain ash (*E. regnans*), however, post the next regeneration event (fire or harvesting) around mid century their seedlings would be out-competed by other eucalypts.

Reflections for weed management

Presuming some general validity of the above evidence and arguments (i.e. new large scale land-use context) achieve a degree of social resonance the following inferences may be useful in reflecting on climate change, land use and weed management and research. Under climate change, the perceived weediness of an individual species may change (including 'sleeping' species) and the landscape context and valuation of 'ecosystem services' will certainly change over large areas.

- Land management will have new range of ecosystem services required by society. Some products may remain *in situ* and are produced over decades relative to traditional commodities produced annually and exported.
- A capability to spatially quantify ecosystem dis-services of weed species (recognising variation between bioregions/soil types) will need to be developed in relation to new land-uses and public good.
- Some landscapes will support new landholders, management regimes and perhaps increased diversity of land-use objectives (e.g. in social amenity landscapes, riparian).
- Plant species that are advantaged and/or promote changed disturbance regimes, particularly those implicated with an increased fire risk, may be perceived as more weedy.
- The increased socio-economic importance of 'environmental weeds' (i.e. inhibiting natural vegetation, regeneration and related processes) with consequent funding (and quarantine) implication.
- Plants that change soil qualities and long-term capacity for the production of increasing valued ecosystem services, e.g. species that out-compete key native species and interfere with processes (e.g. N-fixing *Acacias* spp.). This implies knowledge of (quantification) marginal changes in soil-based ecosystem services and associated benefits with changes in land use.
- Increased understanding of the feedback mechanisms between weeds and soils (compared with those between native perennials and soils) and how these are influenced by changes in water availability will be required; i.e. how much extra benefit do we get from what level of change in an ecosystem service due to what changes in land-use management?
- The importance of sophisticated biological control – over large areas will probably increase.
- There will need to be constant vigilance for early warning of sleeper species expanding ranges under climate change.

There will always be plants in the 'wrong place' from some human perspective. Climate change will bring higher atmospheric CO_2, warmer, drier and more flood and fire prone (disturbance and regeneration events) future. In dealing with the uncertainties of climate change we can, should and will: progressively refine modelling the response of weeds and native species; be vigilant in quarantine and observing a large base-load of potential already on the continent; and, develop new insights from methods of control. These essentially deal with objective aspects of the ecology of the biota itself. However, to perceive a weed requires attributing a present and projected meaning to the landscape where it occurs. These meanings are evolving and our response to climate change will accelerate this process. Landscapes are the interface of earth and atmosphere, between wombats and wedge-tailed eagles, and are critical in the climate change debate and our strategic responses. Hopefully this paper will promote discussion around climate change, our responses, specifically land use, and our evolving perceptions of landscape and ecosystem services, and the socio-ecology of weeds.

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Whither the weeds under climate change

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Much has been made of the potential for climate change to make weed problems worse. Many traits that make weeds invasive also give them a competitive ability in a CO_2 enriched atmosphere (Dukes and Mooney 1999). This has local significance, as modelling of regions susceptible to weed invasion under climate change found that those most at threat from alert and sleeper weed species are in south east Australia (Scott *et al.* 2008). However, climate change modelling has not only found that the potential range for some weeds will increase, but also that other species will be unlikely to persist in their current locations (Potter *et al.* 2009a,b, Steel *et al.* 2008, Sposito *et al.* 2008, Scott *et al.* 2008, Kriticos *et al*. 2006, Kriticos *et al*. 2005, Kriticos *et al*. 2003). Clearly, weed management should be focussed on infestations that are likely to persist in and spread to climatically suitable areas, rather than those that might decline in response to climate change. As temperature and rainfall regimes change in Victoria, the geographic area susceptible to invasion by a weed species (the weed's potential distribution) may:

- expand to include areas of the state not previously suited to the weed, or
- contract as parts of the state become unsuited to the weed, or
- remain susceptible, although with altered climatic suitability.

Often, the potential distribution of a weed species expands on some boundaries, contracts at others and undergoes varying degrees of change in suitability. Fortunately, climatic modelling lends itself to visual representation as maps, which make it easy to see the difference between the potential distribution of a weed under current and future climatic conditions.

Knowledge of how Victoria's climatic conditions will change and how this will impact on the potential distribution of weed infestations gives us another factor to consider when setting weed management priorities. Currently, the Victorian Weed Risk Assessment (VWRA) is used to rank invasive plant species according to the degree to which they pose a threat to agricultural, environmental and social values in the state. This process (see Weiss *et al.* 2004) includes a measurement of the area that is climatically-suited to each weed species being assessed, as well as its biological invasiveness and ecological impacts. The larger the area that the weed could spread to (its potential distribution), the larger the threat it poses. Climate change will alter the pattern and size of the potential distribution of many weed species. This will change their ranking in the VWRA and has consequences for choosing the most effective and efficient management option to use.

What follows is a general discussion of the implications for weed management as climate change impacts on the potential distribution of weed species in the state. Modelling of dozens of species is now available (Potter *et al.* 2009a,b, Steel *et al.* 2008, Sposito *et al.* 2008, Scott *et al.* 2008, Kriticos *et al*. 2006, Kriticos *et al*. 2005, Kriticos *et al*. 2003) and the maps included in these reports will aid identification of which parts of the state will be suited to invasion by specific weeds under climate change.

Increased potential distributions

Victoria's climate can become more suitable for a weed in several ways. For a species that is already naturalised and spreading, a proportion of the state is currently climatically suitable. This area may increase in size as more of the state has temperature and rainfall regimes that suit the species. Alternatively, current climate may be unsuitable for the establishment and spread of a plant species, but under climate change parts of the state might become suitable. Species in this category are not currently able to naturalise in the state but may do so either from propagules dispersed from interstate infestations, or from deliberately-planted sites within the state, such as gardens, crops, pasture or plantations.

The implications for setting weed management priorities are different under each of these two scenarios. For species that are already invasive, an increase in potential distribution causes an increased risk of invasion across the state and raises the threat posed by the species. This may change the appropriate action for a weed from prohibiting its trade to preventing spread to other susceptible areas under current climate, to conducting surveillance and attempting to eradicate if discovered in the expanded part of the climate envelope.

Species that are not yet naturalised and with zero potential distribution under current climate are not presently a priority for weed management. Climate change *was* identified as a consideration in weed risk assessment as long ago as 2001 when the terminology used was 'the enhanced greenhouse effect' (Kriticos and Randall 2001), however the author is unaware of any weed risk assessment that currently includes this factor in any form. That is not to say that land managers are unaware of the issue, but that climate change is not included in a formalised way when setting weed management priorities and its consideration may instead occur on an *ad hoc* basis. Weeds that are likely to become problematic in Victoria only under climate change will not necessarily become a priority for management until we have a systematic method for incorporating climate change into weed risk assessment.

In general, species that might become new weed threats to Victoria are likely to currently be weeds further north in Australia by up to and over 1000 km (Scott *et al.* 2008). We can prevent the entry of these species with border controls, or pathway barriers, or by encouraging the eradication of interstate infestations before the climate in Victoria starts to favour their expansion. This makes cross-border and national weed control programmes, such as Weeds of National Significance even more important and relevant across a broader geographic range.

Decreased potential distributions

Parts of the state will also become less suited to some of our current weed species, and to those species not yet present. This may have the result of reducing the potential distribution of a weed, and thus reducing its importance relative to other weeds. It may also occur as a consequence of a range shift whereby the suitable climate for a weed appears to migrate to a different part of the state. Under either scenario, current infestations that may persist in climatically-suited areas should clearly be higher priority than those that might decline without any enhanced management.

It will be interesting to observe the biological effects on a weed species of this decline in climate suitability. These infestations may become easier to control as the plant becomes less vigorous and produces fewer propagules. For example, a species that can no longer set seed under climate change, due to unsuitable temperatures for flowering, or decoupling from a pollinator may become more suitable as an eradication candidate if it can only reproduce vegetatively and is unable to maintain a soil seed bank from which it can regenerate.

However, regeneration from existing soil seed banks in climatically-suitable years may allow the infestation to persist long after the average annual climate becomes unsuited to the species. Our weed management methods may also be affected by climate change with predicted reductions in the number of suitable spray days, efficacy of chemical and biocontrol options (Harrington *et al.* 2001).

Projections of changed potential distributions under climate change can thus be viewed as an opportunity to further refine the data that we use to prioritise weed management in Victoria. However, if we are to do so, we need to be confident in the results of the modelling. Most of the potential distribution modelling for weeds in Australia focuses only on suitable *climates* for weed growth. Sposito *et al.* (2008) considered the rate of dispersal of weeds alongside changes to potential distribution and concluded that some weeds will be constrained by dispersal to prevent their establishment into new areas under climate change. However, invasive species do tend to be adapted to long-distance dispersal (Carr *et al.* 1992), allowing them to establish in new areas as climatic conditions shift. The effects of climate change on dispersal itself is also worthy of consideration. For example, species that are flood-dispersed (as described in Kriticos *et al.* 2003) may currently be constrained by rare flood events. Even if the potential distribution of such a species were to remain of similar size, or even contract, it may become more widespread more rapidly than under current conditions. Similarly human dispersal of weeds may increase in response to an increase in natural disasters, for example in fodder transported to alleviate drought or in the creation of fire breaks

Climate modelling only provides one aspect of weed risk. A set of risk assessment criteria that addresses the potential for a weed to become more invasive due to climate change could also identify species that might be advantaged by the results of increased atmospheric carbon, such as the carbon fertilisation effect (Dukes and Mooney 1999), water-use efficiency (Kriticos 2008), nitrogen deposition , increased disturbance events, habitat fragmentation (Dukes and Mooney 1999), or release from competitors and predators (Poloczanska *et al.* 2008, Parmesan 2006). Weed impacts may also become worse. For example, a study of ragweed has suggested increased atmospheric CO_2 concentrations could increase pollen production and create worse allergy problems for humans (Ziska and Caulfield 2000).

Using such criteria could reduce the time it takes to identify species that are likely to be advantaged under climate change. This would avoid the need to perform detailed climate analyses (such as has been accomplished by Kriticos *et al.* (2003)) on every single weed species present in Victoria… or Australia… or every introduced species… let alone native plants that might go feral. Indicators of likely increase in range or persistence within current range under climate change include: current broad geographic range and thus broad climatic tolerance (Hughes 2003); phenotypic plasticity and wide fundamental niche (Mackey *et al.* 2008) including environmental and agricultural settings, short generation times, rapid population growth rates (Hughes 2003) and long-distance dispersal mechanisms (Dukes and Mooney 1999).

However, before we can routinely incorporate climate change into prioritising weed management in Victoria we need to have a reliable process. The potential distribution component of the VWRA will need to consider future climatic conditions as well as the current climate in the modelling process. Research is currently underway to determine the most efficient and robust way to achieve this.

Of course, when completed, much of this modelling will suggest yet another change to our priorities for weed management, hot on the heels of the paradigm shift from a focus on widespread weeds to those that are new and emerging. We need to develop models and risk assessment tools that are accurate at an appropriate scale and precise without being too complex to give ourselves confidence in our decisions, and to provide convincing proof not just to the public, but also to the people who have been researching and managing these weeds for years.

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Security in a changing world – a new biosecurity approach for Victoria

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The Victorian Government has launched a new Biosecurity Strategy for Victoria to guide the state's approach to mitigating the biosecurity risks and impacts to primary industries, the environment, social amenity and human health. The risks covered in this strategy are those associated with plant and animal pests and diseases (including zoonotic diseases), and invasive plants and animals across public and private land, marine and fresh water environments in Victoria.

Biosecurity can be defined as:

> The protection of the economy, the environment, social amenity and human health from the negative impacts associated with animal and plant pests and disease and invasive species. Biosecurity is fundamental to the health, wellbeing and prosperity of all Victorians.

Although Victoria has a strong record of identifying and managing biosecurity risks, our natural environment and primary industries face new and emerging biosecurity threats which bring new challenges and require new solutions. These challenges include:

- Climate change will see a shift in climatic zones – pests and diseases may change and/or could have the potential to invade new areas;
- World trade is expanding rapidly – movement of goods and containers is becoming faster and easier;
- People are travelling further, faster and more frequently than ever before – for work and as tourists (eco-tourism is expanding);
- The use of contract labour within primary industries is increasing – workers are now moving between farming enterprises and countries on a regular basis;
- There are changing patterns of land use with more peri-urban small holdings, more timber plantations, more intensive livestock farming and 'new' farmed products (eg, abalone), and areas 'abandoned' from agriculture;
- Increasing contact between humans, livestock and wildlife is resulting in the emergence of new diseases; and
- The review of the national quarantine system.

The **vision** for the new approach to biosecurity in Victoria can be expressed as:

> **The risks to Victoria's people, primary industries and natural environment from animal and plant pests and disease are effectively managed by the combined actions of government, industry and the community**.

Principles

The Victorian Government will refocus its programs to develop a forward-looking, flexible, innovative biosecurity system that will:

- Ensure government, industry and community are partners who understand and respect each others' roles and responsibilities;
- Be underpinned by a risk-management framework, including clear, transparent and consultative processes for decision making and investment; and
- Use the best science and technology to develop innovative and cost-effective solutions to biosecurity problems.

The vision is articulated through six themes.

Theme 1 – Developing partnerships

We will work to strengthen collaboration across government, industry and the community with improved, shared decision making processes and appropriate biosecurity planning for industries and enterprises. The Victorian Government will establish a Biosecurity Standing Committee to oversee biosecurity planning and program delivery and to ensure implementation of the strategy. The Victorian Government will continue to be a leader in influencing national biosecurity arrangements and in responding to the Beale Review into Australia's quarantine and biosecurity systems.

Theme 2 – Strengthening the coverage

Victoria will address the key challenges and gaps in our current system by:

- Reviewing key areas of biosecurity exposure to inform development of biosecurity plans (eg forestry, fisheries, marine, environment, social and amenity threats, zoonotic and wild life disease);
- Identifying gaps in capability and expertise in key areas of exposure; and
- Clarifying roles and responsibilities across government and the community for biosecurity issues.

Theme 3 – Making sound decisions

The Victorian Government will adopt a consistent and transparent risk based approach to biosecurity management with an integrated risk management framework across all areas of biosecurity activity. We will evaluate existing programs against criteria for assessing the appropriate role of government and explore, in conjunction with stakeholders, options for improving private beneficiary contributions to biosecurity programs.

Theme 4 – Building the skill base

Victoria needs the right capability, including skills, tools and knowledge to strengthen our ability to address biosecurity threats. This will include research into the impact of climate change on future pest, weed and disease management. Working collaboratively across the nation, we will ensure the quality and availability of suitable diagnostic capabilities are appropriate to support improved surveillance. We will plan new social research to provide greater insight into individual and community engagement and review relevant legislation to ensure it supports the required biosecurity policy objectives. We will assess the need for new information management platforms to support the biosecurity approach and we will strengthen our commitment to biosecurity communication and awareness.

Theme 5 – Smarter surveillance

Early detection and market access rely on developing smarter surveillance. This will require analysis of pathways and development of active and passive surveillance systems for high risk pathways. This will need networks with the Australian Government, industry and the community to enhance pest recognition and reporting.

Theme 6 – Responding to incursions

We must be prepared to manage an emergency quickly, effectively and professionally. Victoria will investigate models to establish a whole-of-government Biosecurity Emergency Response Management Group to lead emergency response to biosecurity risks. We will plan for industry and community education and capability building and review diagnostic capability and capacity needed to deal with emergency biosecurity incidents. Finally, we will review information management and mapping systems to support emergency responses.

Next steps

Biosecurity Victoria in conjunction with its partner agencies is currently developing projects to examine governance and institutional arrangements as well as stakeholder engagement and is scoping areas of biosecurity exposure. An Implementation Plan should be released for the strategy by July, 2010. During this period we will work with the community and industry to clarify roles and responsibilities.

Conclusion

The Biosecurity Strategy sets a firm foundation to guide the biosecurity planning, preparedness, service delivery and partnerships required to meet Victoria's future needs.

Impacts of Chilean needle grass *Nassella neesiana* on native plant diversity in Australia's indigenous grasslands

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Summary

A three year study of the biodiversity impacts of *Nassella neesiana* in temperate native grasslands of south-eastern Australia has revealed that major disturbance (removal/death of the dominant existing grasses) enables *N. neesiana* invasion. Gaps of about 1 m^2 (as opposed to 10–30 cm^2) in native grass swards are required for establishment. Native grasslands in good condition are resistant to invasion. Native plant diversity (species m^{-2}) is significantly reduced inside *N. neesiana* patches and decreases with increasing patch size. Forbs are the most affected group. Exotic plant diversity (spp. m^{-2}) is similar inside and outside patches. In areas with *N. neesiana* propagule pressure, increased senescence of *Themeda triandra* swards is accompanied by invasion. *N. neesiana* depletes soil water in spring compared to *T. triandra*. This mechanism may explain ongoing losses of native species in *N. neesiana* patches. The negative effects on adjacent *T. triandra* may enhance invasion at patch edges. Invasion is generally absent or very slow when infestations abut healthy grassland. Where grasslands are in poor ecological condition linear expansion rates >5 m per year can be expected. Much of the loss of native plant diversity in invaded areas probably precedes invasion and is caused by other degrading processes including *T. triandra* senescence dieback, mowing and major soil disturbance.

Introduction

Chilean needle grass *Nassella neesiana* (Trinius & Ruprecht) Barkworth (Poaceae: Stipeae) is a C_3 (cool season) perennial tussock grass native to South America that has proved to be highly invasive in Australia. The potentially severe biodiversity impacts of the grass were first made widely known by Carr *et al.* (1992) who identified vegetation formations at risk, including lowland grassland. Later *N. neesiana* was rated, along with *Nassella trichotoma* (Nees) Hack. ex Arechavelata, as the most significant weed threat to temperate grassland biodiversity in Australia (McLaren *et al.* 1998, Groves and Whalley 2002).

Invasions by alien plant species are a significant cause of global biodiversity decline (Coutts-Smith and Downey 2006). In Australia the details of how such impacts occur and what is impacted have been scanty, with even the simplest data lacking for most weeds (Adair 1995), in part because the effects have been considered obvious (Adair and Groves 1998). Until recently, adequate compilations of the weeds actually causing impacts have not been made, nor has information on the species and communities impacted been readily available (Downey and Coutts-Smith 2006, Coutts-Smith and Downey 2006). Most published statements about impact have been 'based on more or less casual observations' (Grice 2006 p. 28). The mechanisms by which weeds impact on ecosystem structure and function have not been widely quantified (Grice 2004, Grice *et al.* 2004), and the causal relationships between invasion and impact have 'generally [been] implied but not demonstrated' (Grice 2004 p. 54).

Detailed studies of *N. neesiana* as a weed were first undertaken in New Zealand, in particular by Bourdôt from the mid-1980s (eg Bourdôt and Hurrell 1989). The ecology of *N. neesiana* was first studied in detail in Australia by Gardener (Gardener 1998, McLaren *et al.* 1998, Gardener *et al.* 2003a, 2003b) and his findings increased the alarm. A very large potential climatic range in Australia, high seed production including clandestine basal cleistogenes, large persistent soil seed banks and adaptations for animal dispersal were amongst the findings of concern. Grazing strategies to increase utilisation in pastures were suggested as the best option, given the seemingly extreme difficulties of eradication (Gardener 1998), and these were investigated in a major study by Grech (2007). Lunt and Morgan (2000 and other studies) greatly illuminated the importance of disturbance regimes and the maintenance of healthy stands of the dominant native grass on the biodiversity effects of *N. neesiana*. Ens (2002) investigated the biodiversity impacts in Cumberland Plain (Sydney) woodlands and found that the dense litter mats and expansive monocultures formed by the grass reduced habitat heterogeneity and caused major changes to the insect fauna, including diversity declines, although some groups were benefited. Beames *et al.* (2005) demonstrated that established integrated management techniques based on selective use of herbicides could cost-effectively deliver substantial population reductions of *N. neesiana* in native grasslands in the Melbourne region.

The impact of *N. neesiana* in the natural temperate grasslands of south-eastern Australia is a particular concern because of the small areas of this endangered ecosystem that remain. Carter *et al*. (2003 p. 76) concluded that extant remnants represented 1.7% of the pre-1750 area (an estimated 5.8 million ha), that only a small proportion of these were in good condition, and that 'few or no… large, species rich' sites existed. *N. neesiana* has been reported to actively invade these grasslands (Hocking 1998), but the mechanisms by which it invades and the biodiversity impacted are poorly understood.

The main dominant species in Australian natural temperate grasslands is kangaroo grass *Themeda triandra* Forrsk. (Andropogoneae), a C_4 (warm season), perennial tussock grass adapted to frequent fire but susceptible to eradication by introduced livestock (Groves and Whalley 2002, Prober and Lunt 2009). *T. triandra* is displaced when *N. neesiana* invades, so studies of the biodiversity impact of the weed need to have a strong emphasis on this keystone native species.

Disturbance frequently increases the invasibility of communities (Hobbs and Huenneke 1992) but generalisations about the relationship between particular disturbances and exotic plant invasions have remained elusive, and some weeds certainly invade without major anthropogenic habitat alteration (D'Antonio *et al.* 1999). Conditions suitable for grass seedling recruitment in perennial grasslands are generally rare or infrequent (Lauenroth and Aguilera 1998), but disturbance is an important factor in the creation of safe sites for seed germination, and any disturbance that damages or kills the existing vegetation favours the survival of juvenile plants (Cheplick 1998). Numerous experimental studies have demonstrated negative effects on grass recruitment due to the presence of established grasses (Lauenroth and Aguilera 1998). Nutrient enrichment has also been identified as a major cause of alien grass invasion worldwide (Milton 2004). Invasion cannot occur in the absence of propagule pressure, but all communities may be thought of as possessing biotic resistance to invasion. Testing of these factors in relation to *N. neesiana* invasion was clearly required.

One of the most critical anthropogenic disturbances in grasslands dominated by *T. triandra* is suppression of fire. In the absence of fire, gradual build-up of dense biomass by *T. triandra* results, after a period of years, in a self-shading effect that causes tussock death (Lunt and Morgan 1998, Morgan and Lunt 1999). This senescence dieback has been found to remove biotic resistance and open the community to invasion by weeds including *N. neesiana* (Lunt and Morgan 2000).

The research reported here concentrated to a large extent on investigations of mechanisms of invasion and impact, which can be viewed as functional aspects of biodiversity change (Aguiar 2005). Results from such studies were expected to illuminate the larger questions about where, when and under what circumstances biodiversity impacts of *N. neesiana* might occur. It was hoped that an improved understanding of impact processes would better enable prediction of total impacts. Other major components of the investigation attempted to identify biota actually impacted, with a focus on vascular plants and invertebrates.

The investigations were undertaken as part of a PhD study by the first author under the supervision of the co-authors. This paper summarises some of the key results.

Materials and methods

Study sites

Investigations were undertaken at five main sites:

1. Yarramundi Reach grassland (35°17.5'S, 149°05'E), Belconnen, Australian Capital Territory, 565 m altitude, located at the western end of Lake Burley Griffin, managed by the National Capital Authority (ACT Government 2005). The site has duplex yellow podzolic soils derived from porphyry that are sandy loams in the upper horizons and yellow clays at depth (Chan 1980). This grassland was not grazed by livestock at least from 1965 (Frawley *et al.* 1995), although Chan (1980) indicated that the northern section was used as natural pasture. It was managed by mowing several times a year until 1995 when mowing was greatly reduced in an attempt to protect the endangered striped legless lizard *Delma impar* Fischer (Frawley *et al.* 1995 p.148). The whole site was burnt by wildfire in December 2000. The grassland contains 16.4 ha of *Austrostipa* association and 4.8 ha of Dry *Themeda* association (ACT Government 2005) and is heavily invaded by *N. neesiana* (Cooper 2009) which has been present at least since 1995 (Berry and Mulvaney 1995).
2. Dudley Street grassland (35°18.8'S, 149°05.5'E), Yarralumla, ACT, 580 m altitude, a 2.2 ha area, consisting of 0.6 ha of *Austrodanthonia* association, 0.9 ha of Wet *Themeda* association and 0.7 ha of exotic grassy vegetation (ACT Government 2005). The site was rated in 2005 as of moderate botanical significance (ACT Government 2005). The native grassland is approaching a critical threshold due to too frequent and close mowing and *N. neesiana* invasion (Cooper 2009).
3. Crace Nature Reserve (35°14'S, 149°08'E), Lyneham, ACT, 580–620 m altitude, 136 ha, formerly used by the Department of Defence, is mainly Australian Capital Territory land with a rural lease over 30 ha (Cooper 2009). The native grassland contains 35.9 ha of *Austrodanthonia* association, 3.1 ha of Dry *Themeda*, 22.5 ha of Wet *Themeda*, 41.1 ha of native pasture (*Austrostipa*) and 33.3 ha of exotic grassland (ACT Government 2005). The site was rated in 2005 as moderately significant botanically, being grossly altered by disturbance and land use in some areas, but retaining moderate to high diversity of native disturbance-tolerant species in others (ACT Government 2005). The site is managed by grazing of cattle and a mob of over 100 Eastern Grey Kangaroos (Cooper 2009).
4. Laverton North Grassland Reserve (37°45.2'S, 144°47.5'E), Altona North, Victoria, 15 km WSW of Melbourne, 15–20 m altitude, is a 53 ha grassland bounded by Kororoit Creek Road and the Princes Freeway, managed by Parks Victoria. The Reserve, described as a low quality 'degraded, grazed remnant' by Lunt (1995) is located at the eastern end of the Western Basalt Plain, has deeply cracking clay and clay loam soils and is almost flat (Craigie 1993). Grazing was the main land use for over 100 years prior to temporary reservation in 1983 and subsequent management has been largely by fire (Craigie 1993, Lunt and Morgan 1998). The native vegetation is mainly *Themeda triandra* tussock grassland with *Austrostipa* spp. locally abundant (McDougall 1987). *N. neesiana* has been present since at least 1987 (McDougall 1987).
5. Iramoo Wildlife Reserve, (37°45.2'S, 144°47.4'E), Cairnlea, Victoria, 16.5 km WNW of Melbourne and just to the west of the Victoria University St Albans campus, is a small remnant Western Basalt Plains grassland reserved in 1996 to protect the largest known population of *D. impar* (O'Shea 2005). The reserve occupies the northern section of the former (1939–89) Albion Explosives Factory site, at an altitude of about 60–65 m, and is bounded by Jones Creek to the east and north, and otherwise

by housing. Grazing with sheep was the main land use from the mid-1800s to 1991 (O'Shea 2005). *T. triandra* is the dominant native grass but *N. trichotoma* and *N. neesiana*, which had began to invade by 1996, have occupied substantial areas (Puhar and Hocking 1996, Hocking 2005). The reserve is managed largely by deliberate burning.

Disturbance field experiment

An experiment was designed to test the 'invasion requires disturbance' hypothesis and examine the effects of a variety of disturbances on *N. neesiana* establishment. Three replicates of 30 different treatments were applied to 1 m^2 plots with 1 m buffer zones in recently burnt *T. triandra* grassland. Each treatment consisted of:

A combination of one of three pre-treatments:

1. Kill of all tussocks of the dominant native grass with glyphosate (= 'full kill');
2. Kill half the tussocks (= 'half kill');
3. No kill of existing vegetation (= 'no kill').

One of five nutrient treatments:

1. Nitrogen (granular urea) at 10 kg N ha^{-1};
2. Phosphorus (triple superphosphate) at 10 kg P ha^{-1};
3. Nitrogen + phosphorus both at 10 kg ha^{-1};
4. White cane sugar (a carbon source) at 0.22 kg C m^{-2};
5. None, and

One of two *N. neesiana* seeding treatments:

1. 500 seeds per square metre, or
2. No seed.

Fertilisers and sugar were applied at these rates on three occasions, at weeks 0, 9 and 17. Seed, fertilisers and sugar were broadcast by hand.

Sugar provides a carbon source for soil microbes and stimulates their population growth, leading to rapid depletion of plant-available soil nutrients (Eschen *et al.* 2007), sometimes referred to as 'reverse fertilisation' (Blumenthal 2009). Applications of sugar or other carbon sources such as sawdust and woodchips have been widely used to suppress plant growth in experimental situations (e.g. Alpert and Maron 2000).

Establishment of juvenile plants was monitored regularly over 69 weeks (July 2007–November 2008), when the experiment was terminated and the above-ground biomass of all plants present was harvested. The experiment was undertaken at Iramoo. The methodology is described in more detail by Faithfull *et al.* (2008a).

Patch floristics

A comparison of the flora of *N. neesiana* patches with areas of native grassland immediately outside them was undertaken at Laverton North (14 patches), Yarramundi Reach (15) and Crace (7). A square metre quadrat subdivided into 10 × 10 cm cells was used to estimate cover of all vascular plants present. Two or four quadrats were assessed within and outside each patch and the species present were classified as native, exotic or, if they could not be identified, as undetermined. Quadrats inside patches were close to the patch centre, and quadrats outside patches were placed so as to be well beyond the transitional zone at patch margins. The mean numbers of species in each category in each sampling zone was calculated. The very few species that could not be identified were excluded from the analysis. Methods used in a preliminary study were described in more detail by Faithfull *et al.* (2008b).

Senescence dieback of Themeda triandra

Pin transect sampling was undertaken in stands of senescent *T. triandra* at Dudley Street and Yarramundi Reach to investigate the correlation between the degree of senescence and the amount of *N. neesiana*. A pin transect involves placing a narrow rod (the 'pin') vertically through the grass sward at set intervals and recording the number of touches on (intersects with) the pin by each plant species, live or dead, along with the height of the intersect above the ground. The technique enables analysis of both the composition and structure of the vegetation.

Soil moisture depletion

Nassella neesiana and the dominant native grass *T. triandra* have complementary growth periods. *T. triandra* is a C_4 (warm season) grass which produces high levels of biomass through late spring and summer (Chan 1980, Dunin 1999, Groves and Whalley 2002, Benson and McDougall 2005) while *N. neesiana* is a C_3 (cool season) grass which grows through winter and spring and produces little new biomass in summer (McLaren *et al.* 1998). A large proportion of the native plant species in temperate grasslands are also spring growers (Chan 1980, Groves and Whalley 2002) so when *N. neesiana* replaces *T. triandra* it competes directly with them for soil resources needed for growth. Phenological complementarity of *T. triandra* minimises this competition. It was hypothesised that increased depletion of soil water in spring by *N. neesiana* could be one mechanism of negative impact on native plant diversity, especially under the extended drought conditions currently being experienced in south-eastern Australia.

Soil moisture readings were made with an MP406 moisture probe (ICT International Pty Ltd, no date), a battery powered, hand held device that measures the dielectric constant of the soil, giving values as direct volumetric soil water, from 0 to 100%. Near-surface (probe depth) soil moisture measurements were taken at intervals of 0.1 or 1 m along straight line transects through the boundaries of *N. neesiana* patches into areas dominated by *T. triandra*, at Yarramundi Reach in October 2008.

Rates of change of infestation dimensions

Chan (1980) was able to use low altitude colour aerial photography to map the distribution of native grasslands in the ACT with relative ease. He distinguished eight major grassland types but ignored areas dominated by exotic grasses. Inspection of more recent, small scale, aerial photographs of Canberra demonstrated that *N. neesiana* patches identified on the ground could clearly be distinguished in photographs taken at an appropriate season. It therefore appeared feasible to determine historical changes in infestation dimensions by interpretation of appropriately selected photos, in conjunction with ground inspections.

Photographs were obtained from government photograph libraries and archives, and from Google® Earth (©Digital Globe). Late spring and summer photography enabled the best delineation of infestations. Patches were progressively more difficult to delineate in older, lower resolution images. Colour and texture contrasts enabled identification of *T. triandra* when photos were taken at the appropriate time of year (autumn being best), and uniform swards of other major grasses could also be identified with some certainty. Areas of *N. neesiana* patches measured on the ground at Crace, Yarramundi Reach, Dudley Street and Laverton North were compared with areas interpreted from scanned, re-scaled and digitally manipulated historical images to calculate rates of change of patch areas and linear expansion rates at patch boundaries.

Results

Disturbance experiment

Establishment was enabled by disturbance that killed the pre-existing vegetation, including the dominant perennial grasses (Figure 1). In the absence of such disturbance, seedlings and juvenile plants largely failed to survive. Areas dominated by healthy growing native tussocks were resistant to invasion. A gap size of 1 m^2 ('full kill' plots) enabled significant establishment, while gaps of c. 10–30 cm^2 largely disallowed it. A maximum of 65 juvenile plants was recorded after six months on the 'full kill' plot where the best establishment occurred, but there was high variance in establishment numbers with a mean of only a few plants per plot. Biomass of *N. neesiana* plants that established in areas with larger gaps was much greater than areas with small gaps 69 weeks after seed application (Figure 2).

Sugar had a strongly suppressive effect on establishment, reducing it by about 90% in full kill plots, and by about 50% in half kill plots after 22 weeks. Sugar had an even more pronounced effect on biomass (Figure 2).

Fertilisation with N or P or both had no significant effect on *N. neesiana* establishment or productivity (Table 1), but reverse fertilisation using sugar significantly reduced establishment and productivity. A soil test prior to treatment indicated available soil P was very low (Olsen P 3.84 mg kg^{-1}) but higher than typical (1–3 mg kg^{-1}) in Australian natural grasslands (McIntyre and Lavorel 2007), and soil N was low (nitrate N 1.1 mg kg^{-1}, ammonium N (KCl) 5.1 mg kg^{-1}). Most of the N and P in natural grasslands is held in unmineralised form in soil organic matter and in the crowns and roots of the dominant grasses (Wijesuriya 1999, Wijesuriya and Hocking 1999). When the sward is killed the decaying vegetation releases a nutrient pulse (Wijesuriya and Hocking 1999). It appears that sufficient nutrients were released from breakdown of the killed grasses to enable establishment of *N. neesiana*, but where sugar was applied the nutrients were immobilised and establishment and subsequent production was greatly reduced.

Nitrogen fertilisation significantly reduced productivity of the dominant native grass *T. triandra* and therefore favoured *N. neesiana*.

A proportion of juvenile *N. neesiana* plants died in summer due to predation by grasshoppers (particularly the yellow-winged locust *Gastrimargus musicus* (Fabricius)) and drought. By the time of harvest, i.e. at <1 year old, 45% of surviving plants possessed one or more flowering or seeding culms.

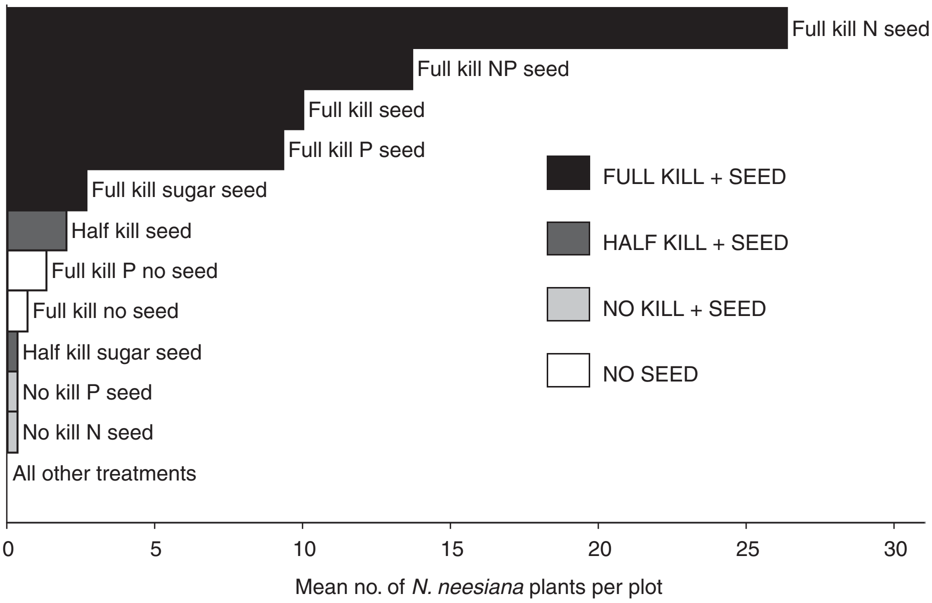

Figure 1. Mean number of *N. neesiana* plants m^{-2} by treatment, 69 weeks after initial disturbance and seed application. Plants established predominantly on full kill plots (herbicide kill of all pre-existing vegetation). Treatments not shown ('all other treatments') had zero establishment.

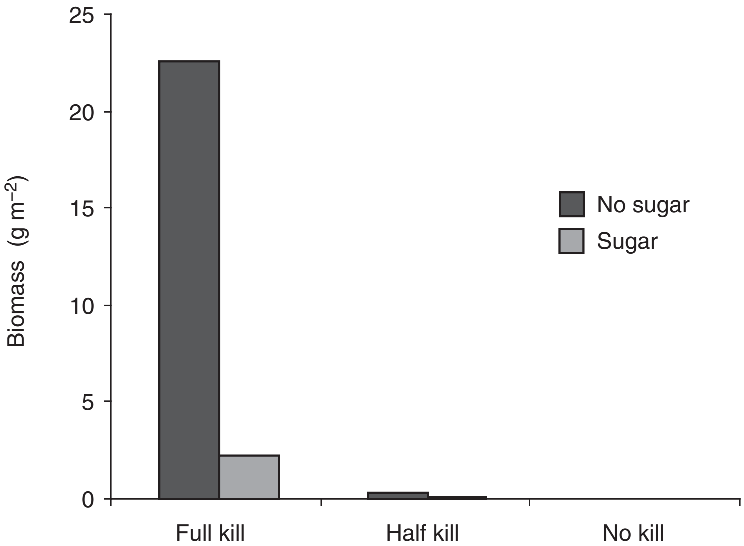

Figure 2. Above-ground biomass of *N. neesiana* by kill treatment, 69 weeks after initial disturbance and seed application (back transformed means). Kill of the pre-existing vegetation strongly enhanced establishment of *N. neesiana* and subsequent biomass production (kill main effect on biomass $P = 8.5 \times 10^{-9}$). Immobilisation of nutrients using sugar strongly suppressed establishment (sugar main effect on biomass P = 0.050).

Patch floristics

Preliminary results from examination of three patches at Yarramundi Reach indicated that presence of *N. neesiana* correlated with reduced diversity of native vascular plants and increased diversity of other weeds (Faithfull *et al.* 2008b) however no statistical testing was undertaken and some methodological deficiencies were identified. Subsequent analysis of a much expanded data set, which incorporates some of this earlier data, presents a somewhat different picture.

Nassella neesiana patches were found to have an impoverished native vascular plant flora compared with adjacent areas of native grassland (Figure 3). Mean native plant species richness (spp. m^{-2}) in *N. neesiana* patches was less than in areas immediately outside the patches at all three grasslands, and significantly lower in two of them. Reductions of 32–65% (back transformed data) were measured. Significant reductions of 31–49% occurred with native grasses at all three grasslands. Dominant or subdominant grasses were the most affected group. Native forbs were significantly reduced at two grasslands (70 and 71%) but not at Laverton North. Proportionately larger reductions were measured at the two grasslands with relatively high native plant diversity (Crace and Yarramundi Reach).

The larger the *N. neesiana* patch, the greater the reduction in native vascular plant diversity (Figure 4). This should not be misinterpreted: larger patches could still contain more native species than small ones, since each increment in area might include additional species. The effect of patch size is strong, with approximately one species m^{-2} being lost with patch size tripling from 100 to 300 m^2. Data not presented here demonstrate that whatever the patch size, native forbs are reduced by

Table 1. Effects of nitrogen and phosphorus treatments on the mean number of *N. neesiana* plants m^{-2} 22 weeks after seed application, and the mean above-ground biomass m^{-2} of *N. neesiana* 69 weeks after seed application. Transformed $\log_{10}(y + 1)$ where y = mean number of *N. neesiana* plants m^{-2} or above ground biomass of *N. neesiana* m^{-2}.

	Transformed				Back transformed	
	No	Yes	SED	P value	No	Yes
No. of plants						
Nitrogen	0.56	0.65	0.115	0.42	2.6	3.5
Phosphorus	0.65	0.55	0.115	0.38	3.5	2.6
Biomass						
Nitrogen	0.48	0.53	0.171	0.72	2.0	2.4
Phosphorus	0.55	0.46	0.171	0.55	2.5	1.9

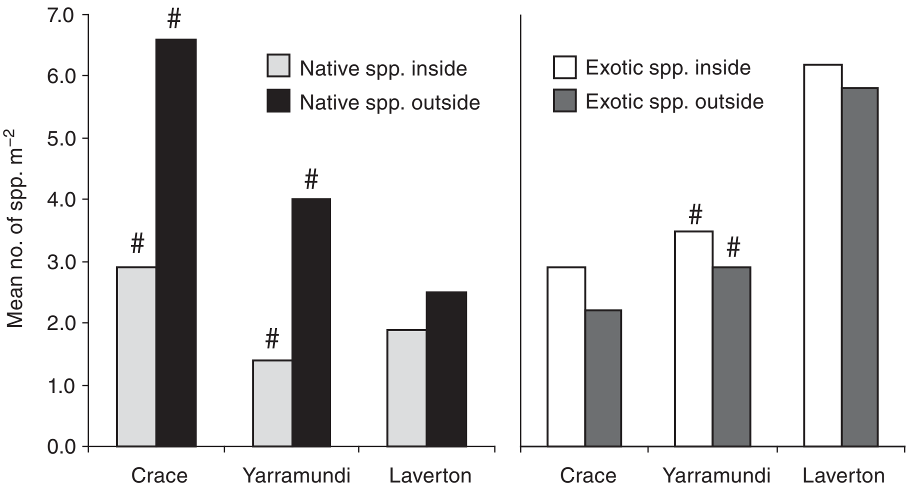

Figure 3. Mean number of native and exotic vascular plant species m^{-2} inside and outside *N. neesiana* patches at three native grasslands (back transformed data). The figures for exotic species do not include *N. neesiana*. Paired columns indicated with a hash (#) are significantly different (P < 0.05). Crace had the highest native diversity and the lowest xenodiversity and *vice versa* for Laverton North.

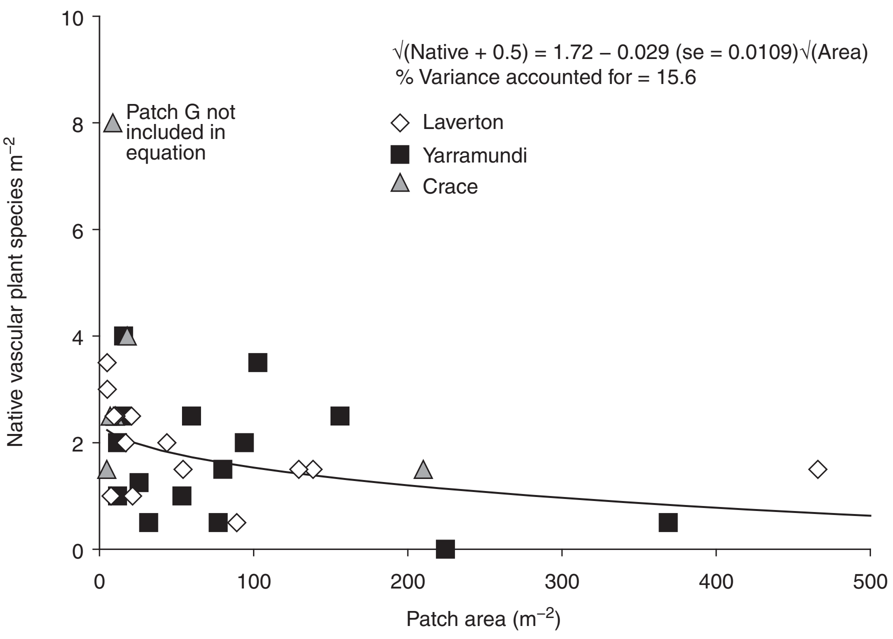

Figure 4. Effect of *N. neesiana* patch size on the number of native vascular plant species m^{-2} at three grasslands. The curve represents the derived relationship.

about two thirds in patches dominated by *N. neesiana* in comparison to areas dominated by native grasses, but that loss of native grasses is more gradual as patch size increases. If larger patches are older than smaller, and this is probably the case with most, but perhaps not all patches, this suggests that *N. neesiana* has a continuing negative impact on native plant diversity once it has become established as the dominant grass.

Laverton North was by far the weediest grassland (Figure 3). Patches of *N. neesiana* were significantly more weedy than areas outside the patches only at Yarramundi Reach. When analysed in aggregate, the grasslands studied had a relatively uniform background of other weed species: invaded areas had similar weediness to uninvaded areas (Figure 5). No exotic plant species was significantly more frequent in quadrats inside patches than outside them.

Senescence dieback of T. triandra

The pin transect studies confirmed that in areas of senescent *T. triandra* the presence of *N. neesiana* increased as the proportion of dead to total *T. triandra* increased (Figure 6, Table 2). These findings corresponded with general qualitative observations of senescence processes and *N. neesiana* invasion in these grasslands. Senescence dieback occurred in mosaic patterns as well as broader areas. *N. neesiana* invasion shortly preceded or accompanied the death of *T. triandra* tussocks and also followed dieback, during and after the breakdown of dead tussocks. In some cases *Avena* spp., indicators of nutrient enrichment, were the first invaders around dead plants. Kangaroo grass senescence dieback is clearly a major cause of invasion.

Soil moisture depletion in spring

A sample transect is provided in Figure 7. All transects showed markedly lower surface soil moisture levels under *N. neesiana* than under *T. triandra* and the difference was highly significant (Table 3). This was the case whether the *T. triandra* was senescent or healthy and when both species were shortly mown, and appeared to be independent of microtopographic position, surface soil features and time of day. *N. neesiana* significantly depleted surface soil moisture in spring, often to very low levels, compared to the dominant native grass in the areas sampled.

Temporal change in infestation dimensions

Interpretation of aerial photos and associated studies on the ground indicate that changes in the areas of infestations is influenced by the health of surrounding grassland and the differing management and disturbance regimes at the sites. *N. neesiana* invasions tended to be slow, except

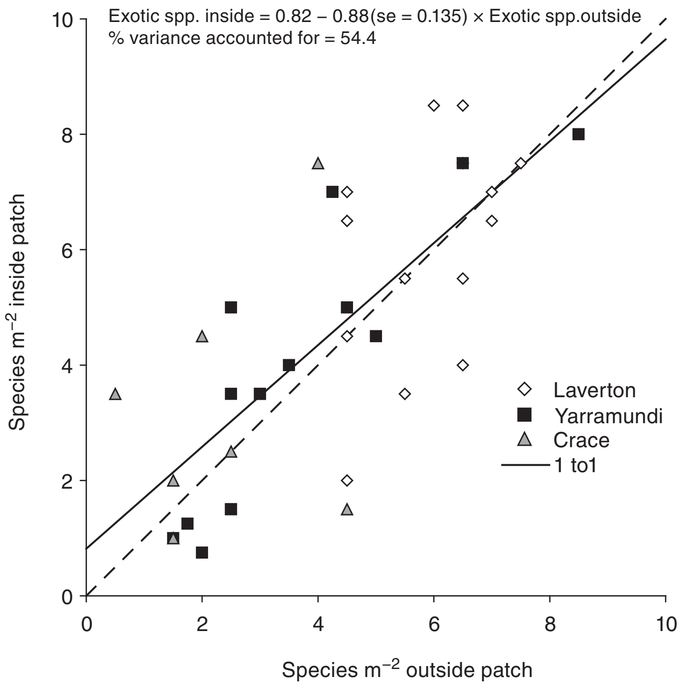

Figure 5. Exotic species m^{-2} inside vs. outside *N. neesiana* patches at three grasslands. Each point represents one patch and *N. neesiana* is not included in the counts. The derived relationship (solid line) is close to 1:1 (dotted line) indicating that exotic species, in aggregate, have a close to uniform distribution across the sites.

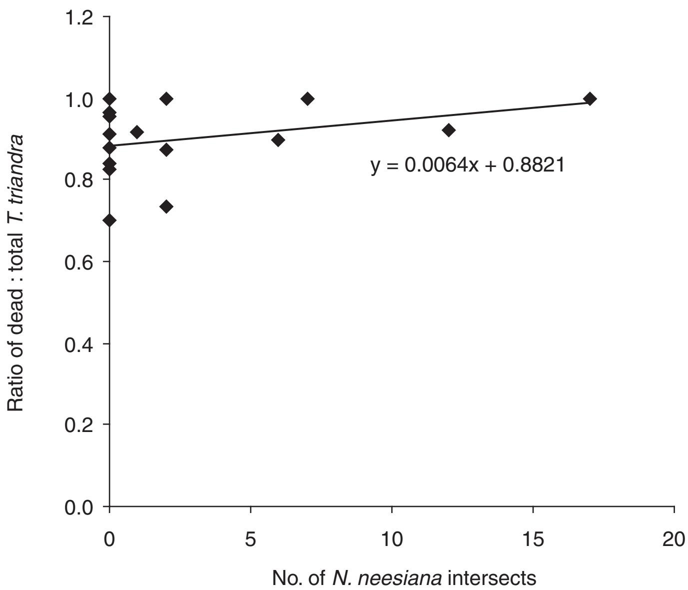

Figure 6. Relationship between the ratio of dead to total *T. triandra* pin intersects at a transect point and the number of *N. neesiana* pin intersects at that point, on a transect through senescent *T. triandra* at Yarramundi Reach, 13 October 2007. Increased *T. triandra* senescence corresponded with increased presence of *N. neesiana*.

Table 2. Summary of pin sampling in senescent *T. triandra* in ACT grasslands. The slopes were derived as shown in Figure 6. The P value for a two sided sign test that the slopes differed from 0 was 0.063. A P value <0.1 is significant evidence that *N. neesiana* presence becomes more likely as the proportion of live *T. triandra* decreases.

Site and transect	Slope of dead/ total *T. triandra* vs. *N. neesiana*
Yarramundi Reach G	0.0064
Yarramundi Reach 0884	0.0441
Yarramundi Reach 0885	0.0039
Dudley Street 0086	0.0014
Dudley Street 0087	0.0082

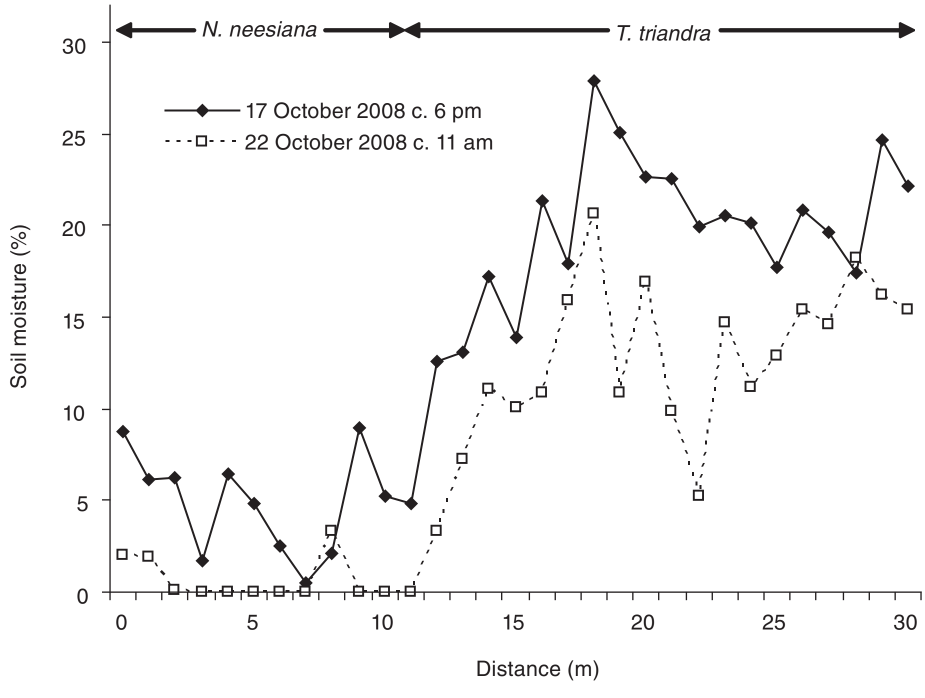

Figure 7. Near-surface soil moisture transect from an area dominated by *N. neesiana* into an area dominated by senescent *T. triandra*, Yarramundi Reach, ACT, 17 and 22 October 2008. The transition zone between the dominant species occurred at 11 m.

where the native grassland was in poor ecological condition (Table 4). Large scale senescence dieback of *T. triandra* at Yarramundi Reach reached a peak very recently and has been accompanied by alarmingly rapid expansion of *N. neesiana*. A patch at Crace was relatively stable under the regime of moderate to intense grazing.

Table 3. Significance testing of mean near-surface soil moisture (%) under *N. neesiana* and *T. triandra* along selected transects at Yarramundi Reach grassland, October 2008, excluding points where neither grass was clearly dominant.

	Log transformed mean	SE	F pr	Back transformed mean (%)
N. neesiana	0.424	0.0617	0.0017	2.65
T. triandra	1.093			12.39

Table 4. Selected estimates of changes in the area of *N. neesiana* infestations at four grasslands, derived from ground measurement (usually the 'final date' and 'final area') and interpretation of aerial photographs ('initial date' and 'initial area' and sometimes final area and date).

Site	Area	Comparison	Initial date	Final date	Initial area	Final area	Rate of change (% year)
Dudley St.	central area	photos	31/3/01	21/1/05	19.6 ha	26.2 ha	+7
Dudley St.	patch	photo/ground	31/3/01	14/10/07	462 m^2	674 m^2	+7
Yarramundi	patches	photo/ground	21/1/05	5/07 or 10/08	8–160 m^2	12–369 m^2	+12 to +112
Crace	patch	photos	22/12/02	31/3/08	554 m^2	599 m^2	+2
Laverton North	patches	photo/ground	24/1/06	9/5/09	24–72 m^2	22–100 m^2	−2 to +15

A large expanding infestation measured on the ground at Dudley Street was found to have encircled a patch of *T. triandra* which gradually decreased in size and disappeared, probably aided by infrequent mowing, prescribed for management of the *N. neesiana*. Expansion rates over four years of 5–7.5 m y^{-1} were estimated along roadsides at Dudley Street subject to frequent mowing. This relatively rapid spread is likely to have been the result of both increased dispersal of *N. neesiana* seed by the mowing equipment and of differential negative effects of repeated close cutting on the native grasses. Within the grassland proper, expansion rates were estimated to range from 0 to 8.7 m y^{-1} over the same period, with values near zero where infestations abutted *T. triandra* grassland in good condition, and high values in mown zones and where the *T. triandra* was senescent.

Interpretation of historical photos of Laverton North grassland was complicated by the presence of discrete patches of *Austrostipa* spp. that were indistinguishable from patches of *N. neesiana*. Ground inspections indicated that some *N. neesiana* patches were fringed on one or more sides by bands of *Austrostipa*. Air photo interpretation was more difficult because of the more diffuse edges of the patches and their higher content of native grasses than the Canberra grasslands. Nevertheless many *N. neesiana* patches delineated on the ground could clearly be correlated with major historical disturbances including earthmoving, the installation of an oxygen pipeline, regular mowing, and livestock tracks, although other patches could not be correlated with such damage. The size of some patches was estimated to have reduced under the regime of regular burning. Overall the management regime of regular burning appears to have resulted in relatively stable infestations and may have favoured partial recolonisation by native grasses.

Discussion

The primary juvenile period of *N. neesiana* was previously considered unknown (Benson and McDougall 2005) or had been poorly documented. Observations from the field experiment confirm that plants can produce viable seed when less than one year old.

Disturbance enables invasion and intact grassland resists invasion

The disturbance experiment clearly demonstrated that death of the dominant grasses enabled *N. neesiana* to establish, and that areas where the existing vegetation was left intact were resistant to invasion. Seedlings established strongly and juvenile plants prospered in the 'full kill' treatment, where gaps of about 1 m were created, but establishment was poor and very little biomass was produced in the smaller gaps of 'half kill' treatments.

Establishment was not significantly effected by addition of nutrients at rates similar to standard pasture applications, but was greatly reduced by reverse fertilisation. Applications of sugar and other C sources are known to stimulate the soil microbial population, which functions as a temporary nutrient sink, so sugar is effectively a nutrient immobilisation treatment (Reever Morghan and Seastedt 1999). It appears that invasion was facilitated by a nutrient pulse unavailable without the 'kill' disturbance, with the nutrients originating from decay of biomass of the killed vegetation. A similar nutrient effect was measured by Wijesuriya (1999), who quantified nutrient enrichment in experimental studies at Iramoo when soil was dug, homogenised and replaced. A large proportion of the nutrients mobilised are believed to originate from rapid decay of fine root matter. Nutrient increases and/or soil disturbances appear to be a critical cause of invasions by high biomass perennial exotic grasses in such grasslands (Morgan 1998).

However the mechanism by which sugar reduced seedling establishment in the experiment were not demonstrated. When applied at high rates, sugar itself, or the microbial biomass stimulated, might have a drying effect on the soil, but such a possibility seems to have been generally ignored in published studies (e.g. Blumenthal 2009). Observations of the pattern of plant establishment (mainly away from plot edges) suggested that competition for water may have been a critical determinant.

N fertilisation was found to have a negative effect on *Themeda triandra* productivity, reflecting its known poor competitive ability at increased soil nutrient levels (Groves *et al.* 2003). C_4 species are believed to be less favoured by N fertilisation than C_3 species because of their higher N use efficiencies (Wedin 1999) although a meta-analysis by Xia and Wan (2008) found no significant differences. The effect would indirectly favour *N. neesiana* and may be of wide importance in an environment subject to generalised N pollution and atmospheric N deposition (Clark and Tilman 2008, Xia and Wan 2008). *T. triandra* is supposedly adapted to a low N environment so is competitively disadvantaged when growing in competition with species that respond to N enrichment (Garden *et al.* 2003, Prober and Lunt 2009).

The precise mechanisms causing the effects were inadequately examined in this experiment and caution should be applied in extending the findings to other grasslands.

Invaded areas have reduced native plant diversity

The three grasslands in which plant diversity was examined have been subject to different sets of disturbances and management regimes operating over widely different time periods, and it is likely that unique biodiversity effects at each site are confounded in the analyses. Nevertheless, in aggregate, areas occupied by *N. neesiana* were found to have markedly reduced native plant diversity. This would be expected if the areas occupied had been substantially disturbed, for example by *T. triandra* senescence, before they were invaded. But higher species densities of other weed species would also be expected, since many other exotic species generally invade grasslands after major disturbance. Increased species richness of exotics within *N. neesiana* patches was detected only at one site (Yarramundi Reach), where the patches were mainly the recent result of senescence dieback of kangaroo grass. *N. neesiana* is probably amongst the most recent exotic invaders of all three grasslands, and the older resident exotics have had longer periods to disperse widely and evenly throughout the sites. Allelopathy is one conceivable mechanism that might explain a more negative impact of *N. neesiana* on one group of plants (natives) than on another (exotics). But there is no good reason to believe that a set of exotic species that has not evolved in the presence of *N. neesiana* and is assembled from a number of different continents should be better adapted to allelopathic effects than the set of native species.

The reduction of native plant diversity as patch size increases indicates a time dependent mechanism of impact, since there is evidence from aerial photographs that at least some larger patches are older than small patches. Resource competition acting over periods of years seems to be a likely explanation, and competition for soil water is one probable contributing factor. Allelopathic effects of *N. neesiana*, if they exist, could also be expected to impact over longer periods, however no direct evidence of allelopathy was detected in this study.

Major reductions in plant biodiversity are associated with *N. neesiana* invasion but in many cases are probably largely or partly a result of prior degradation e.g. the death of native grasses due to senescence, overgrazing and soil disturbance. Major biodiversity loss appears to precede invasion. However, once established, the presence of *N. neesiana* has ongoing negative impact that leads to gradual disappearances of additional native species from the areas invaded. Phenological displacement of the summer growing dominant *T. triandra* mediated through soil moisture levels may be a major mechanism of ongoing losses.

Invasion accompanies T. triandra *senescence*

The confirmation that *N. neesiana* ingress accompanies *T. triandra* senescence comes as no surprise. More than ten years have passed since Lunt and Morgan (1998 p.72) discovered that healthy *T. triandra* grassland resists *N. neesiana* invasion and that 'the most cost-effective method of slowing invasion… is likely to be by maintaining a healthy sward of Kangaroo Grass'. What is surprising is that high quality examples of such biodiversity rich grassland in public ownership have been allowed to senesce and degenerate in the intervening period.

Themeda triandra senescence occurs as a 'natural' process when biomass reduction (by fire or grazing) fails to occur over periods greater than about five years. Biomass accumulation by *T. triandra* is accompanied by rapid or gradual suppression of the native plants that occupy the intertussock spaces and comprise the plant biodiversity of value. Since the native flora consists largely of species with small, short-lived soil seed banks, these species disappear from affected areas relatively rapidly (Morgan and Lunt 1999). By the time senescence dieback occurs much of the flora has been lost and attempts at amelioration by burning lead only to invasion by weeds that have longer-lived seed banks and are better adapted to colonise the damaged areas (Morgan and Lunt 1999).

Soil water depletion in spring – a mechanism of impact

Not all *N. neesiana* invasions are the consequence of senescence dieback of *T. triandra*. Even when they are, a proportion of the native flora appears able to survive in or recolonise the invaded patches. Soil water depletion in spring may be one mechanism by which *N. neesiana* causes ongoing losses of these native species after it has occupied an area. Soil drying during a period when a high proportion of the native plants are growing and flowering must have negative impact upon their growth and fecundity. The later growing *T. triandra* will also be disadvantaged by drier soils, creating a positive feedback cycle for *N. neesiana* that may help propel invasion outward from infestation edges.

At a landscape scale the widespread replacement of summer growing native grasses by cool season exotic grasses for agriculture has been implicated in declines in runoff and stream flow, and increased deep drainage (recharge) (Dunin 1999, Johnston *et al.* 1999, Johnston *et al.* 2003). These changes have greatly contributed to dryland salinity across large areas by raising water tables and mobilising salts stored in the subsoil (Johnston *et al.* 1999, Singh *et al.* 2003, Reseigh *et al.* 2008). Absence of summer growing grasses also limits the use of nitrogen mineralised from organic matter (nitrate and ammonium) in summer, enhancing its leaching in autumn, increasing rates of soil acidification (Johnston *et al.* 1999), and presumably of eutrophication at lower elevations in the catchment. Such changes may be exacerbated if *N. neesiana* replaces *T. triandra* across large areas in native grasslands. *N. neesiana* populations may therefore impact on biodiversity far beyond the areas immediately invaded.

Rapid expansion rates when management is deficient

The aerial photographs and ground truthing indicated that patch expansion is minimal where infestations are bounded by native grassland in good condition. Where infestations abut areas of senescent *T. triandra*, linear expansion rates of >5 m per year may be expected and in areas that are frequently close-mown may be even faster. Where native grasslands are kept healthy by biomass reduction, *N. neesiana* and associated losses of plant biodiversity are kept low.

Conclusions

At the patch scale, *N. neesiana* has major negative impacts on the diversity of flora in Australian temperate grasslands. The effect occurs in grasslands with very different histories and management regimes. The areas assessed were moderate or low quality remnants: more severe impacts can be anticipated where invasions occur in more-species rich grasslands. The larger the area of an *N. neesiana* patch the greater the negative impact. Replacement of a dominant native grass (*T. triandra*) that is phenologically complementary to a large proportion of the native flora is probably a major reason for the severe effects. Displacement of native grasses by *N. neesiana* has complex ecological effects that contribute to landscape-scale environmental deterioration.

Major losses of native plant diversity in areas occupied by *N. neesiana* have probably often preceded its invasion and have been caused by other degrading processes, such as *T. triandra* dieback, overgrazing and major soil disturbance. Studies of areas affected by installation of an oxygen pipeline at Laverton North Grassland, not reported here, indicate that invasion does not necessarily result from severe disturbance, but requires propagule pressure in close proximity. In areas with propagule pressure, increased senescence of *Themeda triandra* swards is accompanied by invasion.

In terms of integrated management of *N. neesiana* in the longer term, the investigations suggest a number of research possibilities that may repay further investigation. The use of C amendments such as sugar may have potential to differentially suppress *N. neesiana* establishment. The ecohydrological effects of perennial grass weeds deserve further study.

The negative impacts of *N. neesiana* can be reduced by grassland management that enables biotic resistance by the native flora, prevents *T. triandra* senescence dieback and restricts soil disturbance and the creation of bare ground by removal of native grasses.

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Otways Eden: collaborative weed management to protect biodiversity assets: an approach in the Department of Sustainability and Environment

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Summary

The Otways Eden Project began in 2004 as part of the Victorian Government's Weeds and Pests on Public Land Initiative. The Otways Eden Project is an example of a landscape scale, priority-asset based approach to decision-making and action. The approach identifies (biodiversity) asset areas and focuses on their protection by tackling new and emerging weeds while they can be eradicated within the project area, and strategically tackling established weeds to protect the high biodiversity assets at risk. Pathways are also investigated and managed.

Biodiversity values were assessed across 140 000 hectares of public land in the Otways, which identified five priority biodiversity asset areas for management. Weeds in the project area were classified in a weed risk assessment, which identified new and emergent, high impact weeds to be prioritised for eradication first. A weed database (eWeed) with mapping capability is used by Parks Victoria and DSE to record high risk weed locations and program treatments. Partnerships between Parks Victoria, DSE, local government, voluntary committees of management and other groups is delivering a successful tenure blind approach across public land.

Introduction

Environmental weeds pose one of the major threats to native biodiversity and this has been formally recognised with the listing of 'The invasion of native vegetation by environmental weeds' as a potentially threatening process under the *Flora and Fauna Guarantee Act 1988* (DSE 2007). The challenge is to protect Victoria's assets against both the significant potential for new introductions of pest plant species whilst also maintaining the effort against those that have become established. To achieve this, public and private land managers must work together, across land tenures, to achieve an integrated outcome that maximises environmental, social and economic benefits.

The Victorian Government currently supports the Weeds and Pests Initiative (WPI) – a four-year program to tackle weed threats on private and public land. The Department of Sustainability and Environment (DSE) and Parks Victoria (PV) manage a number of landscape scale projects under this Initiative for biodiversity outcomes on public land.

The approach

Otways Eden started as a pilot project for implementing the 'Guidelines and procedures for managing the environmental impacts of weeds on public land in Victoria 2007' (DSE). The project's focus was to develop a landscape level approach for managing the environmental impacts of weeds on public land. The project developed a uniform set of principles and priorities to support decision-making across various public land tenures. This is documented in the 'Local area planning for managing the environmental impacts of weeds on public land in Victoria, Otways Weeds Case Study 2008' (DSE). Part of the decision making framework includes eradicating new and emerging weeds before they become widely established, protecting important asset areas and finding opportunities for community involvement.

How this was applied

Program logic

A program logic developed by the working group identifies the following outcomes:

- A monitoring system is implemented to provide the data for reporting and evaluation;
- The Eden's are a long term program that enhance the opportunity for environmental, social and economic gain;
- All NRM agencies participate in planning, governance and reporting ensuring that the outcomes of the project become property of them all;
- There are improved biodiversity outcomes as a result of applying the framework;
- Agencies are able to tackle weeds because they have the appropriate culture, resource and knowledge;
- There is increased community / stakeholder awareness of environmental weeds and their impacts, and this leads to an increase in community action in partnership with the government; and
- An integrated approach to weed management addresses causes and sources through improved knowledge of weed invasion.

The program logic provided the basis for agreed objectives and flowed down to activities to be delivered across the project area.

Landscape scale

The Otways Eden project area covers approximately 140 000 hectares, from Torquay to Port Campbell along the coast and inland towards Colac. It covers all types of public land, including the Great Otway National Park, Otway Forest Park and coastal reserves. The project area was chosen as a suitable landscape scale unit with high biodiversity significance under the management of a group of land managers that are able to physically meet on a regular basis to coordinate their activities. The project area has proved to be of a practical size for coordinating activities between the key public land managers, PV and DSE.

Biodiversity values

Biodiversity asset modelling was undertaken within the Otway region using spatial data to create a map reflecting biodiversity values ranked from highest to lowest conservation significance. The range of spatial data layers used includes Ecological Vegetation Class (EVC) Conservation Status, threatened flora data, threatened fauna habitat, landscape fragmentation and expert opinion. As a result, five important biodiversity asset areas were identified including – Bald Hills, Carlisle River, Carpendeit, Port Campbell and Cape Otway. These biodiversity asset areas are a priority for protection against the impacts of established weeds, starting with the weeds posing the highest risk.

Weed information

More than 250 non-indigenous or weed species are recorded across the Otways Eden project area. These species include established weeds such as blackberry (*Rubus fruticosus*) as well as new and emerging weeds such as bronzy hakea (*Hakea elliptica*) and bluebell creeper (*Billardiera heterophylla* formerly known as *Sollya heterophylla*). Sources of known occurrences were identified using existing databases, staff records and documents. Valuable weed data was also obtained from the community including local friends groups and individuals. Rapid surveys were also undertaken in the vicinity of priority biodiversity asset areas to supplement and verify weed occurrences and distribution. It is important to ensure accuracy with the weed data so the records can be used for large-scale mapping as part of decision making.

Weed risk assessment

The weeds in the study area were put through a weed risk assessment to determine the priority for control of known weeds. Weed records were ranked from high impact to least concern by a panel of experts according to their potential risk to biodiversity assets. Criteria to determine impact included invasiveness, ecological impact, current distribution, the range of EVC's susceptible to invasion, and rate of dispersal. This produced five categories of weeds – High Impact Weeds, Weeds of Importance, Weeds of Concern, Minor Weeds and Weeds of Least Significance. High Impact Weeds include 58 species of weeds that are targeted as the first priority for control in asset areas. High Impact Weeds include bridal creeper (*Asparagus myrsinoides*), bluebell creeper (*Billardiera heterophylla*), English ivy (*Hedera helix*) and sweet pittosporum (*Pittosporum undulatum*) which rate toward the top of the list for the Otways project area.

High Impact Weeds were mapped across the project area drawing on spatial data sets of known occurrences which were confirmed from field survey. Rapid assessments provided significant supplementary information and locations were recorded using GPS. This provided data sets of all locations of established weeds in the asset areas. A priority work plan for managing the new and emerging weeds and highest priority established weeds was developed. Pathways of introduction were also considered in works plans, these include roads and areas of past disturbance. Existing weed data is now supplemented by field data obtained by PV and DSE staff and recorded into the web-based 'eWeed' database as part of ongoing works. The 'eWeed' database with spatial capability, records weed infestations, management activities and weed management outcomes.

Stakeholders and engagement

A communications plan was prepared with the key project officers and Michelle Aitken, Community Engagement Officer, DSE. The communications plan provides direction and targets towards strategic and purposeful engagement. An output of the plan is where a newsletter was developed and distributed to stakeholders to keep them up to date. Forums have also been organised to inform stakeholders.

Voluntary Committees of Management and community groups such as ANGAIR (Anglesea, Aireys Inlet Society for the Protection of Flora and Fauna) have been actively engaged and follow the Eden model in their volunteer work. Community groups and volunteers provide vital surveillance for new weed locations in the reserves they monitor. Numerous new and emerging weeds have been removed as well as control of high impact weeds in asset areas as part of the valuable volunteer activity.

Results

Surveillance has identified 223 new infestations in the project area. These have been recorded into the eWeed database and are programmed for treatment.

During 2008/2009, 720 weed infestations were treated in the project area that includes the Great Otway National Park, Otway Forest Park and other nearby or adjacent reserves. (Infestations ranged from 1–100 ha).

Of these treatments, 533 or 74% were applied to new and emerging weed species (highest priority according to the guidelines) (Table 1). The remaining 26% of treatments were applied to established species expanding their range within biodiversity asset areas (Table 2).

Follow up is undertaken at infestation sites to ensure the treatment has been effective and to program further treatments if required. Four monitoring projects are in place, two following PV protocols and two following DPI monitoring protocols for biodiversity monitoring. These aim to provide data toward the effectiveness of the program. Program evaluation will be undertaken to assess how the Otways Eden is tracking against its program logic and provides an opportunity for fine tuning if required.

Conclusion

The Otways Eden has been going for six years now, and is a great example of how to apply the Biosecurity Approach to weed management. The Otways Eden project has successfully prevented new weed problems across the project area and significantly reduced the impact of established weeds on the five key biodiversity asset areas. The project has provided a great example of how to use the Guidelines, a consistent approach to managing weeds whilst increasing public awareness. The partnership approach continues to create a strong sense of ownership and community support to improve the Otways. Establishing a central database (eWeed) made the planning of operational works and the identification of risks easier to coordinate between agencies and across the project area.

Effective working partnerships were developed using a 'tenure blind' approach. This involved PV and DSE leading the way with support from local government and community groups such as ANGAIR and the Friends of Eastern Otways. Having a single cross-agency project manager appointed (currently Kate McMahon, Parks Victoria Natural Values Ranger) enables strong coordination of working group meetings and leadership on the delivery of the project. The project increased community awareness about the impact of weeds and gave people the knowledge and skills to minimise weed damage.

Acknowledgments

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Table 2. The most commonly treated established weed species in asset areas during 2008/2009

Blackberry	*Rubus fruticosus*
Coast tea-tree	*Leptospermum laevigatum*
Long-leaf wattle	*Acacia longifolia*
Pine sp.	*Pinus* sp.
Willow	*Salix* sp.

Table 1. The most commonly treated new and emerging weed species during 2008/2009.

Asparagus fern	*Asparagus scandens*
Boneseed	*Chrysanthemoides monilifera* subsp. *monilifera*
Bluebell creeper	*Billardiera heterophylla*
Bridal creeper	*Asparagus myrsinoides*
Bulbil watsonia	*Watsonia meriana* var. *bulbillifera*
Himalayan honeysuckle	*Leycesteria formosa*
Spanish heath	*Erica lusitanica*
Sweet pittosporum	*Pittosporum undulatum*
Wandering tradescantia	*Tradescantia fluminensis*

Involving industry in managing weeds – processes and challenges

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Abstract

The introduction and spread of invasive plants by the core business activities of many commercial enterprises has the potential to significantly impact on Australian agriculture and the environment. As part of the Victorian Government's $30.1 million Weeds and Pests Initiative (WPI), the Department of Primary Industries (DPI) is engaging with key commercial enterprises, peak bodies and relevant agencies through the Industry Engagement in Prevention (IEP) Project.

The IEP project is working closely with key sectors of the Agricultural Seed, Fodder, Aquatic Trade, Civil Earthmoving and Landscape industries. The project is working in partnership with stakeholders in each of these industry groups to help them build a greater understanding of their roles and responsibilities for invasive plant management, and further enhance their capacity to utilise this information. In particular, information disseminated comprises of strategic invasive plant management, the risks surrounding weed spread, and roles and responsibilities.

The initial stage of engagement has involved researching, identifying, and consulting with key industry groups to determine relationships, communication and information networks, their level of understanding and knowledge of pest management, and opportunities for future collaboration. It is envisaged that the outcomes from this stage will guide future activities and allow for effective evaluation at the completion of the project. DPI anticipates that the insights, barriers and opportunities identified for each of these industries will enhance and influence future strategic directions in invasive plant management.

Keywords: partnership, collaborate, capacity, biosecurity, introduction pathways, industry grants, WEEDSTOP, invasive plants, weeds, industry.

Introduction

Industry can play an integral part in preventing the introduction and spread of weeds within Victoria. Industry also has a key responsibility in being aware of the threat of pests and weeds poses to Victoria. Invasive plants and animals are projected to cost the Victorian Government and community in excess of $1 billion per year with considerable negative impacts on the economic, environmental and social aspects of Victoria's natural and agricultural assets.

The value of partnership projects between industry and government targeting prevention of spread of pest plants, and eradication of high risk species has previously been demonstrated through the success of the Tackling Weeds on Private Land Initiative (TWoPL) (Anderson *et al.* 2007b).

As part of the Victorian Government's four year $30.1 million Weeds and Pests Initiative (WPI) launched in 2007, the Industry Engagement in Prevention project aims to expand and build on the successful partnership approach and working relationships developed under the TWoPL Initiative. The IEP project aims to increase the level of awareness and acceptance of responsibility for weed prevention roles as part of cores business practices within commercial enterprises, peak bodies and key agencies. Development of partnerships between industry and DPI, and between affiliated industry groups is a positive tool for information distribution on weed management across Victoria.

The IEP project aims to work with five key industry areas, being the Aquatic Trade (aquatic trade and water garden industry), Agricultural Seed (crop and pasture), Fodder (hay and grain), Landscape (educators, constructors, designers and suppliers) and Civil Earthmoving industries. These five industry groups have been prioritised for engagement by IEP staff through the completion of scoping research. This research builds on previously completed and continuing engagement with linear reserve managers such as VicRoads and rail companies, as well as Local Government, and the Nursery and Garden industry. Working with the five industry areas as part of the IEP project will ideally build stronger networks for information flow and increase project collaboration between and within industry groups.

Selection of the five key industries of focus were chosen through a number of criteria, such as utilising information on key industries identified by the Weed Spread Pathway Risk Assessment – Stage Two report (Thomas *et al.* 2007), identifying service delivery gaps, and developing a list of potential industry groups for further analysis.

Biosecurity

On the 3rd June 2009 the Brumby government officially launched the Biosecurity Strategy for Victoria. The focus of the strategy is to protect Victorian agricultural, environmental and social aspects such as human health from the impacts of biosecurity threats. These threats include invasive plants and animals, plant pests and diseases, and animal diseases and pests, such as those transmitted between animals and humans (DPI 2009).

Biosecurity has been defined as the '… protection of the economy, the environment, social amenity or human health from the negative impacts associated with the entry, establishment or spread of animal or plant pests and diseases, or invasive plant and animal species' (DPI 2009).

IEP is one of a number of projects under the WPI initiative which aims to enhance the management of invasive plants and animals within Victoria. The focus on prevention of spread, intervention and improved surveillance set by the Initiative aligns closely with the government's biosecurity approach.

Materials and methods

The prioritisation of biosecurity actions and activities are represented by a risk management approach, denoted by the Invasion Curve (Figure 1).The Invasion Curve highlights the costs and benefits of various stages of intervention for invasive plant management and demonstrates the areas of greatest return on investment. Prevention and early intervention activities for plant species are compared with containment and asset based protection. Prevention of species establishment is deemed the greatest return on resources, eradicating plant infestations before they are widely established. The containment and asset based approach are applied to invasive species that are already prevalent in the environment, where eradication is no longer feasible, and where preventing their further spread is a more effective use of resources (DPI 2009).

IEP key messages

Partnerships with industry, DPI and the community, enhancing surveillance of

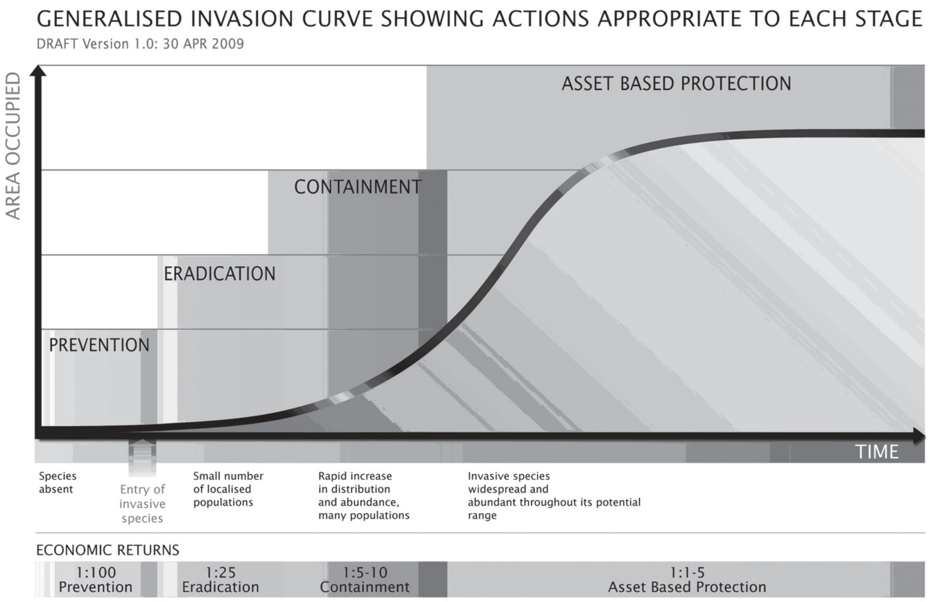

Figure 1. Invasion Curve identifying cost benefits for early intervention and prevention strategies.

invasive plant species with adequate systems and responding to new incursions through the building of networks within organisations are key themes identified within the Biosecurity Strategy for Victoria. IEP, through its project activities, aims to provide industry with information to increase their capacity and build their confidence to more effectively manage pests through an ongoing business approach.

The engagement techniques and clear messages of IEP focus on introductory pathways, modes of spread, hygiene practices and best practice solutions. Engagement with industry is important to build the capacity and confidence of organisations to achieve sustainable integrated pest management practices. Through on ground weed management activities, understanding of roles and responsibilities, improved networks, strategic organisation awareness, changes to business practices, and cultural change, effective pest management can be realised.

Core business activities of industry can contribute to the introduction and spread of invasive plants, including high risk State prohibited weed and Regionally prohibited weed species The IEP project aims to further increase the level of industry awareness and acceptance of biosecurity principles, to take responsibility for the prevention of weed spread and management of pests on land for which they are responsible.

Industry can provide significant benefit to the broader community and be a major factor in reducing the introduction and spread of pests within Victoria, which in turn benefits Victorian business and social and environmental amenities. Recognition of responsibility for invasive plant management and co-development of solutions for spread pathway control strategies within an organisation and across an industry sector can benefit business while acting in accordance with responsibilities under the *Catchment and Land Protection Act 1944* (CaLP). Co-funded research is also establishing working relationships that can foster ongoing practice change for weed management and prevention.

Key messages for each industry group were developed using the AAA Continuum. This allowed for discrete engagement with industry groups who are at different stages for each of Awareness, Acceptance and Acting. Each stage is a progression along a continuum which describes the groups understanding and/or action in relation to weed management. The continuum provides for a system of targeted engagement with each industry group, and provides a way to measure the success of engagement practices (Anderson *et al.* 2007a).

Scoping processes

Industry research and analysis processes enabled the development of effective engagement strategies with key industry stakeholders. These processes aim to understand the industry's structure and the relationships between key stakeholders. Valuable industry insights are recorded including the drivers, barriers and motivators of stakeholders when participating with DPI. A network map of each industry was then developed to provide important information on how an industry operates.

An initial desktop and internet search was completed to ascertain key industry organisations, groups and companies. This allowed for the development of a list of industry and peak body contacts. Semi-structured interviews have been conducted with these contacts which address a series of survey questions. Interviews have been undertaken in person when possible, but the majority were conducted over the phone. These specific survey questions are developed to address broad overarching research questions. These research questions contribute to the development of engagement strategies and add to the body of knowledge relating to the relative risk of industry spreading weeds.

Results

Understanding stakeholder attitudes

Agency representatives have been contacted to discuss their knowledge of the industry including key contacts and existing networks, as well as opportunities, gaps, barriers and future plans. Survey questions have been developed to ascertain the industry's understanding and interest in weed management and prevention and the degree of influence and networking within the industry.

Network mapping

Interview results have been applied to the development of network maps which include relationship links. Figure 2 provides an example of a network map. The more detailed version of this map includes the names of industry bodies and indicates two-way relationships between industry bodies and the direction of communication.

Scoping report

The final scoping report presented tables of preferred contact methods for key stakeholders, their degree of influence, their networks and degree of interest. Communication opportunities were identified and listed within the report. The inclusion of 'insights', 'observations' and 'identified gaps' assisted the IEP project to better identify the potential importance of involving particular stakeholder groups in DPI programs, projects and strategies. Recommendations for future engagement with each industry were highlighted in the report. It is anticipated that these recommendations will have an impact on future strategic directions in invasive plant management.

Engagement plan

An Engagement Plan has been developed for each industry, which is built around drivers and pathways for adoption identified in the analysis. The plan outlines engagement objectives, the behaviour change sought and the needs of the stakeholder for effective uptake of messages. Stakeholder engagement considers the focus of the interaction, the expected level of participation and the most appropriate and effective method/s available. The Engagement Plan is a working document

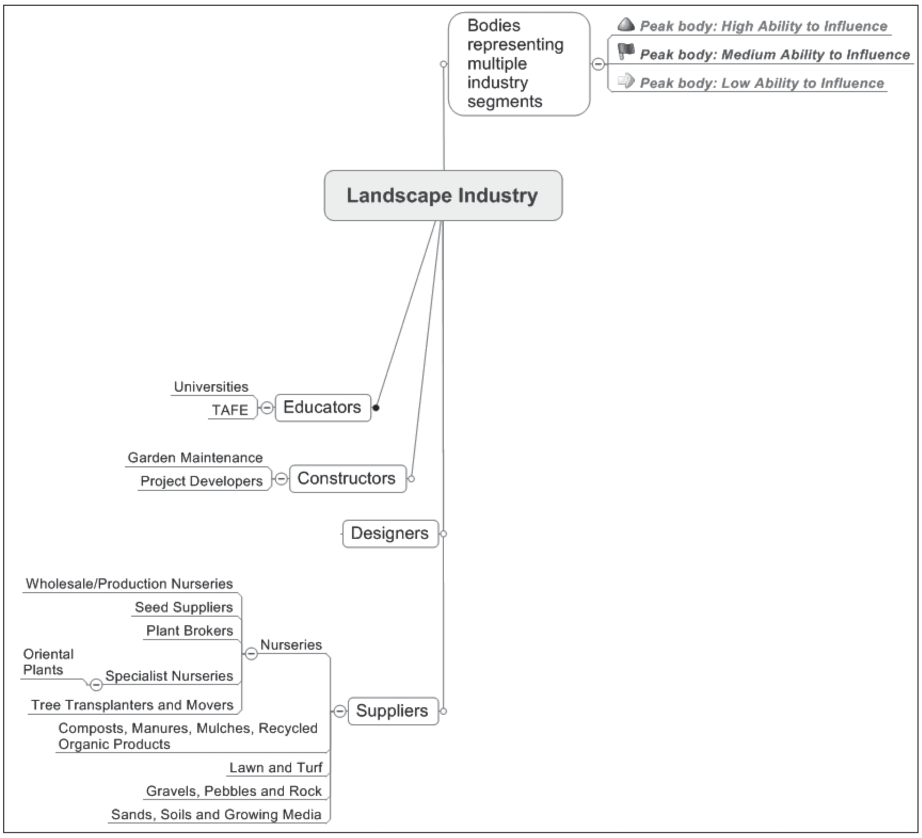

Figure 2. An example of a network map.

and reflects the changes in engagement approaches as the IEP project progresses.

Discussion

Benefits of internal research

For the first time, the DPI performed scoping research internally rather than outsourcing the work to a consulting company. The research involved scoping business networks and operational aspects for the Agricultural Seed, Fodder, Landscape and Civil Earthmoving industries. This enabled partnerships to be established from the early stages of the project. An advantage of performing research internally is that additional information can be captured, including the tone of conversations and other relevant comments (Conley-Tyler 2005). These aspects in the past have not been included in the research report completed by external consultancies.

As a result of completing the industry analysis internally, partnerships officers gained a first hand understanding of the industry's networks and perceptions of weed issues. The partnerships that were already developed during the scoping phase enabled more progressive relationship building during the engagement phase.

Outsourcing scoping processes

Scoping and analysis were carried out externally for the Aquatic Trade and Water Garden industry. Outsourcing this research involved considerable collaboration with DPI staff. Time consuming processes included the selection of a suitable consultant and meetings with the chosen consulting company to identify the scope, the confirmation of timelines, cost and providing information and agreement about preferred layout of the report. DPI was responsible for the management of all aspects of the project during the research, analysis and report draft phases.

At the completion of the externally produced scoping report, DPI partnerships officers studied the research results and commenced engagement with the industries. Without the first hand knowledge that is gained from performing the research internally, more time was needed to ensure the most appropriate engagement approach with key stakeholders was chosen.

Measuring performance

Evaluation for the IEP project measures whether the project has met its objectives, and identifies benefits of engagement with each industry and within industry networks. It also records the development of learnings about how the project was delivered that can be transferred to future programs. At the commencement of the IEP project, key evaluation questions were developed that were to guide all evaluation for the project.

The Aware, Accept, Act (AAA) Continuum is a process that has been adapted from previous research (Anderson *et al.* 2007a) and has been modified for use for each industry. The survey questions asked as part of the semi-structured interviews during the scoping process provided an indication of where stakeholders were placed on the Continuum. These questions were designed so that they could be asked throughout the IEP project to measure shifts in attitudes and actions. This assesses the extent to which the project has achieved its outcomes of building the capacity of targeted industries to manage invasive pests more effectively.

The IEP project also has a Systems Plan designed to identify the project's Monitoring, Evaluation and Reporting data capture and management requirements. It ensures that the required data is captured to demonstrate project success/impact throughout the life of the project. The IEP project Systems Plan also forms a part of the DPI Landscape Protection reporting and information capture environments.

As part of IEP, a component to the delivery of the project is the Weed Industry Grant Program. The program aims to support initiatives by industry that focus on strategic weed management approaches that align with key aims of codes of practice, engagement and information dissemination on legislation and weed management principles, education on high risk weed species, plant and vehicle hygiene and business decisions that encourage enhanced weed management. Grant reports provide supporting evidence by monitoring the progress of IEP funded grants. Industry is expected to complete a grant progress report six months after commencement and a completion report which enables continual improvement of the IEP project.

The Australian Agricultural Contractors Association Incorporated (AACAInc) are currently engaged with the IEP project for the development and training of a representative to be authorised to deliver WeedStop training to its members. A nominated member of AACAInc has undergone a Certificate IV in Workplace Training to become an accredited presenter to deliver the training package at the same level of previously presented sessions. Training and ongoing technical support from DPI will see the AACAInc trainer being fully prepared to deliver the nationally accredited course, with a certificate in modules: 'RTD2312A: Inspect Machinery for Plant, Animal and Soil Material' and 'RTD2313A: Clean Machinery of Plant, Animal and Soil Material' being achieved through the program.

The undertaking of the Certificate IV training and the ability of AACAInc to more widely deliver the relevant content to broader industry networks is a positive collaboration effort between DPI and AACA that initially commenced under the

TWoPL project. It provides AACA with the improved skills to enable the WeedStop program to be more efficiently delivered to the Fodder industry. It further enhances the Fodder Industries knowledge of invasive species, legislative responsibilities, machinery and vehicle hygiene as well as gaining national accreditation to enhance the reputation of individual businesses and the broader industry as additionally accredited service providers.

VicRoads within the Gippsland region is also currently working with the DPI under the Industry Weed Grant program to develop training workshops within the Eastern Region working area. The workshops utilise DPI's WeedStop program, with sessions tailored to enhance the ability of VicRoads staff and contractors to identify weeds, undertake machinery hygiene and increase the understanding of responsibilities under the CaLP Act 1994. This project, along with the AACAInc, project, aligns closely with the Government's Biosecurity approach to pest management, and prevention and early intervention as means of managing invasive species. The project offers an opportunity to VicRoads and stakeholders to enhance working practices while building positive stakeholder and customer working relationships.

Gaining valuable feedback from each of the Industry Weed Grant projects through mid-term and post-project reporting and qualitative feedback is seen an effective way to assess the success of the grant projects, and active collaboration within industry sectors. Feedback from the participating project stakeholders is seen as valuable information for guiding future activities within the project while also measuring the positive broader impact within the industry.

Challenges

Scoping research and engagement plans produced for each industry inform the IEP project on the most effective activities for engagement. Information dissemination through networks and contacts has been researched, but are subject to constraints imposed on businesses and industry markets. A flexible approach is required to recognise limitations placed around businesses, peak bodies and organisations from external factors. Understanding the limitations imposed on industry groups including financial constraints, limited time for additional projects or development, limited members to peak bodies or limited active members to industry groups and pre-existing inter industry relationships are examples of extenuating factors influencing IEP and industry activities.

Drivers for change within industry groups and businesses present additional complications for engagement activities, communication and information exchange. Factors affecting the interest and perceived need for additional information on invasive plant management and prevention within individual businesses and groups may impact upon the success of IEP engagement. The relevance of industry roles and responsibilities for stakeholders and benefits of strategic invasive plant and animal management to their business are important elements for communication. Highlighting advantages of best practice models including codes of practice, machinery hygiene and collaborative projects within industry networks may emphasise potential benefits to individual business success and consequently improve industry participation.

Conclusion

As the IEP project continues to work with key industry stakeholders and develop engagement and evaluation practices based on qualitative and quantitative feedback, the project and its development of partnerships within each of the five areas of focus is expected to increase. Feedback from the participants of the Industry Weed Grant Program will help direct future engagement activities and future grant projects.

The IEP project plans to continue building strategic weed management strategies with industry, focusing on awareness, prevention and eradication strategies for new and emerging weeds across Victoria. As the project progresses it will continue to build the capacity of industry to enhance business practices and knowledge on invasive plants, opportunities for positive partnerships and networking to ultimately benefit Victoria's ability to manage and respond to invasive plant incursions.

Acknowledgments

DPI would like to acknowledge AACAInc and VicRoads in allowing their projects to be used as case studies within this paper. IEP would like to thank all participating industries currently engaged in activities under the initiative including the Industry Weed Grant Program.

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One new active ingredient – two new products to control woody weeds in Australia

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Summary

Aminopyralid is a Group I herbicide similar to fluroxypyr, triclopyr and picloram with increased soil residuality. However, unlike picloram, it may be used safely around *Eucalyptus* spp. Between 2002 and 2007, Dow AgroSciences conducted trials with aminopyralid and tankmixes, for control of lantana (*Lantana camara*), fireweed (*Senecio madagascariensis*) and blackberry (*Rubus fruticosus*) in south-east Australia. This paper summarises the results of those trials.

In 2006, Hotshot™ herbicide (10 g a.e. L^{-1} aminopyralid + 140 g a.e. L^{-1} fluroxypyr) at 500 to 700 mL 100 L^{-1} water was registered for control of lantana, fireweed and associated weeds in agricultural non-crop areas. Hotshot provided more reliable control of lantana across trial sites compared to existing treatments. An update to the Hotshot label is expected in mid-2009 to include fireweed control by boom application.

Grazon™ Extra herbicide (8 g a.e. L^{-1} aminopyralid + 100 g a.e. L^{-1} picloram + 300 g a.e. L^{-1} triclopyr) was registered in 2007 and replaced Grazon™ DS for control of environmental and noxious woody and herbaceous weeds. In two of five trials conducted on 'hard-to-kill' blackberry, Grazon Extra provided more effective control than Grazon DS. Other weeds added to the Grazon Extra label include fireweed, spear thistle (*Cirsium vulgare*), capeweed (*Arctotheca calendula*) and Paterson's curse (*Echium plantagineum*).

Through development of new products like Hotshot and Grazon Extra, Dow AgroSciences continues to invest in research to improve the control of woody and noxious weeds in Australia.

Introduction

In the last decade Dow AgroSciences researched and developed aminopyralid which is a new pyridine herbicide with group I mode of action. It has been tested in cereal crops for improved control of broadleaf weeds and also in range and pasture situations for improved control of woody weeds.

Hotshot herbicide (10 g a.e. L^{-1} aminopyralid + 140 g a.e. L^{-1} fluroxypyr) was developed and commercialised for improved control of lantana in pasture situations as well as excellent control of fireweed.

Grazon Extra herbicide (8 g a.e. L^{-1} aminopyralid + 100 g a.e. L^{-1} picloram + 300 g a.e. L^{-1} triclopyr) was developed for improved control of blackberry. It also controls fireweed, thistles, capeweed and Paterson's curse (Love 2007).

This paper summarises the research that was undertaken to register both Hotshot and Grazon Extra and updates information provided in the paper by Love (2007), with some further new uses.

Materials and methods

Blackberry – high volume hand gun applied trials

Three trials were conducted in New South Wales (NSW) and two in Victoria (Vic.) to determine the concentration of Grazon Extra for effective control of blackberry. Trials were initiated in 2005 and maintained for up to two and a half years to obtain final assessments of regrowth suppression. Trial design was randomised complete block with either two or four replicates. Treatments were applied with a motorised high volume spray unit using a Spraying Systems handgun and D6 or D8 spray tip to apply spray mix at 2500 to 3000 L ha^{-1}.

Efficacy was determined by per cent visual regrowth suppression in each plot. These ratings were then analysed across trials using ARM7 and Minitab.

Lantana – high volume hand gun applied trials

Nine trials were conducted in Queensland (Qld) to determine the concentration of Hotshot required for effective control of lantana. Trials were treated in 2002 or 2003 and maintained for up to two years to obtain final assessments of control. Trial design was unreplicated or randomised complete block with up to four replicates. Treatments were applied with a motorised high volume spray unit using a Spraying Systems handgun and D6 or D8 spray tip to apply the spray mix at 2500 to 3000 L ha^{-1}.

Efficacy was determined by per cent visual control in each plot. These ratings were analysed across trials using ARM7 and Minitab.

Fireweed – high volume hand gun applied trials

Two trials were conducted in NSW to determine what concentration of Hotshot was required to give effective control of fireweed. Trials were treated in 2005 and ran for about 90 days to obtain final assessments of control. Trial design was unrandomised with one replicate. Treatments were applied with a motorised high volume spray unit with Spraying Systems handgun and D6 or D8 spray tip to apply spray mix at 2500 to 3000 L ha^{-1}.

Efficacy was determined by per cent visual control in each plot. These ratings were then included in a summary across trials analysis using ARM7 and Minitab.

Fireweed – boom applied trials

Two trials were conducted in Qld and four in NSW to determine what rate of Hotshot was required to give effective control of fireweed. Trials were treated in 2006 or 2007 and ran for up to 180 days to obtain final assessments of control. Trial design was randomised or randomised complete block with up to four replicates. Treatments were applied with a hand held precision gas powered spray unit, fitted with three metre spray boom and six flat fan spray tips that delivered 100 L ha^{-1} total spray volume.

Efficacy was determined by per cent visual control in each plot. These ratings were then included in a summary across trials analysis using ARM7 and Minitab.

Results

Blackberry – high volume hand gun applied trials

Table 1 shows the results of five blackberry trials. The addition of aminopyralid in Grazon Extra improved the control of blackberry compared to Grazon DS. This was particularly evident in two trials in NSW (052001CP and 052002CP), where pretreated blackberry was considered hard-to-kill due to the previous treatments applied (mechanical and herbicide).

Lantana – high volume hand gun applied trials

Table 2 shows the results of nine lantana trials. Control of lantana was improved where aminopyralid was added to Starane™ 200 (200 g a.e. L^{-1} fluroxypyr) (Love 2007) or when compared to Grazon DS. Hotshot at either rate tested gave similar or better control of lantana than fluroxypyr or Grazon DS.

Fireweed – high volume hand gun applied trials
Table 3 shows the results of two fireweed trials. Control of fireweed was excellent with either rate of Hotshot applied and better than Grazon DS.

Fireweed – boom applied trials
Table 4 shows the results of six fireweed trials. Control of fireweed was excellent with 1.5 L ha^{-1} Hotshot or higher and similar or better than existing standard bromoxynil (25 g L^{-1} diflufenican + 250 g L^{-1} bromoxynil).

Discussion

Blackberry – high volume hand gun applied trials
In two of five trials, addition of aminopyralid to Grazon DS resulted in improved control under hard conditions. Pre-treatment of weeds and then dry conditions at spray time showed that Grazon Extra gave superior blackberry control compared to the existing standard Grazon DS, or glyphosate + metsulfuron. The latter treatment had significant regrowth in two trials by two years after treatment.

Lantana – high volume hand gun applied trials
In nine trials Hotshot gave excellent control of lantana across sites and conditions. Many of the sites treated had either dry soil or large weeds. Despite this Hotshot gave better control than the existing commercial standard Grazon DS and better control than fluroxypyr alone (data not shown) (Love 2007). This demonstrated the value of aminopyralid added to fluroxypyr.

Fireweed – high volume hand gun applied trials
In both trials Hotshot gave complete control of fireweed, which was better than the existing commercial standard Grazon DS. This demonstrated the strength of Hotshot for high volume spraying of fireweed.

Fireweed – boom applied trials
In six trials Hotshot applied at 1.5 L ha^{-1} or higher gave excellent control of fireweed across sites and conditions, which was similar or better than existing commercial standard bromoxynil. This demonstrated the strength of Hotshot for ground boom spraying of fireweed.

Conclusions

Aminopyralid is a valuable new active ingredient for management of woody weeds in Australia. Added to either Grazon DS to make Grazon Extra or Starane (fluroxypyr) to make Hotshot, it improves control of important woody weeds.

Acknowledgments

The authors would like to thank co-workers at Dow AgroSciences who conducted the field trials reported in this paper.

Reference

Love, C. (2007). One new active ingredient but two new herbicides to control woody weeds in New South Wales. Proceedings 14th Biennial NSW Weeds Conference, Wollongong, New South Wales.

Table 1. Improved blackberry control by Grazon Extra.

		Trial	052001CP	052002CP	052002CL	053001RH	053002RH	
		Site	Mogo	Mogo	Ben Lomond	Bolwwarrah	Garibaldi	
		State	NSW	NSW	NSW	Vic	Vic	
		Weed	RUBFR	RUBFR	RUBFR	RUBFR	RUBFR	
		W. stage	Flowering	Fruiting	Flw-fruit	Fruit	Fruit	
		W. size	1 m	1 m	1–2.5 m	1–1.5 m	1.5–2 m	
		Spray date	16-Feb-05	14-Apr-05	21-Feb-05	2-Mar-05	3-Mar-05	
		Density	5 m^{-2}	5 m^{-2}	20 $plot^{-1}$	NR	NR	
		Assessed	Reg. supp'n	Reg. supp'n	Reg. supp'n	Reg. supp'n	Reg. supp'n	
Treatment	Rate mL 100 L^{-1}	Replicates	797 DAA	740 DAA	401 DAA	369 DAA	368 DAA	Av.
Grazon DS	350	1	80	20	100	100	100	68b
		2	60	10	100	100	100	
		3	60	20				
		4	70	30				
Grazon DS	500	1	80	20	100	100	100	72b
		2	70	30	100	100	95	
		3	60	40				
		4	70	40				
Grazon Extra	350	1	70	70	100	100	100	87ab
		2	80	70	100	100	100	
		3	90	80				
		4	80	80				
Grazon Extra	500	1	100	100	100	100	100	98a
		2	100	90	100	100	100	
		3	90	100				
		4	90	100				
Brush-Off®	10 g	1	0	0	100	80	100	41c
Roundup® 360	200	2	0	0	100	98	100	
BS1000	100	3	0	0				
		4	0	0				
LSD (P = 0.05)			12.2	8.3	-	9.9	2.4	

Table 2. Excellent lantana control by Hotshot.

Trial			034012RA	034009RA	034010RA	034003RA	034002RA	024014RA	024013RA	024002CL	024001CL	
Site			Tarong	Tarong	Murphy's Ck	Tarong	Happy Valley	Cabarlah	Tarong	Mun-dubbera	Ban Ban Springs	
State			Qld	Qld	Qld	Qld	Qld	Qld	Qld	Qld	Qld	
Weed			LANCA	LANCA	LANCA	LANCA	LANCA	LANCA	LANCA	LANCA	LANCA	
W. stage			Flower	Flower	Flower	Flower	Flower	Flower	Flower	Flower	Flower	
W. size			1.5–2 m	1.2–2 m	1.5–2.5 m	0.6–1.5 m	0.5–0.8 m	0.8–1.2 m	0.8–1.2 m	0.4 m	1–2 m	
Spray date			2-Apr-03	12-Mar-03	11-Mar-03	17-Jan-03	15-Jan-03	27-Mar-02	21-Mar-02	31-Mar-02	20-Feb-02	
Density			0.25 m^{-2}	0.5 m^{-2}	NR	NR	NR	NR	NR	NR	NR	
Assessed			% control	% control	% control	% control	% control	% control	% control	% control	% control	
Treatment	Rate mL 100 L^{-1}	Repli-cates	341 DAA	362 DAA	430 DAA	416 DAA	391 DAA	314 DAA	364 DAA	382 DAA	421 DAA	Av.
Hotshot	500	1	100	95	100	100	97	86	96	80	60	81b
		2					100	81	92	70	60	
		3									40	
		4									40	
Hotshot	700	1	100	100	100	98	100	100	100	100	90	98a
		2					100	100	100	100	90	
		3									95	
		4									95	
Grazon DS	500	1	100		100	100	100	96	100	100	20	79b
		2					100	91	100	100	20	
		3									30	
		4									30	
Lantana 600	500	1	95		100	95	97					97a
		2					100					
		3										
		4										
LSD (P = 0.05)*			-	-	-	0	0	4.3	0	11	14.2	

Table 3. Excellent fireweed control by Hotshot.

		Trial	052002JD	052003JD	
		Site	Willawarrin	Bellimbopinni	
		State	NSW	NSW	
		Weed	SENMD	SENMD	
		W. stage	Flowering	Flowering	
		W. size	30 cm	40 cm	
		Spray date	3-Mar-05	17-Mar-05	
		Density	0.3 m^{-2}	5 m^{-2}	
		Assessed	96 DAA	82 DAA	
Treatment	Rate mL 100 L^{-1}	Replicates	% control		Mean
Hotshot	500	1	100	100	100
Hotshot	700	1	100	100	100
Grazon DS	150	1	100	43	72
Grazon DS	250	1	100	83	92
Grazon DS	350	1	100	99	100

Table 4. Excellent fireweed control by Hotshot.

		Trial	074010CL	074010CL	074002GM	062001SB	062002SB	072001SB	062001JD	
		Site	Kerry Ck	Kerry Ck	Wacol	Bemboka	Bega	Bemboka	Gloucester	
		State	Qld	Qld	Qld	NSW	NSW	NSW	NSW	
		Weed	SENMD	SENMD	SENMD	SENMD	SENMD	SENMD	SENMD	
		W. stage	Seedling	Flowering	Flowering	6-8 Lf	6-8 Lf	Seedling	Flowering	
		W. size	5–8 cm	8–15 cm	10–20 cm	5–8 cm	10–15 cm	1–10 cm	8–15 cm	
		Spray date	14-Sep-07	14-Sep-07	3-Oct-07	30-Aug-06	30-Aug-06	26-Apr-07	5-Oct-06	
		Density	10	0.5	10	15	15	800	50	
		Formulation	GF-982	GF-982	GF-982	GF-982	GF-982	GF-982	GF-982	
		Soil moisture	Dry	Dry	Moist	Moist	Moist	Moist	Moist	
		Reliability	High	High	High	High	High	High	High	
		Assessed	34 DAA	34 DAA	67 DAA	120 DAA	120 DAA	179 DAA	74 DAA	
Treatment	Rate L ha^{-1}	Replicates								Av.
Hotshot	1	1	70	50	100	100	100	85	90	84b
		2				100	80	75	75	
		3							85	
		4							85	
Hotshot	1.5	1			100	100	100	90		96a
		2				100	100	95	95	
		3							98	
		4							80	
Hotshot	2	1				100	100	90	95	97a
		2				100	100	90	95	
		3							98	
		4							98	
Bromoxynil	2	1				100	20	97	98	88ab
		2				100	80	95	98	
		3							98	
		4							98	
Bromoxynil	2.8	1	100	100		100	75	99	98	96a
		2				100	80	97	98	
		3							98	
		4							98	

Two new cereal crop herbicides

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Abstract

Pyrasulfotole (AE 0317309, Precept 300 EC, Velocity) and pyroxasulfone (KIH 485, Bayer 191, SAKURA 850WG) are two new molecules from Bayer CropScience for use in winter cereal crops.

Pyrasulfotole is currently registered as Precept 300 EC (50 g L^{-1} pyrasulfotole + 250 g L^{-1} MCPA as the 2-ethylhexyl ester plus crop safener: 12.5 g L^{-1} mefenpyr-diethyl) and Velocity (37.5 g L^{-1} pyrasulfotole + 210 g L^{-1} bromoxynil as its mixed heptanoic acid and octanoic acid esters plus crop safener: 9.4 g L^{-1} mefenpyr-diethyl).

Precept 300 EC contains members of the pyrazolone (pyrasulfotole) and phenoxy (MCPA) groups of herbicides. Precept 300 EC is a herbicide which inhibits 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) and also acts by disruption of plant cell growth. For weed resistance management Precept 300 EC is a Group H and Group I herbicide.

Velocity contains members of the pyrazolone (pyrasulfotole) and nitrile (bromoxynil) groups of herbicides. Velocity is a herbicide which inhibits 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) and also acts by inhibition of photosynthesis at photosystem II in plant cells. For weed resistance management Velocity is a Group H and Group C herbicide.

Both Precept 300 EC and Velocity herbicides are for the post-emergent control of certain broadleaf weeds in wheat, barley, oats, cereal rye and triticale.

Pyroxasulfone, proposed trade name SAKURA 850WG is not yet approved for use and expected for registration in 2011. It is proposed for use as a pre-emergent herbicide in cereals is yet to be classified into a herbicide mode of action group.

Pyrasulfotole – background

Pyrasulfotole is a new herbicidal active ingredient of the chemical class of pyrazoles. It was discovered in 1999 and selected for development in October 2002. Approximately five years later the first registrations were granted for the main markets Australia, Canada and the USA. This short development period was made possible by dedicated teams in the countries, closely collaborating with the global team at the headquarter and regulatory agencies.

The regulatory agencies in Australia (APVMA), Canada (PMRA) and USA (EPA) selected pyrasulfotole for evaluation under an OECD joint review. This new approach allowed for harmonised decisions amongst the agencies on endpoints which in fact led to the extremely short review timelines.

Pyrasulfotole has been under development in Australia for weed control in cereals over eight consecutive seasons, commencing in 2001. It was discovered that crop safety could be improved by the addition of the safener product mefenpyr-diethyl ('mefenpyr'). Mefenpyr itself has no herbicidal activity, but when added to pyrasulfotole, improves the level of crop safety by increasing the rate of metabolism of the herbicide active ingredients by the treated crop.

Mefenpyr serves the same cereal post-emergent safening function in the herbicides Atlantis, Cheetah Gold, Decision, Hussar OD, Tristar Advance and Wildcat 110 Selective Herbicides.

Mode of action

In Australia, pyrasulfotole (5-hydroxy-1,3-dimethylpyrazol-4-yl)(2-mesyl-4-trifluoromethylphenyl) methanone, the Group H active ingredient of Velocity and Precept 300 EC Selective Herbicide are novel herbicides discovered by Bayer CropScience. Pyrasulfotole has a primary target site at the enzyme 4-hydroxyphenylpyruvate deoxygenase (HPPD) in the photosynthetic pathway and an indirect inhibition on phytone desaturase in the carotenoid pathway. There is currently no registered product available for use in cereals in Australia, which targets this enzyme.

Weed herbicide resistance in Australia is widespread and growing. Group B herbicides (ALS inhibitors) are the most common herbicide group used to control wild radish (*Raphanus raphanistrum*), the primary broadleaf weed in Australian cereal farming. Walsh *et al.* (2005) found in a random survey in Western Australia that thirty five per cent of all populations collected were found to be resistant to the Group B herbicide chlorsulfuron with a further 25% developing resistance to chlorsulfuron. Sixty per cent of wild radish (*Raphanus raphanistrum*) populations contained plants with resistance to chlorsulfuron. Developing resistance (>60%) was very high to two other key herbicide groups being atrazine (Group C – PS II inhibitors) and 2,4-D amine (Group I – disruptors of plant cell growth).

Pyrasulfotole inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase (Group H – HPPD). The compound offers a robust mode of action mainly against broadleaved weeds based on the simultaneous cutting of three crucial life processes in weeds:

- Plastoquinone biosynthesis: pyrasulfotole cuts off the energy process;
- Tocopherol biosynthesis: pyrasulfotole cuts off the vitamin process; and
- Carotenoid bio synthesis: pyrasulfotole cuts off the chlorophyll protective process.

This triple action turns weeds white (the visible 'bleacher effect') and results in a reliable performance, even against difficult-to-control weeds. The mode of action of pyrasulfotole is new to the cereal herbicide market.

In Velocity, the HPPD (pyrasulfotole) and PS II (bromoxynil) inhibiting

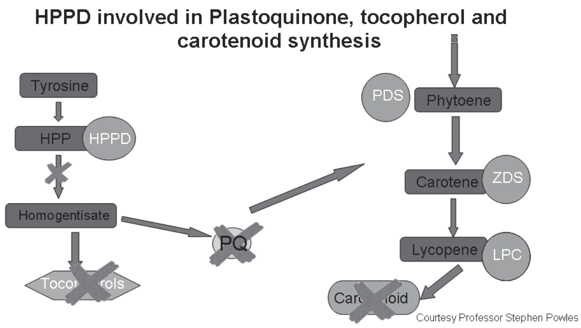


Figure 1. Interaction HPPD and PDS inhibiting herbicides.

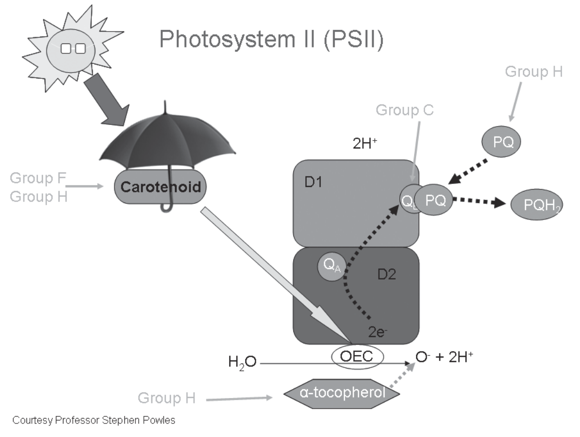


Figure 2. Photosystem II (PSII).

herbicides both directly and indirectly impact on the photosynthetic reactions and in particular photosystem II.

Unlike the Group C triazines, the Group C bromoxynil has a different binding behaviour at the binding protein D1 or QB in photosystem II. Draber *et al*. (1994) refer to the grouping of herbicides that bind in the QB niche into two families based on their interaction with amino acids at this site: the triazine/urea family which shows a strong interaction with Ser 264 and the phenol family was assumed to bind towards His 215. Bromoxynil, belongs to the phenol family. According to Trebst (1991), mutations in triazine resistance lead to an increased sensitivity to phenol-type herbicides. This, together with the fact that bromoxynil has an additional mode of action involving membrane disruption Schmidt (2002) means that resistance to the Group C atrazine does not automatically translate to the Group C bromoxynil and may lead to improved control from bromoxynil.

The herbicide pyrasulfotole is used for post-emergence control of a wide spectrum of broad-leaved weeds in cereals. It is always applied in combination with the safener mefenpyr-diethyl to minimise the risk of crop phytotoxicity. Pyrasulfotole inhibits 4-hydoxyphenylpyruvate dioxygenase (HPPD) and blocks the pathway of prenylquinone biosynthesis in plants. This leads to decreased levels of plastoquinone and tocopherols in the plant tissue and a reduced photosynthetic yield.

Indirect inhibition of phytoene desaturase as a consequence of blocked plastoquinone biosynthesis subsequently leads to a decrease in carotenoids particularly in young, expanding leaves. The resulting foliar yellowing and chlorosis ('bleaching'), are characteristic symptoms of HPPD-inhibiting herbicides.

When pyrasulfotole is applied to the foliage, most of it is taken up quickly. In cases where the herbicide solution comes into contact with the soil only small amounts enter the plants via the roots.

Pyrasulfotole is both phloem and xylem mobile. The mobility in the phloem is of particular importance, since it ensures that the herbicide will be distributed in the assimilate stream from mature leaves (metabolic sources) to the developing, highly susceptible leaves (metabolic sinks) at the shoot apex. Humidity has only a minor influence on foliar uptake and distribution of pyrasulfotole in *Polygonum convolvulus* and wheat (*Triticum aestivum*).

This is also true for the temperature, except for significantly reduced translocation of the herbicide in wheat at lower temperatures. Wheat exhibits a substantial tolerance to pyrasulfotole even without the addition of safener. This tolerance is caused by a much faster metabolic degradation of the herbicide in wheat than in representative susceptible weed species such as *Polygonum convolvulus* or *Kochia scoparia*. The tolerance of wheat to pyrasulfotole increases further by a combination of the herbicide with the safener mefenpyr-diethyl in a 2:1 ratio. The safener effect in wheat cannot be attributed to a reduction of herbicide uptake or translocation. Instead it derives from a further enhancement of the pyrasulfotole metabolism, while addition of safener does not induce the metabolism in *Polygonum convolvulus* (Schulte and Köcher 2008).

Velocity – symptoms and physiological effects

Velocity is exceptionally fast acting. No visible symptoms are observed within a period of two days after herbicide application. General growth depression and yellowing/chlorosis of the young, still developing leaves are visible between three and four days after application, while older leaves and cotyledons are still without any visible effects after this period. About a week after application, leaf necrosis begins to develop on the youngest leaves and with a further delay also on the older leaves. Necrosis progressed further within the 2nd week, and severe damage followed by plant death was observed between two and three weeks after herbicide application.

Velocity – weed control

Velocity is most effective when applied, with good coverage, to actively growing weeds. For reliable control, good contact must be made with each weed plant.

Higher weed density may cause shading of plants lower in the weed canopy and effective control may not occur. The shading of weeds lower in the plant canopy may require a follow-up application of a suitable herbicide to control plants remaining after an application of Velocity. DO NOT use the 500 mL ha^{-1} rate for the control of dense wild radish populations (>75 m^{-2}) or on populations where wild radish leaf shading occurs. For dense wild radish populations, increasing the rate to 670 mL ha^{-1} will improve control in most situations. If coverage is considered an issue on densities less than 75 m^{-2}, then the Velocity rate should be increased to 670 mL ha^{-1}.

Even then full control may not be obtained. Where crop or weed density is high, water volume should also be increased to the higher rate range of 70–150 L ha^{-1}.

Weed emergence after application

Velocity will not reliably control subsequent germinations of weeds. A follow-up application of a suitable herbicide may be required to control remaining plants or plants that emerge after application.

Weed stage

Weed age and weed size normally go hand-in-hand. Small weeds, however, are not always young weeds. To arrive at a sound spraying decision, don't just check the above-ground parts of the plant for size, but also the roots for the age of the weed.

Summary

Pyrasulfotole containing products (Precept and Velocity) are designed as broadleaf weed controlling herbicides. They also control a range of other annual broadleaf weeds with good selectivity in winter grown cereals. Pyrasulfotole targets the enzyme, HPPD (4-hydroxphenyl pyruvatedeoxygenase) providing an aid to growers affected by resistance to ALS (Group B) and PDS (Group F) inhibiting herbicides.

Pyroxasulfone – background

Pyroxasulfone is a novel herbicide discovered by Kumiai Chemical Industry Co. Ltd., and was submitted for its first registration simultaneously in Australia

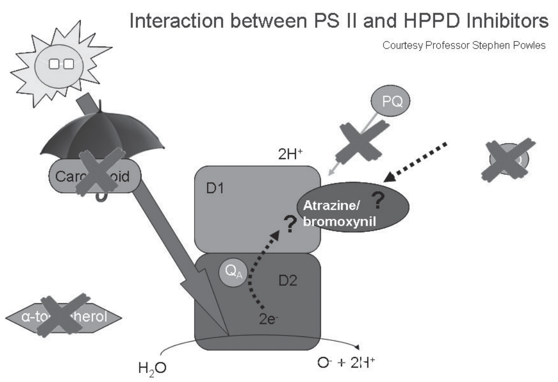


Figure 3. Interaction between PS II and HPPD Inhibitors.

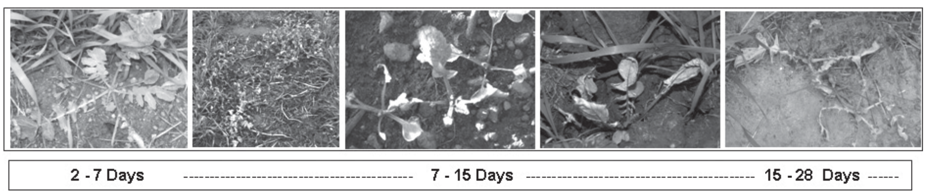
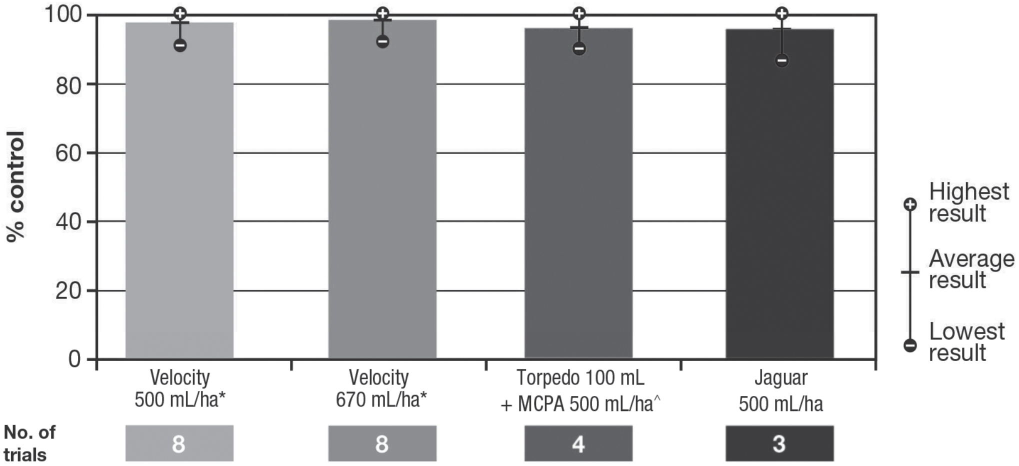


Figure 4. Pyraxosulfone symptoms on wild radish (*Raphanus raphanistrum*).

2–4 leaf WILD RADISH (*Raphanus raphanistrum*)	Crop	State	Weed stage	Rate (mL/ha)	Critical comments
	Wheat, cereal rye, triticale, barley – ≥ 2-leaf (Z12) to fully tillered (Z30)	All States	2 up to 4-leaf	500	Use the 670 mL/ha rate for the control of dense wild radish populations (>75/m²) or where total weed density is high. In dense wild radish populations, increasing the rate to 670 mL/ha will give good control in most situations. Because high weed density may cause shading of weeds lower in the plant canopy a follow-up application of a suitable herbicide may be required to control plants remaining after an application of Velocity Selective Herbicide. Following germinations of wild radish may occur after application. Refer also to comments in the General Instructions under "Weed emergence after application".



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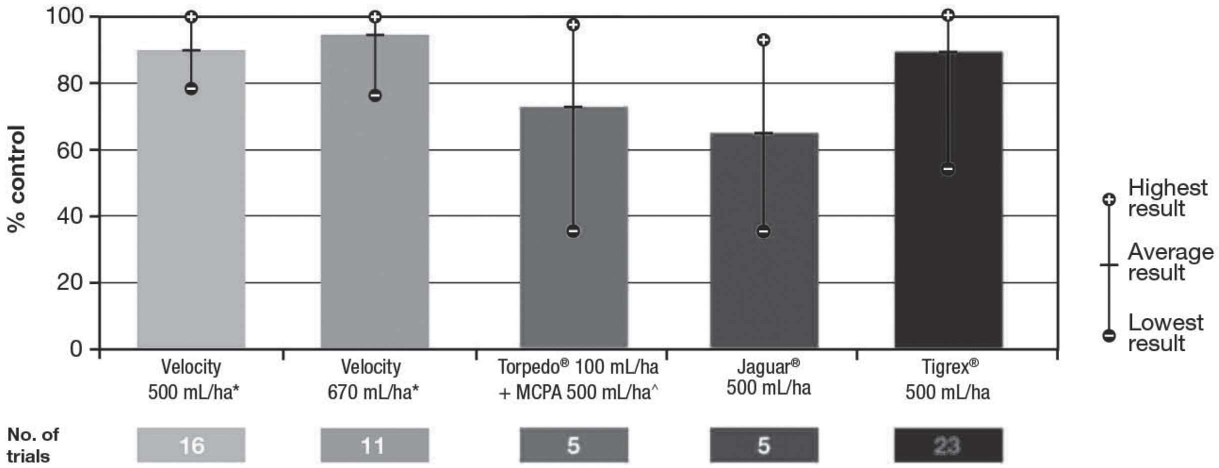
* Hasten 1% v/v ^ Uptake 0.5% v/v

Figure 5. Control of 2–4 leaf wild radish (*Raphanus raphanistrum*).

4–6 leaf WILD RADISH (*Raphanus raphanistrum*)	Crop	State	Weed stage	Rate (mL/ha)	Critical comments
	Wheat, cereal rye, triticale, barley – ≥ 2-leaf (Z12) to fully tillered (Z30)	All States	Up to 6-leaf	670	Use the 670 mL/ha rate for the control of dense wild radish populations (>75/m²) or where total weed density is high. In dense wild radish populations, increasing the rate to 670 mL/ha will give good control in most situations. Because high weed density may cause shading of weeds lower in the plant canopy a follow-up application of a suitable herbicide may be required to control plants remaining after an application of Velocity Selective Herbicide. Following germinations of wild radish may occur after application. Refer also to comments in the General Instructions under "Weed emergence after application".



Trial ID: 03ND10, 03VB06, 04NW09, 04VB07, 04VB08, 04WA05, 04WA09, 04WB10, 04WB17, 05VA08, 05VB01, 05VB02, 06NB04, 06NB05, 06NW02, 06NW03, 06NW12, 06SA03, 06VB04, 06VB07, 06WA09, 06WC08, 07JT02, 07NW53, 07SA10, 07VA23, 07VB05, 07VB21, 07WA57, 07WB08, 07WB12, 07WC02, 07WC03, 07WC05, 07VD84, 08SA12, 08WA06, 08WB09.

* Hasten 1% v/v ^ Uptake 0.5% v/v

Figure 6. Control of 4–6 leaf wild radish (*Raphanus raphanistrum*).

and the US. In Australia SAKURA 850WG (containing 850 g kg^{-1} pyroxasulfone) has been developed as a pre-emergent selective herbicide for the control of a selected range of grass weeds in wheat (not durum wheat), barley and triticale. Initially pyroxasulfone was tested by government researchers in pot and field trials in 2004 and 2005 and was known as KIH-485. The first trials conducted by Bayer CropScience were in 2006, although the majority of the trial work was conducted in 2007 and 2008.

Pyroxasulfone has been found to inhibit the biosynthesis of very long chain fatty acids (VLCFA), however it is yet to be classified into a herbicide mode of action group by any of the herbicide resistance management bodies (HRAC, WSSA or CropLife Australia).

Pyroxasulfone – mode of action

The key target for SAKURA 850WG in Australia is annual ryegrass (*Lolium rigidum*). Annual ryegrass is the major grass weed problem of winter cereal cropping, infesting most cereal cropping areas throughout southern Australia. Surveys have found that most farms in Victoria, South Australia or Western Australia have annual ryegrass with resistance to Groups A (ACC'ase inhibitors) or B (ALS inhibitors). Resistance to trifluralin (Group D – inhibitors of microtubule assembly) is high in South Australia, and ryegrass resistance to glyphosate is becoming more prevalent. SAKURA 850WG has been shown to be active against populations of annual ryegrass resistant to Group A, B and D herbicides.

Weed control

Trials demonstrate the efficacy of SAKURA 850 WG for control of annual ryegrass (*Lolium rigidum*) and barley grass (*Hordeum leporinum*). The proposed use pattern for SAKURA 850 WG is as a pre-emergent herbicide that is incorporated by sowing by seeders fitted with knife points and press wheels or seeders with narrow points and trailing harrows.

The tolerance of cereals has also been evaluated and trial data demonstrates an acceptable level of crop safety of wheat (not durum), barley and triticale to SAKURA 850 WG when the product is applied according to proposed recommendations.

SAKURA 850 WG is a residual pre-emergent herbicide and in some situations may remain active in the soil for an extended period. Trials evaluating the replanting interval required for various crops following SAKURA 850 WG application have been conducted to determine recommended recropping intervals.

In addition to its activity against resistant ryegrass, SAKURA 850 WG offers a number of important features of great potential benefit to cereal farmers:

- a low, convenient use rate relative to many other pre-emergent herbicides;
- flexible incorporation by sowing window, up to 14 days after application;
- a high level of efficacy against annual ryegrass (*Lolium rigidum*), with control generally exceeding 90% when used according to directions;
- excellent control of barley grass (*Hordeum leporinum*), silver grass (*Vulpia* spp.), toad rush (*Juncus bufonius*) and phalaris (*Phalaris* spp.);
- suitability for use in conservation farming systems including direct drilling, and flexibility of seeding equipment options;
- compatibility with a wide range of herbicides and insecticides; and
- very good crop safety characteristics in wheat (not durum wheat), triticale and barley.

The performance of SAKURA 850 WG in field trials against industry standards suggests that it will play an important part in grass weed control in Australian cereal production.

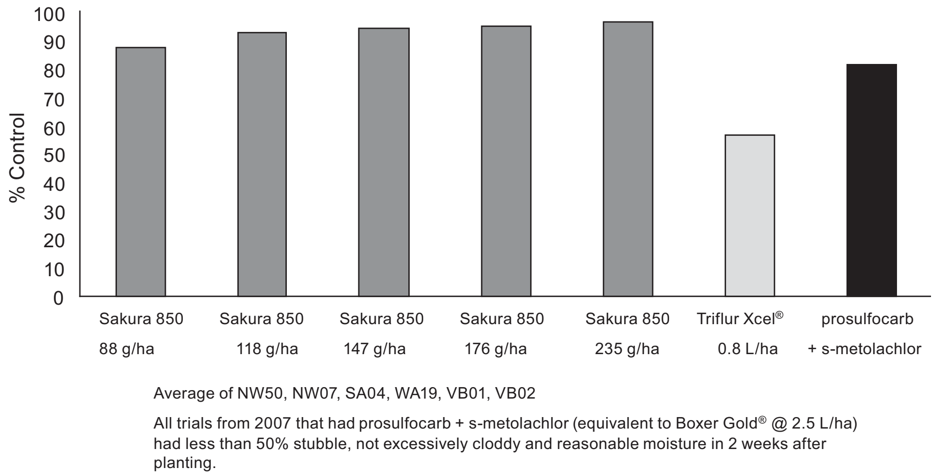


Figure 7. Annual ryegrass (*Lolium rigidum*) per cent control.

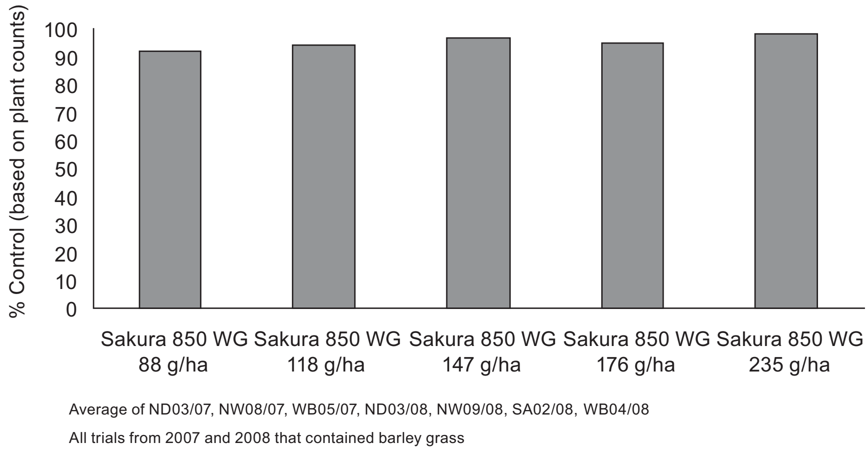


Figure 8. Barley grass (*Hordeum leporinum*) per cent control.

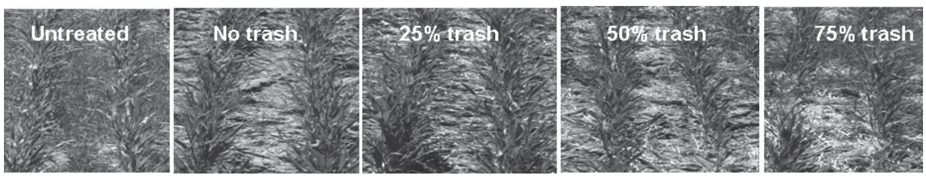


Figure 9. Annual ryegrass (*Lolium rigidum*) control with SAKURA 850WG under different trash levels situations.

Summary

- A new pre-emergent herbicide in winter cereals;
- Targeted launch is 2011;
- Product is an easy to use WG with a low use rate;

Figure 10. Annual ryegrass (*Lolium rigidum*) and barley grass (*Hordeum leporinum*) control with SAKURA 850WG.

- Mode of Action still being determined;
- Controls Groups A, B and D resistant ryegrass;
- High level of control of annual ryegrass (*Lolium rigidum*) (when used as directed);
- Very good residual control;
- Activity does not appear to be influenced by pH;
- Suitable for IBS on annual ryegrass (*Lolium rigidum*);
- Suitable for direct drill;
- Flexible for seeding equipment (harrows or press wheels);
- Similar to other pre-emergent's, for good coverage requirements;
- Good compatibility with knockdown and other pre-emergent herbicides;
- Active to varying degrees on a wide spectrum of grass weeds; and
- Active to varying degrees on numerous broadleaf weeds.

Acknowledgments

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The importance of managing spray drift

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Concerns among the public about possible risks from pesticide spray drift have increased dramatically over the last few years as more people become aware of the issue from internet and media reports. The Australian Pesticides and Veterinary Medicines Authority (APVMA), the federal agency that regulates pesticides, uses scientific information to determine the risks when using each pesticide and decides whether the risks can be controlled safely. Some level of spray drift happens with almost every outdoor pesticide spray application, and the APVMA is now placing stronger use restrictions on pesticide labels to reduce spray drift.

The risks that arise from off-target spray drift are caused by the exposure of people and other living things to a chemical that has drifted to a place where it should not be. Each active chemical is different and can create different kinds of risks. When the properties of a specific chemical are compared with the living things it might affect and linked to the way spray drift deposits accumulate downwind, the APVMA can estimate how far spray drift risks can reach from the application area.

The APVMA has recently refined its spray drift risk assessment policy and is now applying a broader range of drift-control restrictions on pesticide labels. This more stringent regulation is already being applied to all new products and will be applied to all existing products as the APVMA works through them dealing with the higher risk pesticides first.

Of all the factors contributing to spray drift that the APVMA can control with label restrictions, spray droplet size is the most important. It is easy to understand that very small droplets are more likely to drift, but the risk is even greater than most realise. During the past 20 years, growers have heard again and again that they need to apply pesticides with very small droplets in order to achieve good coverage on their targets and therefore achieve good efficacy. But many growers have taken this message too far and apply pesticides with spray droplets that are finer than needed to achieve efficacy.

In fact, with fine droplets efficacy can actually be reduced by losing part of the pesticide to off-target drift – pesticide that was intended for the crop. More importantly, other people including other farmers may be harmed by the drifted pesticide and will justifiably call for greater restrictions or even bans to pesticide use. The APVMA is dealing with this by requiring many pesticides to be applied with a 'COARSE' droplet size. For example, all 2,4-D products must now be applied with Coarse droplets, and by the 2009–2010 season, the other phenoxy herbicides will have the same requirement. The APVMA will ensure that the droplet size required on the label still provides good efficacy for the product.

The new 2,4-D and phenoxy labels will also limit applications to times when the wind speed is between 3 and 15 km hr^{-1} and will forbid applications during times of surface temperature inversions. It is likely that applications of 2,4-D through the night during surface temperature inversion conditions have been one of the biggest factors in the serious damage caused to cotton and vineyard crops during the last several years.

One of the most significant changes that growers must comply with will be new mandatory 'no-spray zones' on pesticide labels. These protective no-spray zones (often called buffer zones) are different for each pesticide and are determined from scientific studies that examine each pesticide's hazards. The no-spray zones will only exist in the downwind direction at the time of application and only when the kind of risk identified on the label is present in that direction. The label will specify the distance from the identified risk where spraying must stop. That area can be treated later when the wind is blowing in a different direction.

Chemical users can find more information on these changes on the APVMA website at www.apvma.gov.au. Look under the heading 'Spray Drift' where a number of downloadable documents can be found including the general policy document *APVMA Operating Principles in Relation to Spray Drift Risk*.

It is important that all pesticide users appreciate that the public is now holding them to a higher standard in relation to spray drift than in the past. Signs of this are clearly evident overseas in recent regulatory decisions and court cases. Public sentiment in Australia is also evident in letters to Ministers and regulators and in many recent media reports. Responsible control of spray drift is a very important issue for the farm community in maintaining access to valuable chemical tools into the future.

Herbicide resistant weeds: management options for Victorian producers

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The frequency and distribution of herbicide resistant weed populations continues to escalate across all Australian dryland grain production regions. The rapid rate of resistance evolution over the last two decades has generally coincided with the adoption of conservation cropping systems heavily reliant on selective herbicidal weed control. Although it is well recognised that the no-till, stubble retention cropping systems are more productive and sustainable than previous systems, a negative aspect has been the associated widespread development of herbicide resistant weed populations. In southern Australian cropping systems several weed species have evolved herbicide resistance (Heap 2009). However throughout southern Australian cropping regions, annual ryegrass due to its genetic diversity and its widespread occurrence at high densities has consistently evolved resistance to a range of herbicides.

Herbicide resistance across Victoria

Similar to all intensive cropping regions of Australia the Victorian cropping regions have significant proportions of herbicide resistant annual ryegrass populations. A recent random seed collection survey of annual ryegrass populations present in crops at the end of the growing season was conducted across the Wimmera region of Victoria. Subsequent screening of the collected populations found particularly high frequencies of diclofop and chlorsulfuron resistance (Boutsalis *et al*. 2008) (Table 1). Although screening identified resistance to these herbicides, it is likely that these populations will also be resistant to similar herbicides with the same mode of action. These results clearly indicate the reliance on diclofop, chlorsulfuron and similar mode of action herbicides for the control of annual ryegrass across the Victorian cropping regions. High levels of resistance to diclopfop and chlorsulfuron have also been identified in the intensive cropping regions of South Australia and Western Australia (Broster and Pratley 2006, Owen *et al*. 2007).

The negative consequence of herbicide resistance is that highly effective herbicides can no longer be used for the control of a problematic weed population. In any paddock where an annual ryegrass population develops resistance to a particular herbicide then this and similarly acting herbicides can no longer be used to control this weed. Therefore, across the Australian crop production regions there are large areas where diclofop, chlorsulfuron and similar highly effective herbicides are no longer useful for the control of annual ryegrass. As annual ryegrass is the most problematic weed species of Australian cropping systems (Alemseged *et al.* 2001) then the loss of the use of these herbicides is a major constraint to these cropping systems.

Selection of resistant weeds

The selection of herbicide resistant annual weed populations is reliant on the production of viable seed entering the seedbank at the end of the growing season. In any large annual weed population there are naturally occurring herbicide resistant individuals. Therefore, whenever an effective lethal herbicide dose is applied the naturally occurring resistant individuals are selected for and subsequently survive this dose. For annual weed populations an effective selection for herbicide resistance is only completed when surviving plants produce viable seeds that enter the seedbank. Consequently the selection for herbicide resistance in an annual weed population can be prevented by intercepting this process. Therefore, when an effective herbicide dose is imposed on a weed population a follow up control strategy should be used to control the potentially resistant survivors of this herbicide treatment. Towards this there are a range of agronomic and management options that can be used to target weeds that survive effective selective herbicide treatments.

Preventing and intercepting resistant seed production

The strategies available for controlling and intercepting the production of viable seeds range from crop-topping using non-selective herbicides and swathing at crop maturity to agronomic factors such as crop competition (Walsh and Powles 2007). These strategies although relatively effective are often difficult for most farmers to implement routinely across an entire cropping program. In Western Australia where high frequencies of herbicide resistant annual ryegrass populations (Owen *et al.* 2007) have been driving farming practices for the last decade techniques targeting weed seeds present in the chaff fraction during harvest have been widely adopted. As many WA farmers have learnt, collecting and managing the weed seed bearing chaff intercepts the replenishment of the seedbank, allowing the continuation of intensive cropping systems.

The frequency of herbicide resistant ryegrass populations across the Victorian cropping regions is much lower than those occurring in WA. However, at harvest techniques targeting weeds seeds still need to be considered by farmers across this region not only to manage current resistant populations but also to prevent any increase in the frequency of resistance. There are a number of systems/techniques available that intercept viable seeds at harvest. These include chaff carts, residue baling, windrow burning and chaff processing (Walsh and Powles 2007). With any of the techniques, it is important to maximise your options and choose paddocks with the greatest risk and/or the higher number of weed seeds, bearing in mind the rotation for the following season.

Chaff carts

Chaff carts are towed behind headers during harvest with the aim of collecting the chaff fraction as it exits the harvester. The weed seed collection efficiency of several commercially operating harvesters with attached chaff carts have been evaluated with these systems found to collect 75 to 85% of annual ryegrass seeds and 85 to 95% of wild radish seeds that entered the front of the header during the harvest operation. These levels of weed seed

Table 1. Frequency of herbicide resistant annual ryegrass populations in Victorian cropping paddocks (Boutsalis *et al*. 2008).

		Trifluralin	Diclofop	Chlorsulfuron	Clethodim
Region	Year	Resistant ryegrass populations (%)			
Wimmera	2005	2	60	60	26
Mallee	2005	7	12	54	0
North Central	2006	2	18	19	4
North East	2006	2	63	68	18

collection clearly demonstrates the value of this method of weed control. However, the collected chaff must be managed to remove the collected weed seeds from the cropping system. Typically the collected chaff material is left in piles in the paddock to be burnt in the following autumn. In some instances this material is removed from the paddock and fed to livestock in feed lots.

Baling

An alternative to the in-situ burning or grazing of chaff is to bale all chaff and straw material as it exits the harvester. This system developed by the Shield's family in Wongan hills increases the proportion of ryegrass seed collected with approximately 95% of seed entering the harvester collected in the bales. The baling system allows for the removal of weed seeds from the paddock in the baled material with this material having an economic value as a feed source.

Windrow burning

The use of chutes attached to the rear of a harvester concentrate the straw and chaff harvest residues into a narrow windrow during the harvest operation (Walsh and Newman 2007). This concentration of residue effectively increases the seed destruction potential of residue burning. With more fuel in these narrow windrows the residues burn hotter and longer than standing stubbles or even conventional windrows. Results from a number of studies have found that 99 and 98% of annual ryegrass and wild radish seeds, respectively, are killed by windrow burning.

Chaff grinding

The processing of the chaff sufficient to destroy any weed seeds present during the harvest operation represents the ideal system for many Australian crop producers. Rendering weed seeds non-viable as they exit the harvester removes the need to collect, handle and/or burn large volumes of chaff and straw residues. Because of the importance and potential significance of this process there have been many attempts at developing chaff grinding systems. The ability to handle and process ever increasing volumes of chaff material is a major constraint to the development of these systems and at present there isn't a commercially available 'chaff grinder'. However, with renewed support and interest in chaff grinding systems it is likely that a system will become available in the near future.

Summary

The negative consequence of herbicide resistance is that highly effective herbicides can no longer be used for the control of a problematic weed population. For the many paddocks where an annual ryegrass populations have developed resistance to a particular herbicide then this and similarly acting herbicides can no longer be used to control this weed. Therefore, across the southern Australian crop production regions there are many paddocks and farms where diclofop, chlorsulfuron and similar herbicides can no longer be used for annual ryegrass control. For Victorian crop producers the challenge is to conserve the use of the herbicides that are currently working for them. To do this they must be diligent in controlling any weeds that survive an effective herbicide application.

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Victorian Weeds of National Significance: what's up with WoNS?

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Abstract

The Weeds of National Significance (WoNS) program works to increase Australia's capacity for effective weed management. This paper briefly outlines current research and management actions for eight WoNS species relevant to Victoria: bridal creeper, boneseed, bitou bush, cabomba, Chilean needle grass, serrated tussock, willows, blackberry and gorse. The paper will focus on a range of working programs including:

***Bridal creeper* research; which suggests that without additional restoration after bridal creeper has been removed from a site, invaded systems may struggle to recover native plant diversity.**

Seed persistence studies for *boneseed and bitou bush* and a new 'high-tech' education resource for schools that engages students in weed issues.

***Aquatic weeds* identification training package; suitable to train weeds officers, waterway managers and community members in identification and early detection of these WoNS and other aquatic weeds.**

***Chilean needle grass* (CNG) research; addressing a range of critical issues such as new molecular diagnostic tools to aid identification of CNG infestations, and potential biological control agents.**

The development and roll out of the *Serrated Tussock Best Practice Manual* and Resource CD, which combines 150 different information products and research papers on serrated tussock into a single, easy to use resource; and addresses the issue of herbicide resistance, highlighting the need for integrated weed management.

The creation of the '*Developing willow management priorities*' toolkit, which assists willow managers to set management priorities and contains a range of materials including mapping tools, identification resources and a kit to run workshops.

The use of the Victorian Community Weed Model to deliver the actions of the *National Blackberry Strategy*.

A *case study of gorse management* using 25 year Memoranda of Understandings (MOUs) with regional organisations to eradicate and promote effective and long term management of gorse, including landcare champions that pledge to watch over gorse management activities.

WoNS programs in Victoria

Bridal creeper

Bridal creeper (*Asparagus asparagoides*) is well recognised as one of Australia's major environmental weeds, impacting on native species diversity and abundance (Turner *et al*. 2008a). Whilst this effect is most obvious on the understorey shrubs and trees bridal creeper smothers, bridal creeper has the potential to modify habitat structure through the accumulation of leaf litter in open habitats such as *Eucalyptus* woodlands, which in turn may affect nutrient cycling and associated invertebrate communities (Stephens *et al*. 2008). In addition, because much of bridal creeper's biomass is below ground in the tuberous root system, mature plants compete vigorously with native species for root space, nutrients and moisture, reducing the resilience of native ecosystems (Turner 2008).

To combat the impact and slow the spread of bridal creeper, biological control agents have been successfully distributed throughout bridal creeper's range in Victoria, with the rust fungus agent (*Puccinia myrsiphylli*) reducing both plant cover and tuber biomass (Morin 2006). A number of findings suggest, however, that without additional restoration efforts these systems may struggle to recover native plant diversity following chemical or biological control. Invaded areas typically have large exotic seedbanks that easily germinate, resulting in either further bridal creeper growth or new weed occurrences such as grasses (Turner *et al*. 2008a, Reid 2008). In bridal creeper invaded sites this is compounded by increased soil nutrient levels that can favour exotic plant growth over native species (Turner 2008). The legacy of the plant's tubers is such that considerable biomass can persist in the soil profile for many years following successful control.

Consideration should be given to the early management of bridal creeper infestations to prevent issues associated with long-term invasion. Additional efforts such as management of multiple weed species (or secondary invaders) at bridal creeper infested sites, and further research into techniques that assist with ecosystem recovery such as fire may also be required (Turner 2008, Reid *et al*. 2008). Fire may be useful to stimulate native plant regeneration, assisting ecosystem recovery, provided that bridal creeper and other secondary weeds are kept at a low post-fire density (Turner and Virtue 2009).

Bitou bush and boneseed

Seed studies Researchers from four major universities are undertaking seed longevity studies for boneseed and bitou bush (*Chrysanthemoides monilifera*). Over 200 000 seeds were buried in long-term trials at sites in Geelong, Wollongong and Brisbane. Seeds will be harvested each year for 11 years to determine seed longevity and seedbank dynamics, which is critical information for current management programs. In addition to this long-term burial study, researchers at University of Queensland performed a Controlled Ageing Test (CAT) on bitou bush and boneseed seeds (Schoeman *et al.* in press). This new approach is a rapid test that artificially ages seeds and provides a relative estimate of seed longevity. Unfortunately, the CAT reinforces anecdotal evidence that some boneseed seeds are likely to remain viable in the soil for over five years. But on a brighter note, CAT results seem to indicate that boneseed seeds may be shorter lived than previously suggested (i.e. <10 years). Over the next 10 years, the long-term persistence (burial) studies will validate and expand on information gained in the CAT.

Weed education Getting the 'weed message' into the school curriculum is a key goal of the bitou bush and boneseed WoNS program. The program joined forces with the Centre for Learning Innovation NSW Department of Education and Training and NSW Department of Primary Industries to develop an education resource that uses the science curriculum to engage students in weed issues (Schembri *et al.* 2008). 'Weeds Attack!' is a web-based, multimedia resource with interactive learning activities that increase weed awareness through a series of challenges. Students are engaged by exciting computer games and 'hands-on' field work. The resource allows students to learn about weed science principles and investigate weed impacts. Weeds Attack! incorporates concepts from the Weed Warriors program that empowers students to act on weed issues using biological control agents. The Weeds Attack! resource was designed by education experts to address the science and technology curriculum, and while developed in New South Wales, the resource conforms to national curriculum standards and could be used in Victorian schools. Weeds Attack! can be used online or is freely available from www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds/schools. The WoNS program is currently seeking to expand Weeds Attack! and include a broader range of invasive species. To become part of this initiative, contact the National Coordinator.

Aquatic weeds

The need for improved early detection and rapid response for all weed incursions is recognised in strategic weed plans at all levels, as it provides the most cost effective management. It is particularly important for aquatic weeds which, due to their prolific growth rates, can rapidly entrench themselves in a catchment and quickly reach a point where they are no longer eradicable. In response, the National Aquatic Weeds Management Group (NAWMG) has facilitated development of a range of early detection initiatives, which have improved capacity to detect new and emerging incursions of aquatic WoNS: alligator weed (*Alternanthera philoxeroides*), cabomba (*Cabomba caroliniana*) and salvinia (*Salivina molesta*).

A current initiative being introduced to land managers is the national aquatic weeds identification training package, developed by the NSW Department of Industry and Investment, and NAWMG in 2006. The package is suitable for weeds officers, waterway managers and community members, each of whom can play a vital role in the early detection of aquatic WoNS and other high priority aquatic weeds. The training package comprises a PowerPoint presentation, participant workbook and live specimens, and aims to provide the community audience with:

- Basic aquatic plant recognition skills;
- The key identification characteristics of up to eight high priority aquatic weeds, including the aquatic WoNS;
- A range of aquatic weed identification resources, including workbook, ID brochures and aquatic WEEDeck;
- An opportunity to apply learned plant recognition techniques to live aquatic weed specimens; and
- Instructions for reporting aquatic weed outbreaks.

The training package is flexible and can be adapted to suit audiences from weed professionals to community members. Aquatic weed species covered by the workshop can also be tailored to suit regional or state priorities. Since the release of this national training package, over 1000 people have been trained in six states and territories. Success has been demonstrated by at least six participants detecting new aquatic WoNS infestations in New South Wales and Queensland. This includes the recent discovery of alligator weed near Mirriam Vale in Central Queensland, which is over 350 km further north than previously known infestations. Five workshops have been run in Victoria so far, leading to reports of cabomba and another targeted aquatic weed. Further workshops are planned, and for information on how to obtain and kit and run a workshop in your region, contact the National Coordinator.

Chilean needle grass

Due to morphological similarities between stipoid grasses identification of these grasses, including natives, is complex. Identification is currently reliant on reproductive characteristics and gross morphological features. Consequently, these weeds are usually identified when seed is present, limiting our ability to strategically manage these weeds prior to seed set. An added impediment to the management of stipoid weeds is that there are currently no biological control agents to complement existing control methods. Two projects currently underway by Department of Primary Industries in Victoria and supported by the National Chilean needle grass (CNG) program are described, which will work together to provide new tools for the identification and control of stipoid weeds.

Diagnostic tools for weed identification
Phytoliths or 'plant stones' are rigid microscopic deposits comprised of hydrated silica in the intracellular and/or intercellular spaces in the stems, leaves and roots of many plants. These deposits often play a both a structural and defence role, and often contribute to the grainy or prickly texture of many plants. Phytoliths vary in size, shape and colour in different plant taxa. This study will investigate both phytoliths and other features such as stomatal configuration to determine whether these features vary sufficiently between species to allow for their characterisation as diagnostic tools. Further diagnostic tools will also be investigated using molecular techniques. Investigation has begun and includes *Nassella* spp, *Amelichloa* spp and a number of native *Austrostipa* spp. It is expected that the tools will be completed and available by June 2010.

Biological control Investigation into potential biocontrol agents for CNG (*Nassella neesiana*) began in 1999. After several years of detailed field studies and laboratory experimentation, potential for biocontrol of CNG is looking promising. The rust pathogen, *Uromyces pencanus* from Argentina has been shown to cause damage to CNG foliage, can be mass reared and to date has been host specific. Host specificity work is being carried out in Argentina that is approximately 50% complete. The remaining testing is scheduled for completion by the end of 2009.

Serrated tussock

Serrated Tussock Best Practice Manual and Resource CD The serrated tussock best practice manual (BPM) and resource CD are now available. The BPM is a comprehensive manual on up-to-date management and control practices, with an emphasis on integrated weed management, the importance of follow up treatments and the need for long-term planning as key factors in successful serrated tussock (*Nassella trichotoma*) management. Management issues such as herbicide resistance are also covered in the BPM. The Resource CD combines 150 different information products and research papers on serrated tussock into a single, easy to use resource and includes a searchable copy of the BPM. Copies of both products are available from the Victorian DPI Bookshop (ph: 136 186) and the NSW DPI Bookshop (ph 1800 028 374).

Herbicide resistance Herbicide resistance is becoming an increasingly serious issue in serrated tussock management. There are now tussock populations in several different locations in both Victoria and New South Wales which have resistance to flupropanate, the herbicide that is widely regarded as the most effective and selective herbicide for its control. Resistant serrated tussock plant populations are proving harder to control, as resistance is carried in the pollen and can therefore be moved by wind, pollinating other tussock populations. Care must be taken that one herbicide type (eg. flupropanate) is not used continuously for serrated tussock management otherwise resistance will develop and spread. Emphasis should be on managing tussock in an integrated weed management framework, which can include careful application and rotation of herbicide types especially to initially kill adult populations. The application of flupropanate needs to be adjusted to suit a given control situation, with attention to proper calibration for herbicide concentration and minimising over-spray. A long-term emphasis then needs to be placed on increasing ground-cover and minimising disturbance.

Willows

Willows (*Salix* spp.) are amongst Australia's most serious riparian and wetland weeds and their management is complex. The 'developing willow management priorities' CD toolkit (Steel *et al.* 2008) was developed to understand willow distribution and risk to improve planning and enable effective decision making for willow management. The process to develop this project also provides a robust model that can be applied to other weed or NRM projects.

Developing willow management priorities CD toolkit The toolkit presents the work and results from comprehensive surveys of willow managers, a series of identification and mapping workshops and a weed risk assessment of 35 willow taxa. Land and waterway managers that are involved in willow management can use the toolkit to set priorities for on-ground management that provide the greatest environmental and economic benefits, and use it as a scientific basis for decision making to manage conflicting views about willows. The toolkit enables users to: view full weed risk assessment results and see which willow taxa are the highest risk to Victoria; see where willows occur using interactive, scalable PDF maps, or by creating (and updating) maps using the willows dataset on ArcGIS 9.2; use regional prioritisation matrices to decide where to focus management efforts; and find out the on-ground and legislative recommendations for willow management in Victoria and nationally.

Mapping tools and workshops kit Mapping tools are provided and include a list of core and suggested attributes for data collection (including willows-specific attributes); a template to record data on; and an example of data collection. These are based on the national core attributes for weed mapping (Thackway *et al.* 2004) and should be applied for all weed mapping projects. A workshop kit contains all the required extension resources to enable users to run willows identification and mapping workshops. Registration forms, a session plan, PowerPoint presentations and photographs are included and intuitive. The workshops kit could be easily modified to run workshops for different weeds, or used as a model to undertake other large scale mapping projects.

Blackberry

The Victorian Community Weed Model (VCWM) is being applied to manage blackberry infestations in priority areas. The VCWM is viewed as a community engagement and empowerment program leading to better coordination, ownership and leadership of weed issues among community members. It has consequently led to the formation of blackberry action groups in Victoria and Queensland.

In Victoria, the North East Blackberry Action Group within the Upper Murray region was established as a pilot group for effective and coordinated blackberry management with the assistance of the Victorian Blackberry Taskforce and the Department of Primary Industries. The North East Blackberry Action Group achieves voluntary control on both private and public land through cooperative partnerships with relevant stakeholders. Land managers set achievable targets and enter into three year management contracts. Education is an important component of the VCWM and demonstration sites set up in North East Victoria have shown contractors and community members correct herbicide application to highlight the link between herbicide effectiveness and pasture re-establishment post blackberry control.

The model has now been applied in Queensland with the establishment of the Community Blackberry Project within the Southern Downs Regional Council area. This has led to the delivery of coordinated extension services and strengthened community action, including the purchase of a twin-reel quickspray unit for use by members of the community. The National Blackberry Taskforce is focussed on supporting the adoption the VCWM by other states.

Gorse

The main challenge for the management of gorse (*Ulex europaeus*) across southern Australia is the longevity of seed remaining in the soil following treatment and removal of the above-ground plants. Seed life is estimated to be between 20–30 years. The National Gorse Taskforce (NGT) has established 25 year Memoranda of Understandings (MOU) with a number of regional and local government authorities in WA, SA and NSW to treat and eradicate gorse from their jurisdiction. These 25 year agreements have enabled the NGT to gain stakeholder agreement to embed recurrent treatment regimes into on-ground gorse management programs. These authorities agree to locate, map and re-visit infestation sites for twenty five years to inspect and conduct re-infestation treatment activities.

A challenge to this commitment is the loss of knowledge of infestation locations after treatment; particularly after staff move on and corporate knowledge is lost. To manage this risk, 'Landcare champions' within the community are sought and invited to become custodians of the knowledge. Their participation and authority to watch over the activities is formalised by co-signing a custodian pledge with the jurisdictional authority and the National Gorse Taskforce. Their written pledge, the maps of gorse locations and a copy of the MOU are housed in two yellow 'Gorse Batons' (document tubes) with a digital storage device carrying the same information. The small and larger batons each remain in the custody of the Landcare Champion and the jurisdictional authority respectively.

The community custodian of the baton has the right to remind the relevant authority of their commitment and to prompt them to abide by the agreement for the life of the MOU. These custodians also have the responsibility to pass on the baton to a new bearer should they be unable to complete their 25 year commitment. Formal annual meetings of the signatories at the anniversary of the signing ceremony assist in maintaining the momentum of the MOU.

Further information

For further information on any of the WoNS National Programs contact the relevant National Coordinator. Contact details can be found at www.weeds.org.au/WoNS/

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

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Summary

We reviewed the literature and surveyed land managers to investigate how natural ecosystems respond following management of Weeds of National Significance (WoNS) in Australia. While most of the 95 papers reviewed measured the effect of management on the WoNS, only 18 assessed the response of other plant species. In these studies, native plant species did not necessarily recover following management, and in many instances the managed WoNS was replaced by other weed species. A further three studies investigated the response of invertebrate communities and an ecosystem process following WoNS management, but none examined the response of vertebrates or microbial communities. A total of 168 replies were received to the land manager survey. Of the 142 land managers who performed some level of evaluation as part of their WoNS management program, 86 monitored the response of native plant species and/or other weeds than the WoNS, mostly using qualitative assessments. These managers reported no vegetation response after WoNS management (7%) or re-colonisation by a combination of native and weed species (52%) or only by native plants (33%) or the WoNS (2%). Our results emphasise the need for incorporating into management programs activities that assess and facilitate the recovery of native plant communities in conjunction with weed removal.

Consult the following for more detail:

Reid, A.M., Morin, L., Downey, P.O., French, K. and Virtue, J.G. (2009). Does invasive plant management aid the restoration of natural ecosystems? *Biological Conservation* 142, 2342-9.

A way forward for non-WoNS priority weeds

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Abstract

***Opuntia* species management in South Australia is clustered under the banner of the leading invasive; wheel cactus (*Opuntia robusta*). Early in 2008 a State Opuntia Taskforce was formed with the intent of raising visibility and improving coordination across NRM boundaries in relation to the Opuntias. The taskforce establishes a working model for non-WoNS weeds of State significance.**

The taskforce was initiated by the NRM governance structure to overcome operational barriers. Roles of the taskforce include cross-NRM border information exchange, review of State policy, clarification of the extent of distribution and degree of threat, coordination of strategic on-ground action, advocacy for a bio-control solution, and oversight for a SA Opuntia Management Plan. A similar cross-NRM operational management group is suggested for the deep rooted perennial weeds, utilising silverleaf nightshade (*Solanum elaeagnifolium*) as the banner species of primary concern.

Introduction

A State taskforce has been established to enable more strategic cross-regional management of *Opuntia* species in South Australia. The leading invasive *Opuntia* species in South Australia is wheel cactus (*Opuntia robusta* H.L.Wendl. ex Pfeiff). This species is increasingly becoming the 'banner species' for the invasive opuntioids cluster, with the term 'opuntioid cacti' adopted in reference to the numerous species of cacti within the subfamily Opuntioideae of the Cactaceae family (Harvey 2009). The impact and potential distribution of wheel cactus are particularly concerning in South Australia, and this species is regarded as a highly significant invasive.

The regional Natural Resource Management Boards in South Australia established the taskforce as an initiative to enable statewide management of the opuntioid cacti. The benefits of national scale management are apparent in relation to the Weeds of National Significance, however for weeds that are a significant priority at state level, but not nationally significant, a need for improved cross-regional management was apparent. The taskforce provides for statewide coordination of policy and control strategies, whilst also maintaining linkages with community.

Background

The opuntioid cluster group includes wheel cactus and other Opuntia species of concern such as prickly pear (*O. stricta*) and devil's rope (*O. imbricata*). However the invasiveness and potential impact of wheel cactus rank it the most significant member of the group in South Australia. Wheel cactus, is an invasive weed native to high-altitude regions of central and northern Mexico (Williams 2006). The species is well adapted to the semi-arid environment of southern Australia and was valued as a hedge and garden plant in the years following settlement of the pastoral districts in South Australia. There are three main loci within the State where it is now naturalised; in the central Flinders Ranges, the Parnaroo hills and around lower Lake Torrens. Additionally it occurs in low density, and very locally at higher density, in scattered locations around most of the semi-arid areas of South Australia (Figure 1).

The 20 Weeds of National Significance (WoNS) in Australia have strategies for control priorities at a national scale and Australian Government funding is targeted to the implementation of these strategies (Commonwealth of Australia 2008). Wheel cactus is not classified as one of the Weeds of National Significance (Thorp and Lynch 2000). In comparison weeds that are not Weeds of National Significance; non-WoNS weeds, are not specifically assisted at a national scale. As such, management of wheel cactus is administered by the States, and the establishment of a State Opuntia taskforce is an initiative that attempts to achieve the benefits of higher level strategic coordination at that scale.

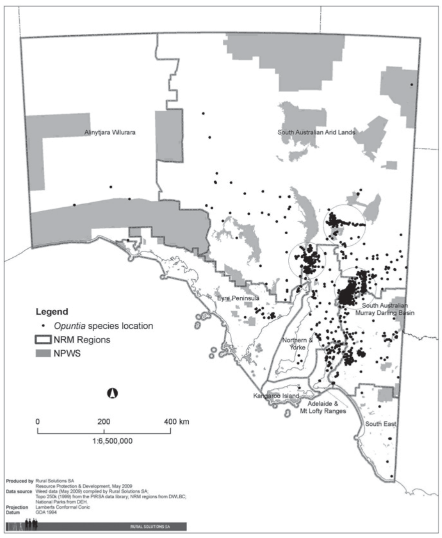

Figure 1. *Opuntia* spp. distribution in South Australia showing three major areas of infestation (modified from Harvey 2009).

Significance

Like a number of other environmentally impacting weeds, the gradual expansion of wheel cactus was largely unnoticed in South Australia until relatively recently. Concern raised by the small Blinman-Parachilna community in the Flinders Ranges in 1999, initiated a locally driven control effort (personal communication L. Edmunds). The landscape at risk is mountainous, rugged and spectacular, one of eight Australian landscapes designated an 'Iconic National Landscape' in 2008 (Tourism Australia 2009). This significance has leveraged awareness of the potential impacts associated with wheel cactus expansion, and the significant potential for expansion from multiple sites of occurrence around South Australia.

Wheel cactus is declared under the *South Australian Natural Resources Management Act, 2004*, within the prickly pears (*Opuntia* spp.) group. Risk, or threat and feasibility of containment, assessments have been undertaken at both State and regional scales. These assessments identify risk categories from 'medium' to 'very high' for wheel cactus in rangelands landscapes (Harvey 2009), with the degree of risk being greatest in ranges country. The impact is relatively minor at low densities, however wheel cactus has a specific photosynthetic biochemical pathway (Crassulacean Acid Metabolism) that minimises moisture loss and provides a competitive advantage under arid conditions (Nefzaoui and Ben Salem, 2002 cited in Williams 2006) that leads to gradual infilling and dominance. When established at higher densities, reduced flora and fauna species diversity is an assumed consequence.

Wheel cactus is potentially able to spread throughout significant areas of the southern rangelands in South Australia. It reproduces from fallen cladodes or pads (Angus 2005 cited in Williams 2006) or from seed that is spread by birds and other animals that feed on the fleshy fruit. Also recent climate change modelling indicates conditions in the southern areas of South Australia are likely to become more suitable for wheel cactus and expansion of relatively benign occurrences of wheel cactus is predicted (Kriticos *et al.* 2009).

The level of concern in relation to environmental and production ramifications of permitting wheel cactus to expand its range and establish at high density escalate when cost of control is considered. Stem injection into roughly one in five pads, or foliar spray if vehicle access is possible, are the two principle methods used. Costs have been estimated at $4.50 per plant on average (Edmunds 2006), with additional cost incurred in treating new recruitment that inevitably follows the initial removal.

State taskforce

The concept of a cross-regional taskforce was initiated by the SA Arid Lands Natural Resources Management Board. The taskforce establishes a multi-regional collaborative forum that can undertake activities beyond the capacity of individual regional authorities with respect to invasive cacti. It was envisaged as a vehicle that could better coordinate uniform policy, advocate the significance of the problem and develop a statewide strategic approach to control (Table 1). In particular, the taskforce was established to overcome barriers difficult to resolve at a regional scale. Membership consists of representatives of four natural resources management regions and a State agency technical advisor. Reporting is directly to each of the organisations represented.

In its inaugural year the taskforce has been able to achieve a number of critical capacity building activities. These include:

Redrafting of the South Australian policy for *Opuntia* species:

- Existing State level policy captured plants commonly known as prickly pears that were in the genus *Opuntia*. Recent revision of nomenclature mean there are several genera (including *Austrocylindopuntia* and *Cylindropuntia*) that should be included. The revised policy refers to opuntioid cacti and includes species within the subfamily Opuntioideae.

Development of a State distribution map:

- Existing distribution mapping was haphazard and generally at a regional scale. The lack of a statewide distribution map was recognised as a limitation in planning cross-regional activities and in advocating the extent of the problem on a larger scale. A single map has been generated from collated data supplied by each regional authority.
- A reliable estimate of area infested was not available. The taskforce undertook to collate this information and derived a total area infested by opuntioids in SA of over a million ha (Table 2), of which approximately one third (350 000 ha) is under active control and the remaining two thirds (700 000 ha) is uncontrolled (Harvey 2009).

Input into a State Opuntioid Cacti Management Plan:

- The Department of Water, Land and Biodiversity Conservation undertook to develop a management plan that would guide implementation of opuntioid policy across regions. The taskforce was able to function as a reference group and provide input to the plan's development.

Submission of a funding application to pursue preliminary studies into a biological control solution:

- An application to progress a biological control solution was made in partnership with key research providers focusing on wheel cactus which is listed as a candidate for biological control (Australian Weeds Committee 2009). Although unsuccessful valuable scoping of the work required to develop this control option is progressed.

Collectively these foundational activities have strategically positioned the management of the opuntioid group of cacti.

The model

Species cluster

It is significant that the taskforce is not limited to one cactus species. Instead the model that has been adopted utilises the comparatively higher profile of wheel cactus to develop strategic management of invasive cacti more generally. The potential for this model is to enable strategic principles to be applied under a leading invasive species, to a group of weeds that have a range of commonalities. It is envisaged that by addressing multiple species within a management group resources can to be applied with greater efficiency. The 'species cluster' concept is appropriate where several closely associated species have similar distribution and management practices for control do not differ substantially. If this model can demonstrate effective management of a species cluster, a cross-NRM operational management group could similarly be applied to the State's other primary non-WoNS weed of concern; silverleaf nightshade (*Solanum elaeagnifolium*) as the banner species for the summer active deep rooted perennial weeds.

Community linkages

The taskforce member regional bodies are each governed by a community based Board that is optionally supported by local groups. The community based natural resources management structure reflects increasing recognition of the integral requirement for participatory decision making. A function of the NRM Boards is to 'provide mechanisms to increase the capacity of people to implement programs or to take steps to improve the management of natural resources' (sec. 29(1)(c), *Natural Resources Management Act, 2004*). A strength of the taskforce model is its integral commitment to engagement through

Table 1. Extract of purposes from the State Opuntia Taskforce terms of reference.

i	To coordinate and provide for the exchange of information between the various opuntia control initiatives and field work around the State.
ii	To provide recommendations for the better coordination of opuntia policy.
iii	To investigate and promote more strategic and cost effective options for opuntia control.
iv	To raise awareness and see support from other States (and at the National level) in order to accelerate the implementation of any bio-control opportunities.
v	To assist with the implementation of existing control methods.
vi	To provide a clearer overall picture of and better evaluate the risk to the State represented by the spread of opuntia species.

Table 2. Area (ha) of opuntioid cacti in South Australia (adapted from Harvey2009).

SA NRM Region								
Adelaide and Mt Lofty Ranges	Alinytjara Wilurara	Eyre Peninsula	Kangaroo Island	Northern and Yorke	SA Arid Lands	SA Murray-Darling Basin	South East	Total (ha)
<1	0	111 453	0	217 734	687 300	27 115	0	1 043 604

the regions, and through community. As such an ongoing consideration of the taskforce is to foster processes for community engagement in opuntioid management.

Local 'cactus champions' are invited to regionally held meetings and the contributions of these individuals has emphasised the degree of importance local communities place on preventing wheel cactus spread. It has also highlighted their need for support from regional and State authorities to assist in achieving that goal. The Blinman-Parachilna Pest Plant Control Group in the Flinders Ranges is an example of investment though a community group that the taskforce recognises has contributed to on-ground opuntia control and also increased community capacity for strategic management in the longer term.

The way forward

The taskforce has laid the foundations, in its inaugural year, for regions to collaborate in defining priority control zones for management approaches of prevention, eradication, containment and impact reduction. Specific recommendations for management at a State scale are articulated in the South Australian Opuntioid Management Plan. Recommended management includes prevention of introduction, active management of current infestations, research and community engagement (Harvey 2009). The taskforce, being a collaboration of regional natural resource management bodies is particularly well positioned to ensure strategies developed for prevention and management are coordinated across the borders of regional administrative bodies. And, importantly, the taskforce has intrinsic linkages with community through the community based decision making structure in South Australian natural resources management.

Conclusion

Weeds that are significant at a State level require coordination of policy and strategy that is at a strategic scale but also closely linked to regional communities. The South Australian Opuntia Taskforce for the opuntioid cacti, a weed group with common management goals and practices, is proposed as a model which achieves these objectives. The taskforce has adopted the highly invasive species; wheel cactus, as a banner species to provide strategic direction. The success of this model is illustrated by the development of key management tools including a statewide distribution map, State management plan and policy review. These foundational achievements will benefit regional natural resources management boards in linking higher level strategic planning with local community engagement in cactus management.

Acknowledgments

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Thirty years of silverleaf nightshade, *Solanum elaeagnifolium*, on the Eyre Peninsula

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Summary

Silverleaf nightshade (*Solanum elaeagnifolium*) is one of the most intractable deep-rooted perennial weeds in the agricultural areas of south-eastern Australia. Its incredible root system makes it near impossible to eradicate, however, controls and intervention techniques have been developed that have contained spread and increased farmer profitability particularly on sandy soils. Local trials and demonstrations over 20 years have lead to an acceptable outcome that has involved a compromise of chemical solutions based on many years of fieldwork. Research into the plant's biology is still wanting and with climate change apparent, the likelihood of spread may increase due to changes in land use and management.

Introduction

Silverleaf nightshade (SLN) was not a well-known plant in the area where I have spent most of my working life. As with my first occurrence with the plant, where I sent an incorrect sample in for my first weed collection, most landholders unfamiliar with the plant will require quite an amount of coaching to understand the subtle differences with this plant and native look-alikes. In the 1980s many cereal farmers made the mistake of thinking this was purely a summer weed and of little consequence to winter cereal crops grown on the Eyre Peninsula (EP). Likewise spread mechanisms for the weed were usually blamed on tillage equipment, as the plant was well known to have a tuber like root system. Little heed was paid, or even known that livestock readily ate the berries and passed out the seed. While most landholders who had the problem could see it was an issue, attitudes were 'we can't do anything other than sterilise the ground'. Rumours of a biocontrol abounded and a foreign bug from a far off land seemed like an excellent 'silver bullet'.

This paper is a small snapshot of the many field trials conducted by myself and colleagues over a 30 year period and the changes in attitudes and practices that have taken place during that period.

Discussion

After a few years of general fieldwork I began to realise that this weed was not only spreading unchecked but was also causing real yield losses. I started on the long road of getting a community focused on the plant, which until that point had been 'too hard'. It had been called 'tomato bush' by most and I saw this as a barrier as we had at least four other native *Solanum* species that looked much like SLN. So began the task of converting a community to calling the weed silverleaf nightshade or SLN which mainly involved lots of publicity and almost annoyingly correcting landholders at group and field meetings.

Around the same time I took a good look at the historical data, the 1970s trials in particular, and soon realised after talking to those concerned, that they believed the weed was being looked after by the Government! In the early days of trials we thought SLN might have had a soil preference or some biota requirement. This was due to the staggered nature of the clonal outbreaks. I think it is fair to say that the plant has no preferences and the triggers for establishment in our part of the world are relatively simple, an area I will discuss later in the paper. Generally, the perception of farmers in the 80s was that SLN was spread slowly by machinery and there were no controls!

I began to talk to farmers about the differing subspecies and identification and how small outbreaks could be controlled with spot treatment. Equipment was very basic with many only having a firefighting knapsack, which was never calibrated. Spot spray techniques improved as many farmers in the region began to chase skeleton weed, but results were generally poor and the science of root uptake was not well understood (and probably still isn't). We began to look at spot sprayers and calibration and soon worked out that those using Tordon 50D® (the chemical of choice) might be applying anything between 6 and 60 litres per hectare and so an extension program followed. At this time glyphosate was relatively expensive at around \$16–18 L^{-1} and so in 1982 when rope wicks arrived they looked like a great saving and may be suited to weeds that stood off the ground. Poor design and paddock rocks ruined any early aspirations we had in that area. Boom sprays became larger and more sophisticated and nearly every farmer had one but the concept of summer spraying was not understood and anyway the sheep needed something to chew on! At this time pasture was almost 40% of the mixed farming makeup.

In 1988 along with my friend John Heap, a canny researcher from Adelaide, I pursued our suspicion that livestock (mainly sheep) were spreading this weed and that poisoning from the plant was not an issue. I must say that it was the mapping of outbreaks that led me to this discovery, and very soon after we started the sheep dung trial we realised that a massive amount of seed was being passed on a daily basis and that the germination rates were also quite high. This lead to a rethink about contaminated livestock statewide and an excellent extension program followed. The trial showed that sheep may excrete around 300 seeds per day and that while most seed had passed through by day 4–8 some seed was still in the sheep after four weeks. Suddenly the emphasis went from tillage equipment to livestock and even spread within paddocks due to winter tillage was now questioned. Having said that, I had been looking at this plant for many years and was still yet to see a seedling in field conditions. So what were the triggers for germination and more importantly perennial establishment? I will explore this matter near the end of the paper.

A farmer friend, Geoff Bammann, is a very innovative chap and loves a challenge and it was with his help that I started my string of chemical trials. I had, of course carried out many small plot trials on other species by this time, but given the clonal nature of SLN, I guessed that larger plots that could be easily reaped were the way to go. The various formulations of 2,4-D had been trialled but in most cases the yield increases were varied and in the 5–10% range. These had mainly been carried out on the better farming land with heavier soils (2–6 SLN shoots m^{-2}) but my observations were that it was in our sandy soils where SLN was prolific (20–40 shoots m^{-2}) that the real problem lay. This posed a challenge of convincing farmers to spend money on their poorer land and also to remove cover from late summer to opening rains in May/June; rendering paddocks almost non-grazing!

A lot of the decisions about chemical choices revolved around \$ ha^{-1} and with interest rates high, farmers were loath to make new investments. Pretty soon though we were getting yield increases of 30% or more and this was being quickly replicated in the field by a handful of farmers. Over the next 10 years or so we continued our trials, always testing new products and additives and with the drop in price of glyphosate the community began to embrace the concept of broad acre SLN control in a 'whole of district' manner. I found it particularly useful to ask landholders to switch off the boom spray and then in the following crop carry out a simple herringbone trial to prove yield increases.

Over the years we tested many mixes and additives, timing trials (which meant all spraying finished by 8 am); carpet wipers, mow and spray, just to mention a few. Many of these were simple 'suck and see' experiments and won't be included here. The results below are those treatments, which I believe have a reasonable amount of science behind them!

What I have not covered in this paper are the hours I spent in deep pits looking at the roots of this plant and the challenges that poses. If we are not on top of the biology of this plant we are starting a long way behind with any easy solutions.

Results

The following are a compilation of the many trials and observations I have conducted over the years (Table 1). I have not published exhaustive figures but rather picked best treatments of the day. This paints a picture that SLN certainly causes significant yield losses in winter cereal grains ranging from 10–40% depending on the nature of the soil, the plant's ability to produce summer shoots and the timing of opening and closing growing season rain events. Should anyone wish to discuss any aspect of any trial or require further data I am happy to assist.

Conclusions

Many years of working with this weed and an active community interaction have cemented the point that attitude change in the rural community is usually slow and best based on observations and not fear! Having said that, the change can take place quite rapidly when the observations are clearly visible, well tested and produce cost-benefit figures that are realistic. It is not enough to simply prove your point in one field with one landholder from one social group; but to spread your wings, being careful to stick with science even though that community loves silver bullets. Speaking of silver bullets there is no doubt that while bio-controls have their detractors, when it comes to this plant almost every single affected landholder is hanging out for a helping hand.

No doubt the biggest change in the spread of this weed has been the control of movement of contaminated livestock. However, spread still continues and given the pressures of farm build-up, leasing of properties, and corporate farming, there appears to be little consideration given to this long-tem issue.

The other great change has been the advent of 'summer spraying' and while I would like to attribute some of this to my tireless efforts, the truth may be that

Table 1. Trials and observations carried out on silverleaf nightshade in Eastern Eyre Peninsula).

Trial type	Id	Best result % yield increase	Best product per ha	Comment
Obs	Prisc 1982	30%	2,4-D ester	Excellent shoot reduction but plots were very small and outbreaks were inconsistent
Obs	Camp 1983	Nil	Glyphosate 50%	Rope wick broke on paddock rocks and was impractical
Trial	Hendo 1990	20%	2,4-D ester	Good conditions 88% shoot reduction. Farmer application with harvester size plots
Trial	Bamm R E 1993	30%	1 L glyphosate 2,4-D ester	Slower kill and included summer grasses which meant more moisture retained and possible disease break
Trial	3 site trial 1996	80%	1 L glyphosate 500 mL amine 2,4-D	A surprising result which at a later date showed the mix worked before antagonism set in
Trial	Shard 1998	55%	1 L glyphosate 1.5 Surpass®	Great conditions and Surpass (present as dimethylamine and diethanolamine salts) proved a winner
Trial	Wegner 1998	36%	2 L glyphosate (200 L water)	This trial showed more glyphosate is no better 4 L ha^{-1} than 2 L ha^{-1} and that using more water could be a cheaper option
Trial	Ramsey 1999	Nil	Variety of glyphosate mixes	Trial set up with triticale crop, but it rained every week and so weeds and crop were both satisfied
Obs	Bamm SP 2000	30%	1 L glyphosate 2 L Surpass	Consistent improvement with surpass as well good timing for application (early in ideal conditions)
Trial	grave trial 2000	99%	20 kg Graslan®	No mature SLN shoots for nine years. They do appear near plot margins but die eventually. No crop for seven years
Trial	Bamm CB 2001	25%	1.5 Credit and Bonus® 100 mL 2,4-D ester	Just testing a new glyphosate product 'Credit and Bonus' with 20+ SLN shoots m^{-2} in the plots
Trial	Price's 2002	20%	1 L glyphosate 400 mL (625) amine	Yet another trial to reinforce local farmer approval. Split application to avoid antagonism was trialled and while best result was not significant
Obs	Spray roll 2003	Nil	1 L glyphosate	We were looking to damage plants for better intake, but our equipment failed to produce!

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…/Table 1 continued.

Trial type	Id	Effect on SLN	Product	Comment
Obs	Road translocation 2003	Kill single shoots	2,4-D amine vs. glyphosate	Looking at whether treating a single shoot which was part of a clone might effect adjacent plants
Obs	Paint scrub trial 2007	Single shoot death	Glyphosate 2%	Again trying to test translocation to adjoining shoots but added the effect of Scouring chemical versus painting. Significant effect in two days with scouring
Obs	Dung trial 1991	30 day cleanout	10 sheep control fed	Most SLN seeds out in eight days but some seed appearing up to 30 days

the drop in the price of glyphosate in the late 1990s was a real godsend for this process. Even under the current poor economic climate, almost every farmer who has significant SLN in my area sprayed all their paddocks this summer. Which is a massive turnaround from the early 1990s.

At this point looking back over my fieldwork, two things appear to stand out. It appears the combination of chemicals glyphosate and a phenoxy give best value for money in broadacre controls and a chemical like Graslan needs to be developed, that will positively kill new outbreaks with a better than 60% result.

Meanwhile as I mentioned previously, the nature of farming locally has changed with much less tillage and more use of herbicides generally. Farm sales are still carried out covertly and many landholders discover all too late that they have purchased SLN.

Having this plant covered by various State legislation is good for branding it a 'noxious weed' but at times it also puts it in a bag of old time thinking along with things like horehound and one wonders if the new generation of farmer takes legislation seriously anyway!

Cash strapped grains bodies certainly don't take SLN seriously and in fact may also think that because governments have SLN on their list that they are 'handling it'! This weed fell off the list when WONS (weeds of national significance) were being considered and I suspect that was because it is a low threat to native vegetation and conservation zones. I have not seen the plant invade native vegetation other than where it is disturbed, grazed, or in poor condition.

As I will demonstrate in my visual presentation people are far more understanding of the issues this weed poses once they see the root system and have its physiology explained. This is a plant that can cope with the most severe applications of stress be it climatic or human projectiles. Once established it simply adjusts and in many instances I have observed that it will survive for years underground without ever seeing the light of day!

The future and climate change

To understand where this plant might go in the future, I would like to paint the picture of how I believe it survives and thrives. As observed by many, germination is triggered by a variation in day and night temperatures of 15/30°C and sufficient sustained moisture conditions to break down the mucilaginous coating of the seed.

In the climate of Eastern EP ideal conditions (temperature fluctuations) mean the window of opportunity is quite narrow. It is also interesting to look back at rainfall records and see when explosions of this weed may have happened in relation to rain events. Given that we are looking at the months of November to March as far as the temperature range is concerned and remembering that perhaps as low as 5% of the days during that period might fit within the range, the chances of ideal conditions are quite low.

The rainfall occurrence during that period is much easier to look at than temperature fluctuations and the scenario of falls that might allow germination, then having follow-up rain to allow establishment, seems to fit with when we have had significant population expansion of the weed locally. For example, see the Table 2 below for such periods.

Along with some local knowledge and talking to some older farmers before they passed on, it appears SLN established after the War probably in 1946, which was a very wet year. Then we have to wait til 1971/72 for another ripe period, which also fits with the fact that farmers started complaining around then and so the research started to happen in the mid 1970s.

As for the 1990s I can vouch for the fact that the periods of 1993 and 1998 saw significant establishment and also coincided with when I was undertaking a fairly intense series of field trials and observations.

So it appears we either need a significant rain event prior to Christmas with a sufficient follow up to get the plants established or, one or more significant rain events in late February early March. It would be reasonable to assume that with climate change the occurrence of temperature variation will increase and more severe rain events in summer are likely. Also, with more sporadic cropping opportunities general summer spraying may occur less and SLN may have more windows of opportunity to establish.

In closing my wish for research would be to gain more knowledge in the area of root morphology and anatomy of the plant (which may be similar for other deep rooted perennials) and a better understanding of how chemicals could be more targeted to kill such root systems.

Table 2. Monthly rainfall (mm) for Cleve, Eyre Peninsula. Bureau of Meteorology station 18014.

Year	Jan	Feb	Mar	Nov	Dec
1946	34.3	163.2	18.3	83.2	49.2
1971	3.1	10.6	74.2	45.7	32.9
1972	71.7	64.4	2.6	7.4	5.8
1992	15.0	6.6	67.0	47.0	140.6
1993	76.4	10.2	25.6	18.2	48.8
1997	13.0	124.6	10.2	34.0	39.8
1998	53.6	14.6	18.0	34.2	17.2

Acknowledgments

This is not an exhaustive list but just some of the people who have shared their time and enthusiasm in my personal battle with SLN. John Heap, John Charlton, Stan Cornish, Tony Zwar, Peter Sheridan, Geoff Bammann, Duncan McCallum. Thanks!

Reducing badly behaving plants: recent national weeds research

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Summary

Between 2004 and 2008 the Australian Government committed $44.4 million to the national Defeating the Weed Menace program to identify Australia's most threatening weeds and to implement measures for their control.

A research and development (R&D) component of the program was managed by Land and Water Australia on behalf of the Department of Agriculture, Fisheries and Forestry and the Department of the Environment, Water, Heritage and the Arts. The goal of this three year R&D component was to generate new knowledge to prevent the development of new weed problems, to reduce the impacts of existing weeds of national priority, and to build capacity for their management into the future.

Between June 2006 and November 2008, 27 projects were directed to:

- **assessing risks of different pathways of weed ingress;**
- **impacts of land use change on weed incursion;**
- **developing 'best practice' early detection, survey and eradication of potential weed species;**
- **identifying biocontrol agents for priority weed species;**
- **developing new integrated weed management strategies that incorporate an understanding of landscape scale ecological processes;**
- **quantifying the impacts of weeds on sustainability and the environment (including the ecological costs of weeds) and the relative benefits and costs of different weed control measures; and**
- **providing knowledge to support a national information system for weeds.**

A key focus of the R&D has been the generation of knowledge products designed to maximise uptake of the information generated. As the program drew to a close in June 2009, key cross-project learnings were highlighted and input relevant to future weeds R&D at the national level identified.

Keywords: weeds R&D, national priorities, key learnings, adoption.

Introduction

In June 2006 the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) contracted Land and Water Australia (LWA) to manage, on behalf of both DAFF and the Department of Environment, Water, Heritage and the Arts (DEWHA) the $5.4 million research and development (R&D) component of the national weeds program 'Defeating the Weed Menace'.

LWA was a national research broker seeking to increase knowledge and to encourage understanding and informed debate which will inspire innovation and action in managing our natural resources sustainably.

In this capacity, LWA sought to ensure that the research projects contracted benefit not just the rural production systems affected by weeds, but also the diversity of species and ecosystems that make up our uniquely Australian landscapes. Weeds are estimated to cost Australian agriculture around $4 billion per annum. Although less well documented, the costs to nature conservation and landscape amenity are thought to be of a similar magnitude.

The projects

Twenty-five projects addressing a broad sweep of weeds-related issues were contracted through two open calls for proposals. Together these projects (see Table 1) saw an investment of some $4.54 million of DWM funding, together with $4.31 million of cash and in-kind contributions from weeds research organisations and interested third parties.

Two additional projects were commissioned later in the program, each directed to addressing gaps in new knowledge about weeds.

A study of the needs of potential end-users of a national information system for weeds indicated clearly that priorities other than biosecurity surveillance loom large as potentially benefiting from a nationally coordinated information system on weeds.

Several jurisdictions also invest heavily in the development of biological control agents for weeds. However, our understanding of how best to select target weeds for which biocontrol will become an important part of management remains limited. Within the DWM R&D program one project was directed to developing a framework to improve the targeting of weed biocontrol projects within Australia.

Discussion

In addition to the information generated from each of these projects individually, several important themes emerged from across the whole program which will assist in managing invasive plants that impact adversely on agriculture and the environment.

Researching and managing landscape rather than weeds

One of the factors highlighted by many of the DWM R&D projects is the complexity of interactions between landscape processes and the differing components of the landscape. Projects addressing land use and changes in that use, whether through grazing management, changes to our aquatic waterways or peri-urban settlement all draw attention to the need to better understand and integrate holistic landscape management, rather than simply address the particular weed of concern. Colloff *et al.* (2009) provide an integrated framework for managing weeds within a broader natural resource context.

The importance of monitoring and evaluation

Related to this is the importance of longer-term monitoring and evaluation in assessing the effectiveness of weed management. As our knowledge of complex ecological processes and their interactions increases it is becoming increasingly apparent that adaptive management of weeds will rely on longer term monitoring than is usually associated with a 2–3 year funded project. The project completed by Reid *et al.* (2009), in particular highlighted this need as it relates to recovery of natural systems after a Weed of National Significance has been removed.

Facing the challenges of biological control

Also highlighted by the suite of DWM R&D projects are the numerous challenges faced in seeking effective biological control agents. Both a review of biocontrol work in Australia during the past decade (Auld 2009) and a framework to assist in better targeting of plant species for biocontrol (Paynter 2009) are legacies seeking to assist in addressing these research challenges.

Weed behaviour changes in response to climate change

As the impacts of human-induced climate change increase, plants will behave badly in different ways. While only one of the DWM R&D projects (Scott *et al.* 2009) focused directly on the implications of climate change for weed spread, several contained elements relevant to weed

Table 1. DWM R&D themes and projects.

Research theme and sub-themes	Projects	Lead researcher/Lead organisation
Developing 'best practice' early detection, survey and eradication	Managing weeds under future scenarios for environmental flows in the Murray River	Dr Matt Colloff, CSIRO Entomology
Assessing risk of different pathways of weed ingress	Modelling climate change impacts on 'sleeper' and 'alert' weeds	Dr John Scott, CSIRO Entomology
	Pathway risk analysis for weed spread within Australia	Prof. Brian Sindel, University of New England
	Serrated tussock: Managing native pastures to prevent invasion	Dr Aaron Simmons/Prof. David Kemp, Charles Sturt University
Identifying biocontrol agents for priority weed species	Biological control and ecology of alligator weed	Dr Shon Schooler, CSIRO Entomology
	Development of new biocontrol agents for parkinsonia	Dr Tim Heard, CSIRO Entomology
	Improving management of salvinia in temperate aquatic ecosystems	Dr Bertie Hennecke/Assoc. Prof. Kris French, University of Wollongong
	Importation and release of a new biological control agent for Scotch broom	Dr Jean-Louis Sagliocco, DPI Victoria
	Boneseed rust: a highly promising candidate for biological control	Dr Louise Morin, CSIRO Entomology
	Enhancing noogoora burr biocontrol in northern Australia	Dr Louise Morin, CSIRO Entomology
	Importation, rearing and field release of the cape broom psyllid	Mr Ken Henry, SA Research and Development Institute
Land use change impacts on weed incursion	Land use effects on soil nutrient enrichment: Risks for weed invasion	Dr Elizabeth Lindsay/Dr Saul Cunningham, CSIRO Entomology
	Effect of land use and peri-urban development on aquatic weeds	Dr Lauren Quinn/Dr Shon Schooler, CSIRO Entomology
	Understanding and determining mechanisms to prevent weed invasion in coastal vegetation	Dr Tanya Mason/Assoc. Prof. Kris French, University of Wollongong
Developing new integrated weed management strategies at landscape scale	Developing a model for environmental weed management in fragmented landscapes	Mrs Melissa Herpich, Department for Environment and Heritage, SA
	Optimising management of core mesquite infestations across Australia	Dr Rieks van Klinken, CSIRO Entomology
	Elucidating relationships between distribution and invasion in riparian zones	Dr Fiona Ede, DPI Victoria
Developing efficient methods for surveying and eradicating agreed emergent weeds	Best practice on-ground property weed detection	Prof. Brian Sindel, University of New England
	Exploring agents of change to peri-urban weed management	Ms Jo Harding, Upper Murrumbidgee Catchment Coordinating Committee
	Cost-effective surveillance of merging aquatic weeds using robotic aircraft	Dr Salah Sukkarieh, University of Sydney
Quantifying the impacts of weeds on sustainability and the environment…	Quantifying costs and benefits of buffel grass	Dr Margaret Friedel, CSIRO Sustainable Ecosystems
	Pinus radiata in bushland: Assessing the issues in the Green Triangle	Mrs Melissa Herpich/Dr Andrea Lindsay, Department for Environment and Heritage, SA
	Quantification of the environmental and control costs of weeds	Dr Samantha Setterfield, Charles Darwin University
	Evaluating the environmental benefits from managing WoNS in natural ecosystems	Dr Adele Reid/Dr Louise Morin, CSIRO Entomology
	Ecological, economic and social considerations in spray control of hymenachne	Prof. Bob Miles, Central Queensland University

management in a changing physical climate. The projects that focused on weed management in riparian and floodplain areas drew attention to the complex interactions between weed invasion and management and altered water regimes in the face of climate change. Similarly, the project assessing the environmental and control costs of tropical tall grasses drew stark attention to the interactions between climate change, changing fire regimes and the influences of some weed species on fire.

Plants of commercial value also behave badly

Several of the projects completed with the DWM R&D program focused on improving understanding and management of plants of commercial value that also pose considerable threat from invasion of natural areas, waterways and other systems. Miles *et al*. (2009) address policy, institutional and management issues designed to improve the future impacts of plants as diverse as buffel grass (*Cenchrus ciliaris*), gamba grass (*Andropogon gayanus*) and para grass (*Urochloa mutica*), pine wildlings (*Pinus radiata*) and the ponded pasture plant hymenachne (*Hymenachne amplexicaulis*).

Other needs and opportunities highlighted by the DWM R&D program are many and varied (Auricht and Yapp 2009). Cross-disciplinary and interdisciplinary research is increasingly recognised as important in addressing the social, economic and environmental impacts and management of weeds, whether in rural production systems, in natural environments or where the plant species involved has both production value and invasive weed characteristics

By combining spectral data analysis, smart algorithms enabling machine learning and the use of unmanned aircraft in weed detection it is becoming increasingly possible to detect and manage weeds in difficult and inaccessible areas (Sukkarieh 2009).

Weeds are a persistent problem which costs Australia dearly. Only by combining the efforts of a diverse set of technical expertise with on-ground commitment and vigilance are we likely to manage them effectively in a changing world. Even then, effective long-term monitoring not just of the weeds, but of what comes after they have been controlled or removed will be an essential element of effective adaptive management in the medium to longer term.

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Effects of flupropanate on non-target species – glasshouse

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Abstract

Flupropanate is considered a selective herbicide that is used in the control of Chilean needle grass (*Nassella neesiana*; CNG) and serrated tussock (*Nassella trichotoma*; ST). The full extent of the effects of flupropanate on native and improved pasture grasses and legumes is unknown. Evidence from DPI experiments has shown that flupropanate has a degree of selectivity and can damage non-target species such as introduced pasture grasses, legumes and native grasses (Snell *et al*. 2007). The non-target effects of flupropanate need to be better understood to avoid damage to desirable species, whilst also clarifying controlled actions listed under the EPBC (Environmental Protection and Biodiversity Act) act for the Victorian volcanic plains.

A glasshouse experiment using soil from Oaklands Junction (Vic) was setup to validate the non-target effects of flupropanate applications up to 2 L ha^{-1}. Target plants used were CNG and ST. Non-target native species used were kangaroo grass (*Themeda triandra*), poa tussock (*Poa labillardieri)*, wallaby grass (*Austrodanthonia duttoniana*) and spear grass (*Austrostipa bigeniculata*). Non-target introduced species used were perennial rye grass (*Lolium perenne*), cocksfoot (*Dactylis glomerata*), phalaris (*Phalaris aquatica*) and subterranean clover (*Trifolium subterranean*). All plants were grown in the glasshouse and sprayed using a laboratory track sprayer after an acclimatisation period. Plant growth was monitored for 14 weeks after application, with all plants destructively harvested at the end of the trial.

ST was effectively killed by rates of flupropanate up to 2 L ha^{-1} whilst CNG was not effectively controlled. Apart from a transient decline in growth vigour, flupropanate application up to 2 L ha^{-1} did not significantly affect the native or introduced grass tested. Subterranean clover was significantly affected by low rates of flupropanate.

An assessment of the extent of serrated tussock resistance in the Rowsley Valley, Victoria

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Summary

A 100 km^2 serrated tussock resistance survey in the Rowsley Valley of Victoria has confirmed that serrated tussock resistance is far more widespread than had been previously thought. Approximately 20% of surveyed sites surrounding a property previously confirmed with serrated tussock resistance to flupropanate had significant survival (resistance) to an application of label rate flupropanate compared to known susceptible serrated tussock plants treated at the same time. This suggests that serrated tussock resistance is not localised and should now be treated as a widespread issue. Any further Government investment that is deemed appropriate could be in the form of support for awareness and extension packages to affected land managers and/or ongoing research into new management techniques for this Weed of National Significance. This paper makes suggestions for how land managers can deal with the potential loss of flupropanate as a management tool and makes recommendations for how Governments and Industry should respond.

Keywords: serrated tussock, *Nassella trichotoma*, flupropanate, resistance.

Introduction

Serrated tussock (*Nassella trichotoma* (Trin. & Rupr.) Barkworth) is a South American exotic unpalatable perennial grass that has been classified a Weed of National Significance in Australia due to its severe agricultural and environmental impacts (Thorp and Lynch 2000). It was first identified in Australia in 1936 and has since spread to occupy more than 2 million ha (Osmond *et al.* 2008) with an estimated potential distribution of 31 million ha (McLaren *et al*. 1998). It is costing Australia millions of dollars in lost agricultural production while also invading and replacing Australia's endangered native grasslands (McLaren *et al.* 1998). Despite years of research, there are still limited control options for managing weeds such as serrated tussock in Australia (Michalk *et al.* 1999). The only registered herbicides for control of serrated tussock in pastures are flupropanate, glyphosate and 2,2-DPA. The ability of organisms to develop resistance to a particular chemical control agent after constant exposure to that chemical over many generations is well documented in the scientific literature (Lebaron and Gressel 1982). Flupropanate is widely regarded as the most selective and effective herbicide for controlling serrated tussock while its residual action in the soil can prevent serrated tussock regrowing for three to five years (Campbell and Vere 1995). It is classified by as a Group J herbicide that inhibits plant lipid synthesis and is regarded as a relatively low risk herbicide for resistance (Croplife Australia 2008).

Flupropanate resistance has been identified in a population of serrated tussock in Victoria with serrated tussock surviving application rates as high as 8 L ha^{-1}, which is four times the recommended rate used for controlling this species (Noble 2002). A national serrated tussock resistance survey was undertaken by the Victorian Department of Primary Industries during 2004 to determine the extent of resistance in Australia (McLaren *et al.* 2006) and resistance has now been confirmed at three sites in Australia (two in Victoria and one in NSW) (McLaren *et al.* 2008).

Durai (2008) conducted detailed serrated tussock population crossing studies of known flupropanate resistant and susceptible serrated tussock plants. His results show that resistance can come from both parents, strongly suggesting a genetic origin with 80–90% matching of seedling type to maternal parent type strongly indicating the involvement of a maternal component in the inheritance of flupropanate resistance, with a minor proportion of resistance heritable through pollen. He therefore hypothesised that the maternal cytoplasm of the female parent plays a significant role in the transmittance of flupropanate resistance. The minor transmission of resistance via pollen observed in all crosses suggested transmission also by a component in the pollen grains.

Another critical factor in serrated tussock resistance is understanding how serrated tussock reproduces. Durai (2008) showed that the majority (85–90%) of serrated tussock flowers don't physically open (pollen is transferred within the closed flower) meaning that only 10–15% of serrated tussock flowers are available for pollen transfer. The implications of this are that a serrated tussock plant resistant to flupropanate will produce at least 85–90% resistant seeds as they will fertilise within the unopened flower. However, only a relatively small proportion (10–15%) of the flowers will send out resistant pollen to potentially spread flupropanate resistance great distances.

A critical issue for weed management authorities wishing to contain serrated tussock resistance to flupropanate is understanding the current extent of resistance infestations. If the resistant serrated tussock is confined within a very small area (i.e. to a single property), then the serrated tussock resistance can be prioritised for management with Government assistance for direct control costs and compliance. If the serrated tussock resistance is widespread then management becomes more problematic and Government investment is likely to be directed towards extension and advice promoting integrated control.

This paper reports on an assessment of the extent of serrated tussock resistance occurring within a 100 km^2 region surrounding a known serrated tussock resistance site located in the Rowsley Valley of Victoria. This project aims at helping Government scope their future response to the serrated tussock resistance issue.

Materials and Methods

Field component – serrated tussock sampling

A known serrated tussock population resistant to flupropanate occurs on a property in the Rowsley Valley of Victoria (37°41'S, 144°21'E) (McLaren *et al.* 2008) (Figure 1). To assess whether serrated tussock within the general vicinity of this 'resistant property' were also resistant to flupropanate, serrated tussock samples (a serrated tussock tiller with roots attached) were collected from within a 5 km radius (100 km^2) of this property during May 2008. This area was grided and assigned numbers (1–100). For a 2 km radius (16 km^2) surrounding the known serrated tussock resistant property, roadside and paddock collections of serrated tussock samples were made within each square km. For the additional 84 km^2 away from the 16 km^2 selected around the affected property, 50% of the grided sites were selected using a random number generator (42 sites × 10 serrated tussock plants = 420 plants). A further two sites were sampled on advice from local landowners. An additional 40 individual serrated tussock plants were collected from St Albans Victoria, (37°45'S 144°47'E) during May 2008 that was previously known to have serrated tussock susceptible to flupropanate. In total, 640 individual serrated tussock plants were assessed for flupropanate resistance.

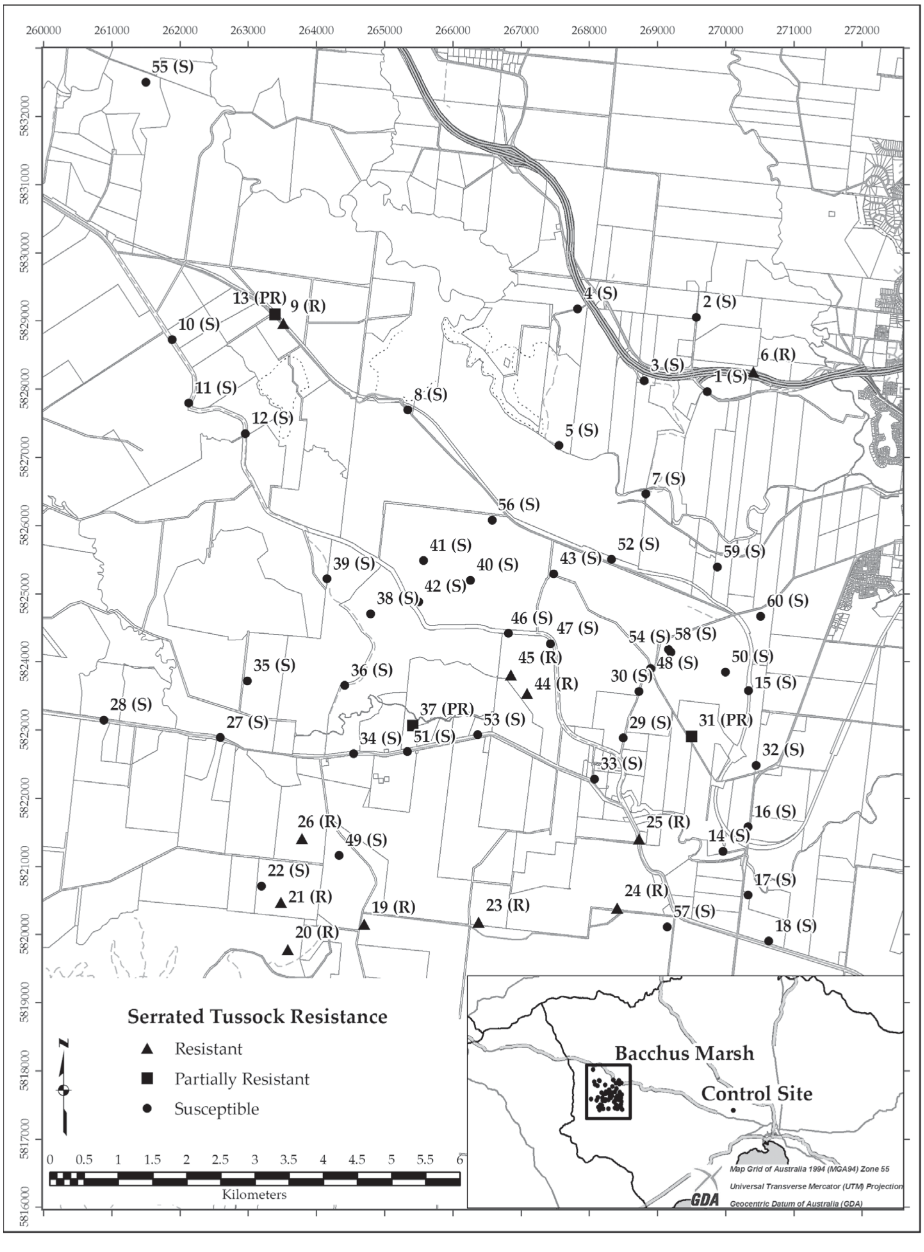

Figure 1. Map of serrated tussock resistance survey locations and resistance probabilities after treatment.

At each sampled location, 10 individual serrated tussock plant samples (tiller and roots) were collected and placed into labelled plastic bag recording date collected, location name and latitude/longitude. Samples were returned to DPI Frankston and plants from each sample location were potted into two 15 cm pots using standard potting mix (five individual serrated tussock samples per pot). After potting, the serrated tussock plants had their leaves trimmed to aid in recovery after transplanting and were then grown for three months in a greenhouse at an average temperature of 20°C, watered on alternate days and were randomised fortnightly until plants were growing actively.

Application of flupropanate

The sampled serrated tussock plants were sprayed with Taskforce® (745 g a.i. L^{-1} flupropanate) using a mechanical track sprayer in a spray cabinet with a standard flat nozzle (SS11002), to deliver a spray volume of 150 L ha^{-1} at 280 kPa at the recommended field rate (1.49 kg a.i. ha^{-1}). Known flupropanate sensitive serrated tussock plants collected from St Albans were included in the experiment as controls. Assessment of flupropanate resistance was based on a visible injury scale of 0 = healthy to 9 = dead for each individual serrated tussock plant sampled. Assessments of flupropanate impacts to the surveyed serrated tussock samples were made at 89, 120, 173, 212 and 262 days after treatment (DAT).

Results

Statistical analysis

The sites plus untreated controls were analysed as a two replicate fully randomised one-way analysis of variance, with each pot being a unit of analysis (Payne 2006). The mean damage scores of each survey site, and of the untreated control, were compared to the St Albans treated control using 95% and 99% hypothesis tests using one-sided Dunnett's simultaneous comparisons (Miller 1981). These tests allow comparisons of many treatments with a control, while maintaining the nominal significance level.

The statistical analysis of flupropanate impact on the sixty serrated tussock sites surveyed from the Rowsley Valley 89 days after treatment are shown in Figures 1 and 2. Eleven out of the sixty surveyed sites (18%) were not significantly affected by the flupropanate treatment (99% probability) suggesting they were truly resistant to flupropanate. Similarly, an additional eight sites (12%) were not significantly affected by the flupropanate treatment (95% probability) suggesting they were very likely to be resistant to flupropanate. Thus, almost 30% of the sites surveyed in the Rowsley Valley were comparatively unaffected by the recommended (2 L ha^{-1}) flupropanate treatment compared to the known flupropanate susceptible serrated tussock plants collected from St. Albans (Sites 61 and 62). Serrated tussock plants sampled from collection sites 22 and 54 died before application of the flupropanate treatment suggesting that they may have been already sprayed with herbicide at the time of collection.

A map of the survey region showing sites and results of the serrated tussock flupropanate survey is shown in Figure 1. Two of the sites showing resistance (sites 44 and 45) come from the original property identified with resistance. It can be seen that the resistance is quite widespread and is not isolated to a single property. Several 'resistant' sites occur along Reids road (Sites 21, 20, 19, 23) and close to Glenmore road (Sites 34, 37, 53, 33, 25) (Figure 1).

By the last assessment (day 262 DAT) 14 of the 60 flupropanate treated serrated tussock survey sites still had live serrated tussock plants (Figure 3). The majority (11 out of 14) of these corresponded to those sites identified as resistant locations from assessment 1 (89 DAT).

Discussion

This 100 km^2 serrated tussock resistance survey of the Rowsley Valley of Victoria has confirmed that serrated tussock resistance is far more widespread than had been previously thought. Approximately 20% of surveyed sites had significant survival to label rate flupropanate application (resistance) compared to known susceptible serrated tussock treated at the same time.

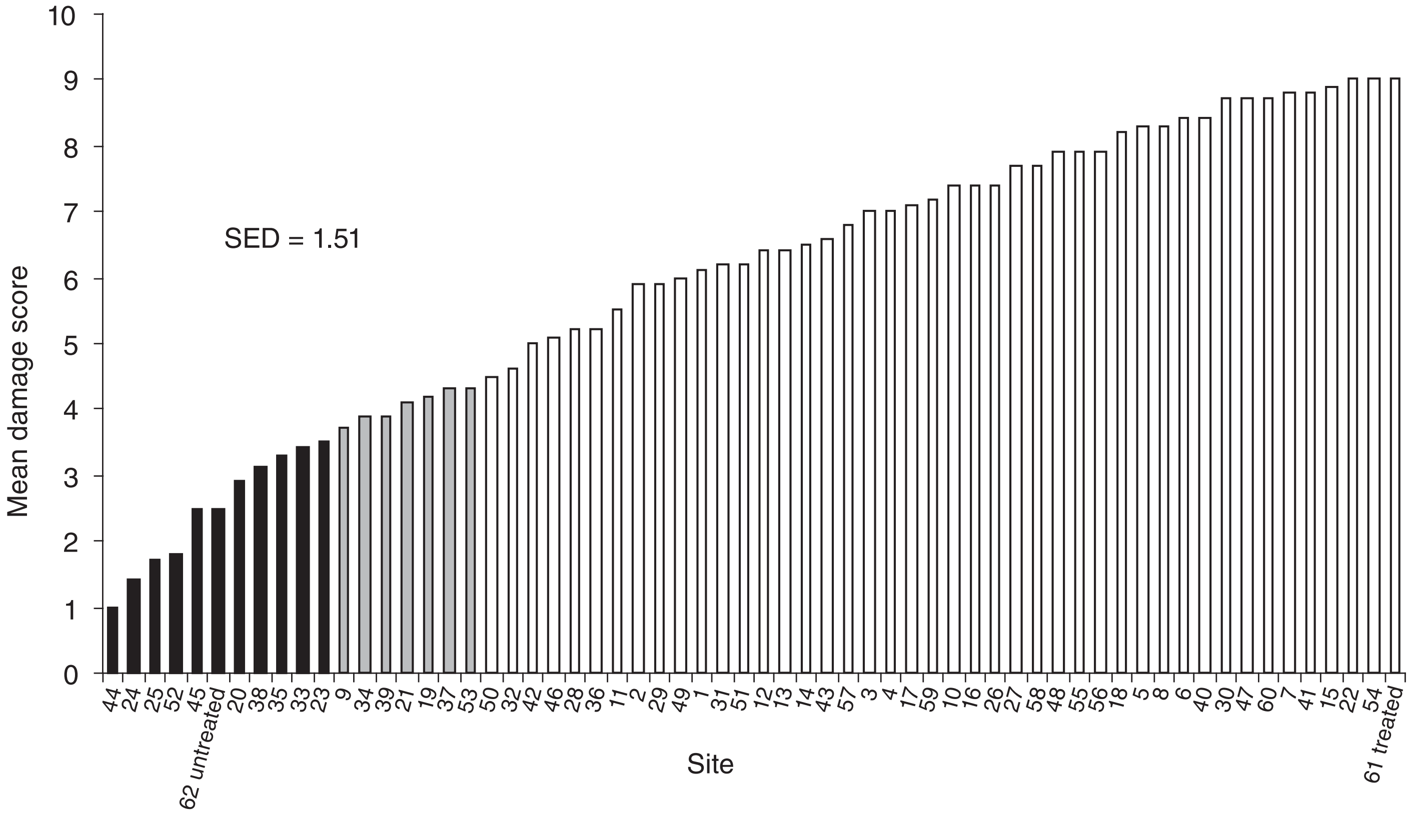

Figure 2. Rowsley Valley serrated tussock resistance survey results 89 days after treatment. (Mean damage score: 0 = healthy, 9 = dead) 61 = known susceptible treated, 62 = known susceptible untreated (Dunnett's simultaneous comparisons). ■ Resistant (99% probability), ▨ resistant (95% probability), □ susceptible.

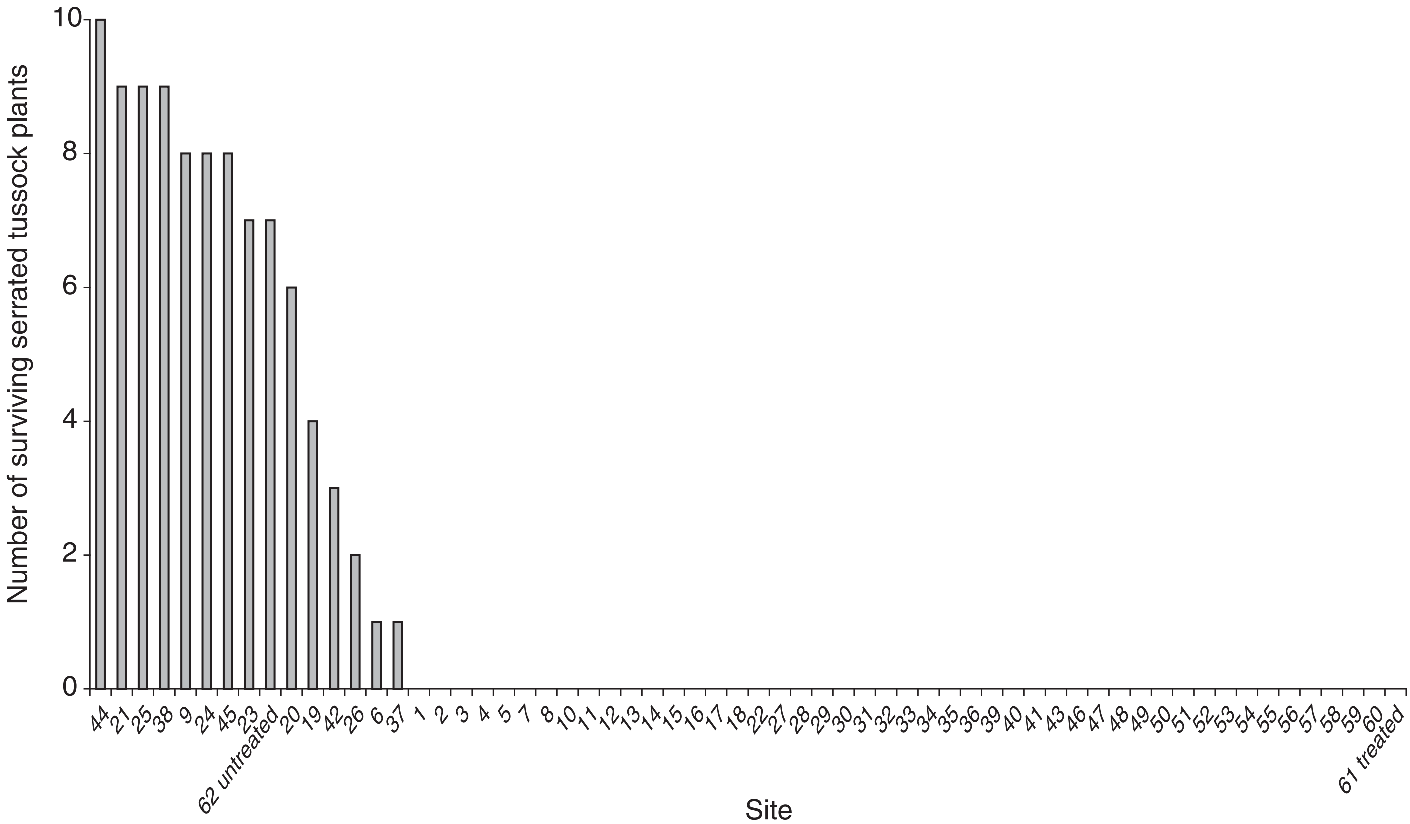

Figure 3. Number of surviving serrated tussock plants 262 dat (10 = all surviving).

The Victorian Serrated Tussock Working Party in collaboration with the Victorian Department of Primary Industries and affected local Governments have been driving a concerted serrated tussock compliance program with the ambitious aim of preventing all serrated tussock in Victoria from seeding. This program has been highly successful and it has been estimated that of the 130 000 ha of serrated tussock identified in Victoria in 1998, 45 000 ha are now under long term control (Osmond *et al.* 2008). The herbicide flupropanate, has been widely regarded as the best chemical control option for serrated tussock management as it has some selectivity (Campbell *et al*. 1979) and its residual action can prevent serrated tussock germinations for several years after application (Campbell and Vere 1995). The potential loss of flupropanate as a control tool for serrated tussock due to resistance would severely limit control options for land managers and potentially set back the many serrated tussock management gains made by the Victorian Serrated Tussock Working Party.

The likely spread of serrated tussock flupropanate resistance will depend upon the nature of the inheritance, the breeding system and the amount of gene flow. The maternal nature of the inheritance, coupled with the high proportion of self-pollination (Harding 1983) and cleistogamy, has probably resulted in rapid establishment of resistant seeds among the field populations (Durai 2008). Coupled with a low persistent transmission of resistance by pollen up to many kilometres away, this suggests the likelihood that flupropanate resistance has already escaped from the original site to surrounding areas (Durai 2008).

Living with flupropanate resistant serrated tussock:

1. Rotate your herbicides There are currently three herbicides – flupropanate, glyphosate and 2,2-DPA registered for control of serrated tussock in pastures. If using chemical control, land managers should alternate the use of these herbicides from year to year. Both flupropanate and 2,2-DPA are Group J herbicides (Croplife Australia 2008). Land managers should be aware that *Sporobolus fertilis* plants resistant to flupropanate have also shown some resistance to 2,2-DPA (Ramasamy *et al*. 2008). Serrated tussock plants not dieing 6–12 months after flupropanate application (depending on rainfall) should be targeted for spot spraying with glyphosate or physical removal.

2. Reduce serrated tussock population levels To reduce the likelihood of developing resistance, land managers should attempt to keep serrated tussock populations as low as possible. Fewer serrated tussock individuals will mean fewer chances of selecting resistant individuals. Increasing beneficial plant competition is a key factor in managing serrated tussock. Practicing good agronomy by using competitive pasture species with appropriate use of fertiliser, grazing management, disease management and weed control is critical. Mechanical control through chipping and cultivation are excellent ways of controlling serrated tussock and minimising resistance. Land managers should also consider crop/pasture rotations to help minimise resistance where appropriate.

3. Stop serrated tussock seeding The key to serrated tussock management is reducing the seedbank. If land managers can prevent seed set for several years and there is little recruitment from surrounding properties, then the serrated tussock seedbank will decrease through time. In some situations slashing, burning or spray topping serrated tussock can be useful tools to reduce seeding. Using combinations of grazing to reduce the height of beneficial grasses and chemical wipers to apply herbicide selectively to serrated tussock is also a very useful tool. Development of new seed drill technology for rocky terrain (Rock-hopper – AgriCon Pty Ltd) is also providing more options for rehabilitation of what was previously non-arable land.

4. Change land use In some difficult situations it may be better to change land use from pastures to Agroforestry (Campbell and Nicol 1999) or to cropping (Osmond *et al.* 2008) or in some situations, if there is good competition, simply locking land up and removing grazing can be enough to provide enough competition to reduce serrated tussock dominance. In some difficult non-arable, situations it has been better to promote re-vegetation and competition using tea-tree to smother dense serrated tussock populations (Osmond *et al.* 2008).

5. Importance of integrated control This survey has identified several new serrated tussock populations potentially resistant to flupropanate in Victoria. There is a real risk that flupropanate will become less effective if land mangers don't quickly change the way they are using it. The consequences are more herbicide usage, greater serrated tussock dominance, greater herbicide pollution, increased environmental damage and reduced profits for farmers. Land mangers need to consider mechanical control, cropping rotations, pasture rehabilitation and grazing management to reduce the likelihood of resistance. A common theme with herbicide resistance is that weeds will quickly adapt through natural selection if they are constantly exposed to the same management technique (Warwick 1991). Land managers need to confuse the weed by applying a range of different weed management techniques. This survey reinforces the need to practice integrated weed management to control serrated tussock.

Recommendations

1. Produce a serrated tussock flupropanate resistance brochure highlighting what land managers should be looking for if they suspect resistance on their property. This brochure will also highlight what actions should be undertaken by land managers to reduce the impact of serrated tussock flupropanate resistance.
2. Conduct an extension program within the Rowsley Valley district to inform land managers of the serrated tussock resistance issue.
3. Provide land managers within the affected region with a copy of the Serrated Tussock Best Practice Management manual that documents a range of integrated serrated tussock management options.
4. Contact and inform local Shires, Councils, Parks and herbicide contractors about the flupropanate resistance issue.
5. Prioritise identified flupropanate resistance serrated tussock locations for spot treatments using glyphosate.
6. Conduct a state-wide serrated tussock resistance survey.
7. Support research into other serrated tussock control techniques including the use of classical/inundative biological control of the serrated tussock seedbank using soil borne pathogens.

Acknowledgments

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Removal of Chilean needle grass, *Nassella neesiana*, from roadsides across Australia using wick wiping

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Summary

Field trials to evaluate removal of wick-wiping were successfully set up and evaluated in three states across eastern Australia, covering the primary predicted range of spread: Queensland, New South Wales (ACT – Australian Capital Territory) and Victoria. Autumn assessments of treatments showed clear and major effects of wick-wiping in reducing the density and cover of Chilean needle grass (CNG) down to negligible levels in Victoria and Queensland. Similar levels of mortality were recorded for strips/areas treated in similar ways in 2006–07 at each of these sites. This confirms a high level of reproducibility over sites and over time. These results were confirmed in follow-up spring assessments, carried out to check on the actual mortality of CNG, as compared with browning off. Outcomes in the ACT were more moderate, with only around 50% to 70% of the CNG tussocks being removed. In the ACT there was no opportunity for re-measuring areas treated in previous years. It appears that the effectiveness of treatment is affected by the type of wick wiper used, the extent of active growth of CNG during herbicide application and the height of CNG above the other vegetation at the time of wick-wiping. In all instances where CNG plants were killed by wick wiping, the mortality of other off-target species was minimal. Establishment and assessment of trials has involved local and regional agencies, and best ways to utilise the technique have been identified. The outcomes of the project and previous wick-wiping outcomes have been included in the National Best Management Practice Guidelines for Chilean needle grass (2007).

Introduction

Chilean needle grass *Nassella neesiana* (Trinius & Ruprecht) Barkworth (Poaceae: Stipeae) is a C3 (cool season) perennial tussock grass native to South America that has been declared as one of Australia's worst twenty weeds, through its inclusion as one of the Weeds of National Significance (WoNS 2007). It is a highly invasive weed and has a serious impact on agricultural and native ecosystems (WoNS 2007). In agricultural settings, Chilean needle grass is a vigorous competitor and can severely reduce pasture productivity by displacing more palatable species. In natural ecosystems, Chilean needle grass is thought to be one of the worst environmental weeds threatening native grasslands, because it is a vigorous competitor, can displace native grass species, the seed-banks are difficult to manage and it can rapidly invade disturbed soils and thus interfere with revegetation programs.

Chilean needle grass (*N. neesiana*) spreads rapidly along roadsides, invading into farmland and conservation reserves, but control on roadsides has been expensive and patchy. A pilot program of annual wick-wiping to selectively remove *N. neesiana* on roadsides near Melbourne, resourced jointly by VicRoads, Government Agencies and Victoria University, and carried out in 2005–06, was found to be highly successful (Hocking 2007). The method required more extensive testing, across a range of land types and climates.

The national Chilean Needle Grass wick wiping project set up replicated trials across the range of vegetation types, climatic conditions and soils in SE Australia, and investigated variations of the successful pilot methods. Project partners were roadside and related land managers, contributing mowing and wick-wiping equipment, and tying trials with existing roadside vegetation management strategies.

The aims and objectives of the project were:

- To test the effectiveness, on a national scale, of wick wiping methods found to be effective for removal of Chilean needle grass from roadsides in Victoria;
- To document the types of vegetation remaining after treatment, that was able to grow replace any Chilean needle grass that had been removed; and
- To use the trial sites to demonstrate to roadside managers and other land managers, the effectiveness of the method, and provide these managers with straightforward procedures for how to incorporate this control method into their annual weed control strategies and budgets.

The project addressed the following National priorities:

- Priority 4. Strategic management (eradication and control) of isolated and outlier infestations of Weeds of National Significance – outcomes of the project have the capacity to progressively remove Chilean needle grass from the outer extent of infestation along roadsides and help to control the spread of Chilean needle grass from beyond its existing range.
- Priority 5. Strategic management of core infestations of Weeds of National Significance – the techniques developed have the capacity to progressively remove Chilean needle grass from existing major roadside infestations.

Lunt and Morgan (1998, 2000) and Morgan and Lunt (1999) detailed how disturbance regimes (primarily senescence of native grasses) were strongly correlated with invasion by *N. neesiana* and that the maintenance of healthy competitive stands of the dominant native grass minimised invasion. Beames *et al.* (2005) demonstrated that using integrated management techniques based on selective use of herbicides, aimed at keeping as much of the preferred vegetation in place during weed removal, could result in longer term removal of *N. neesiana* in native grasslands in the Melbourne region. Gardener (1998) and Gardener *et al.* (2003) found that the more other competitive species were removed during herbicide control of *N. neesiana*, the higher was the likelihood that seedlings of *N. neesiana* would recruit in the gaps created, from the high level seedbank that this characteristic of active *N. neesiana* infestations. More recently, Faithfull *et al.* (2008 and 2009 – this conference) have demonstrated convincingly that *N. neesiana* tends to invade native grassland areas following disturbance brought about by senesce and death of the dominant native grasses.

While roadsides are often dominated by exotic species rather than natives, it is likely that reductions in *N. neesiana* along roadsides can be assisted by its selective removal, leaving behind as much of the preferred species (native or exotic) as possible. Grech (2007) has also found that maintenance of vigorous pasture species can also help to limit invasion of *N. neesiana*. The focus of the project reported here was the selective removal of *N. neesiana* through wick-wiping, by exploiting the height differential between *N. neesiana* and other more preferred species, leaving behind these preferred species as competitive repressors of *N. neesiana* re-establishment (Hocking 1998, 2005). The intent of the wick-wiping technique was not so much to remove *N. neesiana* in a single year, but rather to integrate wick wiping as part of an ongoing mowing regime along roadsides, to manage down infestations over several years, until selective spraying by hand was financially feasible as a way to remove the final remaining *N. neesiana* plants and those in places less accessible to wick-wiping.

Materials and methods

Field trials to evaluate removal of wick-wiping were successfully set up and evaluated in three states across eastern Australia, covering the primary predicted range of spread: Queensland, New South Wales (ACT) and Victoria (see Study Sites below).

The method used depended on applying glyphosate herbicide, in concentrated form, to the flowering stems of CNG, when these were projecting above the canopy of other off-target species. Field trials compared the effects of wick wiping (Figure 1) against no treatment controls. Trials were established as treatment strips of at least 10 m in length, and each treatment was replicated at least five times. The form of wick-wiping machinery chosen for each site was that most commonly used in the region, to optimise the potential for success, and to fit in with the expertise of the machinery operators.

Heights of plants were recorded prior to application of the herbicide by wick-wiping, using an intercept pin method. In this method, strikes for vegetation on a vertical pin were recorded at 10 cm intervals along a central line transect for each replicate treatment strip, with the height at which each species touched the pin being recorded. These were aggregated into total pin strikes for each species over the full number of treatment strips.

Glyphosate was applied via the wick wiper in spring of 2007, when seed heads were forming. The strength of glyphosate was between 2- and 3-fold dilution of concentrated glyphosate. The choice of spring for application was chosen from a combination of previous studies in Victoria. The height set for the wick-wiper was determined for each site by using the results of the pin intercept method described above. The number of touches for each of the major species was recorded and aggregated within height intervals to determine the average height, as well as the nature and extent of height separation between *N. neesiana* and other plant species (see Results).

Mortality of *N. neesiana* and other species was recorded at each site by randomly locating two 1 × 1 m quadrats in each of the replicate wick-wiping treatment strips, within a 20 cm outer border, to avoid edge effects. The cover of each plant species, as well as the number of surviving *N. neesiana* tussocks (and other native and exotic tussock forming grasses) was recorded. Densities for each treatment strip were calculated by aggregating the data from each of the two 1 m^2 quadrats and reducing to density per square metre.

Study sites

Investigations were undertaken at three key sites:

1. Yarramundi Reach grassland Belconnen, Australian Capital Territory (35°17.5'S, 149°05'E).
2. Calder Freeway central median strip, just west of Calder Park Raceway, Victoria (37°39.5'S, 144°44.4'E).
3. Clifton Showgrounds, Clifton, Queensland – approximately 180 km west of Brisbane (27°55.3'S, 151°55.0'E).

Results and discussion

Autumn 2008 assessments of treatments showed clear and major effects of wick wiping in reducing the density and cover

Figure 2. Effects of wick wiping on CNG removal at Calder Freeway site, Melbourne.

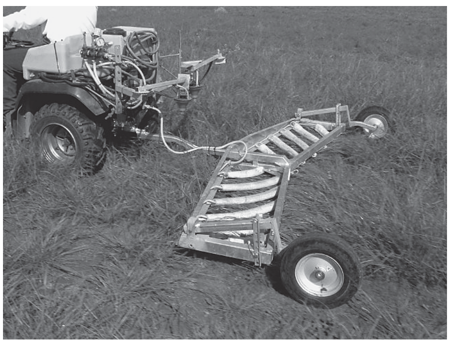

Figure 1. Wick wiper in action on flowering CNG at Clifton Showgrounds, Queensland.

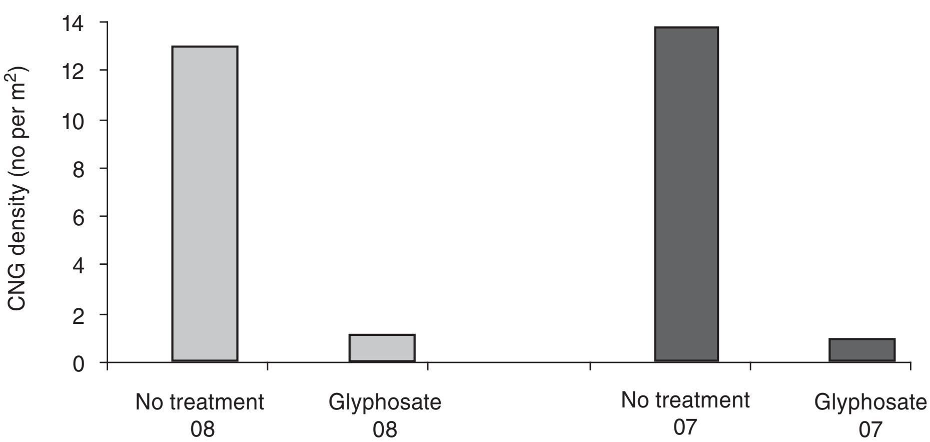

Figure 3. Chilean needle grass densities with various treatments, Calder Freeway site – assessed May 2008.

of *N. neesiana* down to negligible levels in both Victoria and Queensland (Figure 2).

In Victoria, in two separate years of application, wick wiping was effective in removing at least 95% of mature *N. neesiana* tussocks (Figure 3). Mortality of off-target species appeared to be small. There was some regrowth of *N. neesiana* from seedlings. However, in future it is likely that these will be easy to remove by a follow up round of wick wiping treatment in the subsequent spring.

Results in Queensland were equally impressive, and while there was not data to compare directly over two years, next to the 2007 wick wipe treatment strips was an area wick wiped the year before, which showed even lower densities of *N. neesiana* after two successive years of treatment (Figure 4).

Measurements of the maximum heights of plants at both the Victorian and Queensland sites have shown that, in spring, *N. neesiana* was clearly standing well above all other species, and was a clear target for herbicide brushing, if wick wiping was set at an appropriate height (Figure 5). The height chosen was 20 cm for each of the sites, but in other circumstances it may have varied between sites and types of grassy vegetation. Follow up surveys in the autumn after wick wipe treatment showed that most of the lower height species suffered minimal death as a result of the treatment.

Outcomes of trials in the ACT were more moderate, with only around 50% to 70% of the CNG tussocks being removed (Figure 6, 7). This is likely to be the result of the lower heights of CNG at the time of treatment. Even in spring, the CNG in the ACT was at a much lower maximum height than at the other sites, possibly resulting from the colder spring growing temperatures than elsewhere.

It appears that the effectiveness of treatment is influenced by the type of wick wiper used, the extent of active growth of CNG during herbicide application and the height of CNG above the other vegetation. It is worth noting that Grech (2007) carried out similar wick-wiping trials on agricultural pasture land in Victoria, with more mixed results, so the application of this method to pastures for selective removal needs further investigation.

In all instances where *N. neesiana* plants were killed by wick wiping, the mortality of other off-target species was minimal.

Conclusions

Wick-wiping appears to have high potential for control of *N. neesiana* along road sides, where a height differential is apparent between *N. neesiana* and other more desirable species, at the flowering time for *N. neesiana* in early spring. The extent of kill of *N. neesiana* in Victoria and Queensland was unexpected, and very promising for rapid removal along large tracts of roadside. The opportunity to apply wick-wiping in two consecutive years at each of these sites demonstrated that the results were not year-dependent. The results from Canberra show, however, that the wick-wiping method needs to be applied appropriately, and where there is not sufficient height differential between *N. neesiana* and other species, or active growth of *N. neesiana* during the time of wick-wiping, the method may be less than fully effective. Finally, it is possible that the wick-wiping method described above may also be useful for other invading exotic perennial grasses, where these show high levels of growth and significant height differential with other grassy species, during early spring growth.

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Clifton Shire weed management team, National Capital Authority and ACT Parks and Wildlife, VicRoads, Iramoo Sustainable Community Centre staff and the National CNG Task Force. The research was funded through the Federal Government Defeating the Weed Menace Program 2007–08.

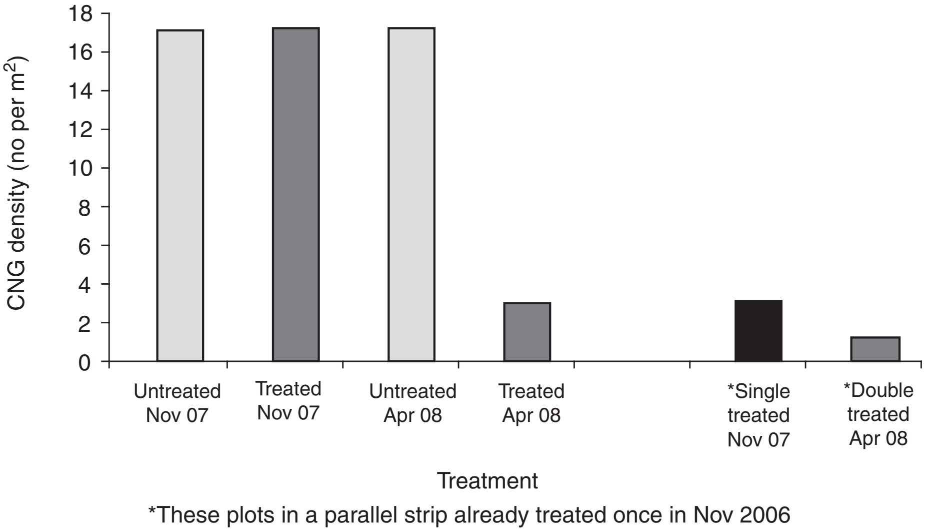

Figure 4. Chilean needle grass denities in treated and untreated plots – treatment in November 2007 at Clifton Showgrounds, Queensland.

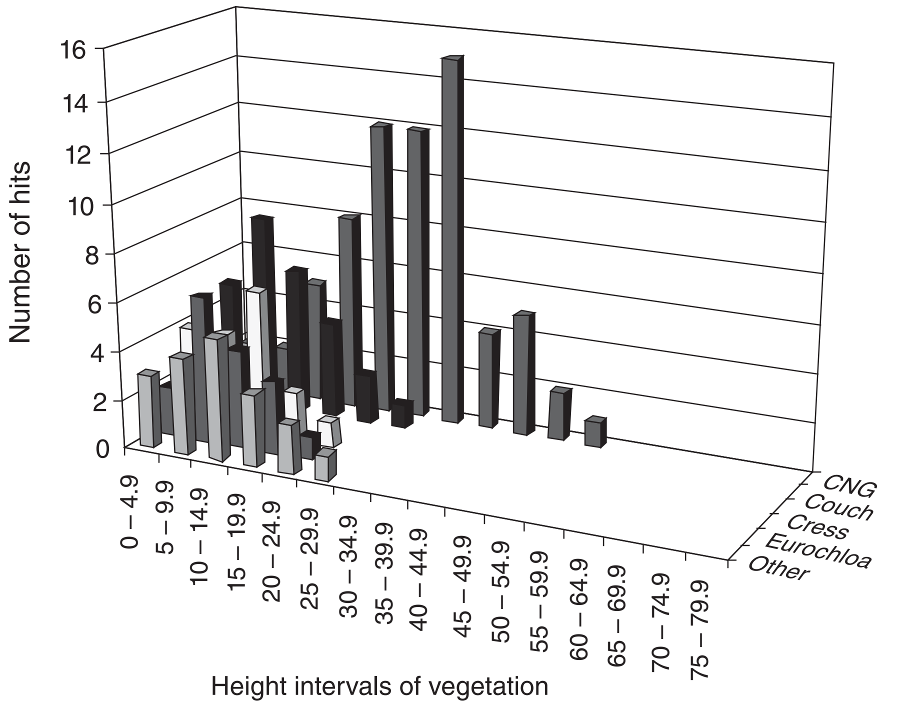

Figure 5. Number of touches of vegetation for each height interval, Clifton Showgrounds November 2007.

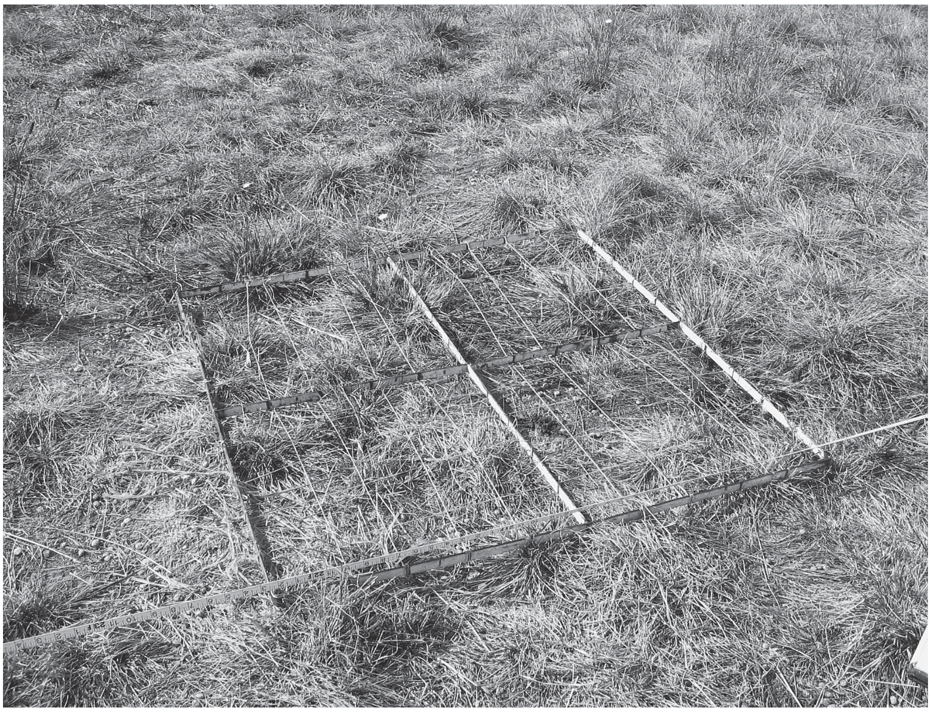

Figure 6. Effects of wick wiping on CNG removal at Yarramundi Reach, Canberra. Note that some CNG tussocks have survived.

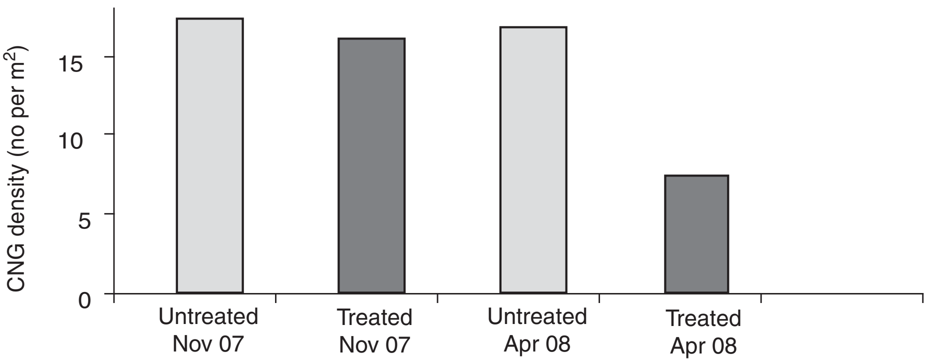

Figure 7. Chilean needle grass densities in treated and untreated plots – treatment applied in November 2007, Yarramundi Reach, Australian Capital Territory.

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Integrated community action on weeds in South Gippsland

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The South Gippsland Landcare Network (SGLN), through community action, helps to preserve, protect and enhance the environment of South Gippsland. The Network covers an area of approximately 4 280 square kilometres, from Nyora to Welshpool and from Mirboo North down to Yanakie. The Network has 20 Landcare Groups representing approximately 800 members.

SGLN has coordinated an integrated community based pest plant and animal program for the past ten years providing community education and advice, increasing community awareness of issues and control techniques and coordination of joint approaches to priority problems.

SGLN plays a key role in bringing together all the groups/organisations together to work in a coordinated manner. Preventing the spread and minimising the impact of noxious weeds is a shared responsibility for private landowners and government bodies.

Community weed management concerns were identified in the Local Area Weed Plan (LAP) developed in 2000. This community concern for weeds and a coordinated approach to control was highlighted and strengthen in 2006 with the establishment of the South Gippsland Community Weeds Taskforce. In 2007, the SGLN Strategic Planning process also identified pest plant and animal control via a coordinated partnership approach as a priority for Landcare in South Gippsland. This paper will focus on activities and innovations over the past two years.

A revitalisation survey undertaken by SGLN in July 2009 had 68% of respondents interested in learning more about weed control. This confirms the importance of our community program and the need to maintain funding for this vital work.

The SGLN Community Pest Plant and Animal Program (CPPA) aims to support landowners to take action and ensures this action complies with State Government legislation for pest plant and animal control. SGLN is working closely with local and State government to ensure all actions undertaken are in a coordinated manner and will ensure maximum benefit and also that priority species and areas are being tackled.

Partnerships are vital to the success of any project and weed management and control is no exception. SGLN is not directly responsible for the management of land and has no legal standing when it comes to compliance on weed issues; we must working closely with the range of public and private land owners and managers if we are to be successful in controlling weeds in South Gippsland.

A successful partnership is where each party contributes something and receives something in return. Our mapping projects are a prime example.

The Network has undertaken several weed mapping projects over the last 12 months for our partners. A contract with VicRoads to map weeds on VicRoads roads in South Gippsland and one to map shire roads in the South Gippsland Shire have not only brought in income for the Network but more importantly assisted those organisations to better target their weed control programs. The program has been extended to include rail trail areas and community managed reserves.

The weed mapping for Shire of South Gippsland is done as part of a Memorandum of Understanding between the Shire and Network where the GIS equipment that Martin uses and the mapping software is owned by the Shire and used by Martin free of charge in return for various smaller mapping projects. A project to map the Shire reserves in 2009 has resulted in many reserves being sprayed for the first time in many years. A great result for weed control in South Gippsland.

Smaller mapping tasks on Parks Victoria have allowed integrated weed control programs to be implemented and newly identified infestations to be hit before they are able to spread.

This coordinated program is assisted by the fact that Martin Chatfield is located in the Parks Victoria office in Foster allowing for greater integration of a range of projects and outcomes.

One of our showcase partnership projects is the biological control of bridal creeper (*Asparagus asparagoides*) in South Gippsland. The project commenced with mapping all known sites of bridal creeper sites with a GPS system. A meeting was held in May 2008 with a view to coordinating spore water release across the region by representatives from SGLN, Baw Baw Shire, Bass Coast Shire, South Gippsland Shire, Wellington Shire, Department of Primary Industries (DPI), Department of Sustainability and Environment (DSE), Parks Vic, Friends of Venus Bay, Coastcare and Vic Roads. Instruction on spore collection and distribution was provided by an officer from DPI and environmental officer from Wellington Shire

With assistance from the Wellington Shire Environmental Officer and Vic Roads, spore water was collected from East Gippsland and distributed with the assistance of a DSE fire tanker and Parks Vic personnel. The release was throughout the South Gippsland region and adjoining shires on infested sites as per our mapping. Results monitored for 2009 indicate very good up take of spore with all known sites monitored and contained.

The whole project has greatly increased the awareness of bridal creeper by all stakeholders. SGLN continues to monitor and look out for any new infestations through the Network and holds field days and workshops and provides extension to the broader public.

The South Gippsland Community Weeds Taskforce (CWT) was formed in 2006 in response to the community concerns on weeds and the changes in government policy in weed control and the allocation of resources to tackle the issue. SGLN provides administration and executive support to the CWT.

Weeds are a great concern to most landholders in the region, so by combining voices and resources the group hopes to gain coordinated positive actions and to apply for relevant funding and contribute to and be actively involved in policy development and change.

Membership is open to all interested parties. Membership in 2009 includes South Gippsland Landcare Network, Hallston Landcare Group, Arawata Landcare Group, Foster North Landcare Group, Triholm Landcare Group, Great Southern Rail Trail, Friends of Venus Bay, Parks Victoria, South Gippsland Shire Council, Department of Primary Industries, South Gippsland Water, VicRoads, Greening Australia, Yarram Yarram Landcare Network, Bass Coast Landcare Network, West Gippsland Catchment Management Authority, and Coastcare.

The aims of the Community Weeds Taskforce are to:

1. Identify priorities for weed control;
2. Create and co-ordinate partnerships to tackle weed control priorities;
3. Monitor progress;
4. Use our critical mass to apply for funds and lobby for policy changes;
5. Educate and inform the community about weed control; and
6. Foster cross border (shires, public/private land etc) action.

The CWT supports community action on weed issues; an example is a public meeting held in March 2009 and hosted by the

Triholm Landcare Group was attended by over 40 people from four Landcare Groups, Shire councillors from Baw Baw and South Gippsland and South Gippsland Water. The purpose of the meeting was to gauge public opinion on the Draft Invasive Plant and Animal Framework and the reduction in compliance role of DPI with regards to ragwort and other weeds. The meeting overwhelming decided to write to all Ministers to seek further input into the policy framework that will have a dramatic effect on the productivity of their land. The CWT attended the meeting and actioned the responses to the Minister. By combining our voices we have been able to raise the profile of the Draft Invasive Plant and Animal Framework and ensure the Minister is aware of the community concerns over possible policy and legislation changes.

Ragwort is a huge community concern in the South Gippsland region and whilst it is ragwort that has generated the anger and frustration of the local community, the Draft Framework has wider implications for all weeds in the region.

The CWT has also worked closely with the South Gippsland Shire on exploring funding opportunities and cooperative projects to tackle roadside weeds.

Community education and awareness are a high priority for the SGLN CPPA. The provision of information to the community takes many forms – printed material, one to one interaction at local markets, information days, talks to local groups and of course the internet.

All these avenues are part of the program each offering a service to our community that is highly regarded.

The production of a series of weed brochures is an ongoing component of the program. The six produced so far are:

- SGLN Pest Plant and Animal Control Program;
- Weeds;
- Ragwort;
- Thistles;
- Cape ivy; and
- Dolichos pea.

The production of these sheets is scheduled to coincide with key control programs and the need for high quality easy to read information. They are included in our Welcome to Landcare Packs as well as handed to landholders at field days and site visits. They are also proposed to be placed in community houses and rural supply agencies to increase the awareness of the weeds we have locally.

Martin regularly attends the Foster Farmers Market and various other markets and country shows with the SGLN display trailer. The trailer is set up with a screen and laptop that has a weed display running on a loop. The trailer also has all the SGLN printed material about weed control and Landcare in general. Martin is available to address landholder questions and provide a range of information. This has also lead to Martin being invited to speak to a range of community organisations such as Probus, Landcare, and Friends of Groups.

Weed specific field days offer the opportunity to bring together landholders, both public and private to address their concerns and usually implement a coordinated effort to tackle the problem. For example biological control of bridal creeper on the Cape Liptrap coast. A coordinated program of rust collection, release and physical removal of bridal creeper is having a significant impact on the control and spread of bridal creeper.

The Program also offers support to landholders who have concerns about weed problems on neighbouring properties and ongoing non-compliant landholders.

With increasing number of people relying on the internet for information, the establishment of a regionally specific website (South Gippsland Weeds Website http://www.southgippslandweeds.com.au) that is both informative and interactive, was another step forward for the SGLN Community Pest Plant and Animal Program.

South Gippsland Water has been sponsoring projects for the South Gippsland Landcare Network for a number of years and the 2007/2008 sponsorship included the development of the South Gippsland weeds website. The website was designed locally by a web design company called Loud Mountain.

The focus of the website is to provide the user with an easy to use, up to date and visual method of identifying weeds in our local area and how to control them. With a range of people purchasing land in South Gippsland, many with little knowledge of our local weeds species and the damage they can cause, identification in the first incidence is vital. Since the site was launched, in November 2008 it has received 2193 unique visits with an average of about 300 per month. The feedback received from landholders, State and Local Government agencies within and outside our region has been extremely positive.

The weed gallery section of the website has a series of high quality photos in different growth stages and identifying parts of the plant. Currently 52 weed species are featured on the website, each with multiple photos at various growth stages and links to control methods and details on the type of weed, e.g. environmental, noxious, regionally controlled. These photos are updated regularly as new specimens are located. The majority of the photos have been taken by Martin Chatfield locally so they represent how the weeds look locally.

The website has been designed as interactive with visitors to the site being able to ask questions of Martin, request a site visit, or even upload a photo of the weed they need identified and Martin will get back to them. Since the launch approx. 20 photos have been sent in for identification and assistance with control.

With a range of SGLN's range of weed information sheets available to download and print, suggestions for alternatives to environmental weeds in 'plant me instead', a range of frequently asked questions (FAQ), bi-monthly weed talk articles, weed of the month profiles, control methods, legislation requirements and links to other weed and pest information, the South Gippsland Weeds website has it all. The site is regularly updated and maintained by SGLN staff courtesy of sponsorship of South Gippsland Water.

For further information on the website, there is a poster titled 'Technology tackling weeds in South Gippsland' presented at the conference.

The SGLN CPPA through the CWT is also ensuring a community voice to government on weed policy and legislation. Martin Chatfield has been involved in the Noxious Weed Review for West Gippsland with regular updates to and input from CWT meetings and from our partner organisations.

The CWT submitted feedback on the Draft Invasive Plant and Animal Framework (IPAF) and will coordinate community responses to the updated draft released in August 2009. It is vital that the community is well informed and involved in the development of policy that directly affects their own area.

The SGLN CPPA program has been funded over the past three years via State funding – Victorian Action Plan for Second Generation Landcare. The funding in 2008/2009 was not sufficient for the full time employment of the Pest Plant and Animal Officer, and this is where our existing partnerships have assisted the program to maintain a full time position. Contracts for weed mapping, coordinating weed contractors and project coordination via Federally funded programs have brought in the dollars needed and at the same time given the Network the opportunity to expand the services we are able to provide. The partnership projects that have arisen from project funding have enhanced the program.

Future funding of the program will depend on projects we are developing with our partners and will be driven by trying to match community needs and expectations with changing State and Federal funding priorities. The challenge to maintain funding and meet community needs is always there and will continue. SGLN is committed to continuing an integrated community weed control program and we will just have to explore all options to ensure it is funded well into the future.

Community action on weeds is essential and the support for that community action is vital. The community both public and private rely on good sound advice and a mechanism to ensure their voice is heard. The South Gippsland Integrated Community Pest Plant and Animal program provides that advice, offers the voice and ensures that governments at all levels remember that weeds are everyone's business and can't be left to the community to tackle them all.

Partnerships and cooperative projects are the future of weed control in South Gippsland along with a strong community voice to government via the Community Weeds Taskforce. One difficulty we will always have is convincing State and Federal Government that just because a weed is not on the National list, doesn't mean it is not as important.

Ragwort may be well down the State priority list but it is still an issue in South Gippsland and we will continue to work together to ensure the rolling hills of South Gippsland don't turn yellow in spring.

The spread and detection of weeds on Australian farms

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Abstract
Two recent University of New England research projects funded by Land and Water Australia in the Defeating the Weeds Menace program, sought, through national surveys of weeds inspectors, other weeds professionals and landholders, to assess how weeds are spreading within Australia; identify ways to reduce these risks; assess current weed surveillance levels and practices amongst landholders and weeds inspectors; and identify ways to improve weed detection by these groups on-ground. Some of the findings are presented in this paper.

Introduction
Despite the $4 billion annual cost of invasive weeds to the Australian economy through lost agricultural production and the devastating impact of weeds on natural ecosystems, no comprehensive studies have previously been undertaken to ascertain the way that weeds spread once present within Australia, or how farmers and weeds inspectors go about detecting new weeds once they arrive.

Two recent University of New England research projects funded by Land and Water Australia, sought to assess the relative risks of sources (sites) and pathways (means) of weed spread within Australia; identify ways to reduce these risks; assess current weed surveillance levels and practices amongst landholders and weeds inspectors; and identify ways to improve weed detection by these groups on-ground.

Most recently naturalised taxa are still only locally distributed, and so it is critical to identify the primary pathways for the spread of these, as well as more widespread weeds, so as to be able to prevent movement to un-infested areas. However, if weeds do move to new areas then early detection is the first step in their control. Weeds are only ever very rarely eradicated from an area (reduced to a zero population). Those weeds that have been eradicated have been detected early in their spread. And every dollar invested in the eradication of a newly established weed results in benefits of $9.90–$26.80 (NRMMC 2007).

An evaluation of Australian and international literature identified twenty-four weed sources and seventeen weed pathways (both natural and a consequence of deliberate and accidental human activity) for weed spread (see Table 1). While every effort must be made to prioritise high risk pathways of weed spread for management and regulation, the number and wide diversity of potential sources and pathways demonstrates the difficulty of the task of preventing weed spread altogether.

After scoping the issues with focus groups, three national surveys were undertaken in late 2007 and early 2008 of over 100 weed professionals, 600 landholders, and nearly 150 weed inspectors, drawing on their expertise of weed spread and detection in the Australian context.

Table 1. Ways in which weeds spread in Australia.

Weed spread pathways in Australia
Deliberate spread by humans
Ornamental plant trade
Mail order plant trade
Aquarium plant trade
Medicinal plant trade
Food plant trade
Fodder trade
Revegetation and forestry
Accidental spread by humans
Human apparel and equipment
Machinery and vehicles
Construction and landscaping materials
Agricultural produce
Research sites
Livestock movement
Waste disposal
Natural spread
Birds
Other animals
Wind
Water

Weed sources

The survey of weeds professionals found that, of the weed sources identified in the review of literature, the most important include transport sites (roads, railways, water courses and airports), land in transition (degraded or abandoned land), pastures and rangelands, ornamental horticulture sales sites, and private gardens.

Weed spread pathways

Weeds professionals were also asked to evaluate each weed spread pathway with regard to:

- Its capacity to transport seeds and other propagules and facilitate weed spread;
- The effectiveness of current regulatory and management structures seeking to negate the pathway; and
- The expected importance of the pathway in the future.

Each pathway was found to have a relatively high overall capacity to facilitate weed spread. However, fodder trade, aquarium plant trade, agricultural produce, ornamental plant trade, water, and machinery and vehicles were considered particularly capable, while research sites, revegetation and forestry activities, and food plant trade were considered relatively less capable pathways.

According to farmers and weeds inspectors, weeds are most likely to spread onto farms via birds, wind, water, vehicles, machinery, livestock and fodder (Table 2). Variation in response on a state or territory, or property type basis may reflect topographic/landscape features, management philosophies, and circumstances. For example, water and floods are considered to be of minor importance in weed spread in SA where much of the state is dry and there are few major river systems.

At least 50 per cent of weeds experts surveyed considered that the current regulatory and management arrangements are inadequate for each weed spread pathway. This was particularly apparent in relation to the plant trade pathways (ornamental, aquarium, medicinal and food plants), fodder trade, and revegetation and forestry.

Table 2. Main pathways for weed spread onto farms as identified by farmers in Victoria and nationally.

Pathways of weed spread	Victoria	National
Birds	34	28
Wind	34	28
Water	18	28
Vehicles	8	21
Livestock movement	13	19
Fodder movement	21	16
Machinery	7	15
Wildlife/vermin	16	14

Various management improvements were suggested, including targeted education and extension activities, improved weed risk assessment processes, further research into control measures, enforced control of specific weeds and pathways, and extra staff and resources. Natural pathways were generally regarded as being difficult to regulate or manage, which suggests that the emphasis here should be on removing the source infestations.

The future importance of weed spread pathways

Many experts indicated that 'natural' pathways of weed spread (water, wind, birds and other animals) are likely to remain as important in the future. Pathways involving human activity that appear likely to increase in importance include fodder trade, ornamental and aquarium plant trade, agricultural produce, and machinery and vehicles.

Management of weed spread in the context of gardening and landscaping, agricultural production, and natural resource management appears likely to become more crucial over time, due to:

- The increasing popularity of gardening;
- Landscape fragmentation, increased traffic movements and growth of peri-urban zones;
- The declining number of herbicides available for use in waterways; and
- Projected climatic variability, leading to a need for drought-tolerant food, fodder and ornamental plant species, the movement of weed-contaminated fodder into drought affected areas, and perhaps enhancing the capacity of natural pathways to carry viable seeds and other propagules.

Sufficiency of information

Lack of information on a pathway's importance does not generally obstruct more effective management. Nevertheless, the pathways which experts know least about and which may need further research to determine their importance in Australia are Human apparel and equipment, Food plant trade, Revegetation and forestry, Other animals, Waste disposal, Medicinal plant trade and Construction and landscaping materials.

The pathway that stands out as having the least sufficient information to design effective management strategies is Birds, followed by Other (wild) animals. Other pathways lacking effective management strategies, and in need of research include the trade in Medicinal plants, movement of weeds in Human apparel and equipment, and in Waste disposal, all pathways that tend to avoid detection by authorities.

Many respondents were unaware of past research on the particular pathway on which they were commenting, indicating a lack of effective extension or acquisition of information, even at this 'expert' level. This issue needs ongoing investigation, both at this level and that of the broader community, given the overwhelming emphasis of respondents on education, extension and publicity for better management of weed spread within Australia.

Weed detection

Weeds inspectors

The surveillance strategies of inspectors are determined most notably by their own professional judgement, legislative guidelines, and availability of resources. Target lists of weeds are used by the majority of inspectors when searching for weeds, and are particularly important in Victoria. Respondents from Tasmania on the other hand are relatively less likely to use target lists. Declaration of a new weed is viewed by a slim majority of respondents as a positive influence on farmer weed surveillance, though the intended visit of a weeds inspector is viewed as influential by over 75 per cent of respondents, perhaps being a more direct 'threat' than declaration.

Inspectors are most likely to target 'high risk' properties, with known target weeds, a history of weed introductions, located near known infestations, or for which complaints have been received. Overall, all inspectors carry out frequent inspection of locations where weeds have been found previously. Less than one fifth of inspectors inspect on an ad hoc basis. Victorian inspectors appear to be more thorough in their inspections of properties. The higher the percentage of properties inspected regularly, the greater the time usually between property visits.

Time of year appears to be the most important factor determining when inspectors look for new weeds, though this factor prompts respondents from SA, WA, NT and Victoria to look for new weeds more than it does for those from Tasmania, NSW and Queensland. The most frequently used form of transport when inspecting for weeds are passenger vehicles and on foot. Likely hospitable areas are generally targeted, though a random walk or drive is also commonly used, rather than specific transects. The average area of a paddock inspected overall is 62.8 per cent but this varied between states. For example, Victorian respondents inspect almost twice the area in each paddock than SA respondents. The surveillance and detection strategies believed to work best include regular visual inspections of properties, responding to complaints and hearing word of mouth about new weeds, and education and extension activities. Overall, respondents are reasonably satisfied with their weed surveillance strategies. Victorians are the most satisfied while Tasmanians are the least satisfied. New weeds are most often found along roads, water ways, and where livestock are fed.

To identify a new plant, weeds inspectors mostly refer to weed identification books and brochures, consult with other local experts such as agronomists and send specimens away to herbaria and botanic gardens. Nearly half of the inspectors have no problem identifying plants. However, the most commonly indicated impediment is insufficient experience.

Weeds inspectors appear to use a variety of procedures to record the occurrence of a new weed, though the most commonly indicated include using GPS to record the weed's location, recording the location in a database, and marking it on a map. The software used includes various GIS and mapping packages, and tailored database packages including Pestinfo and IPMS (specific to Victorian weeds inspectors). While the response group was ambivalent about whether there were impediments to standardised reporting, those who see such impediments believe that the main ones are inflexible or non-standardised reporting systems. IPMS in particular is viewed by Victorian respondents as an antiquated system.

Over 74 per cent of respondents have experienced hesitance on the part of landholders to report weeds caused by the costs associated with weed control, fear of potential sanctions or enforcement, lack of interest, and insufficient knowledge. Respondents are relatively undecided overall as to whether information on the distribution of weeds on private property should be made publicly available.

Inspectors appear to undertake a range of responses to discovery of a new weed. The highest proportion carries out further searching to map the distribution of the weed. Overall, respondents have rated the level of coordination of response to weed outbreaks as being reasonably good, being rated highest in SA and lowest in the NT. Stress and burnout amongst weeds inspectors appears to be more prevalent in Victoria and WA, and less prevalent in Queensland.

Inspectors consider that landholders have a moderate commitment to weed detection overall, with only just over 10 per cent believing that landholders have a high level of commitment. The main incentives committing landholders to weed detection and control are believed to involve landholder knowledge, while the main impediments to landholder commitment involve various 'costs' (financial, time, staffing). The landholders assessed as least committed to weed detection are part-time farmers (absentee landholders, lifestyle farmers, and farmers with off-farm employment). For this reason, a specific extension booklet for owners of small farms entitled 'Weed Detection and Control on Small Farms: a Guide for Owners', has been developed and is available for education activities with this group of landholders (see below).

The most committed government agencies according to the inspectors include weeds authorities, and State agriculture and environment departments, while the least committed include State crown lands departments, roads authorities and the Commonwealth government.

Most (76%) inspectors believe that weed surveillance could be improved through supply of increased resources and personnel, community awareness and education, and through more of their time being devoted to in-field detection work. Although less critical, improvements to weed identification would involve weed identification training for staff, landholders, volunteers and the general public, as well as dedicated weed identification resources.

Other suggestions for improving weed detection involve the themes of training and education of staff, landholders and the general public, increased government resources and funding, improving inspection techniques, and changes to legislation.

Farmers

The individual weeds of most concern to landholders overall are thistles, followed by Paterson's curse, Bathurst burr and blackberry, though these percentages varied considerably between states, while when minor species were grouped, those weeds of most concern were other perennial broadleaf weeds (29.0%), followed by other annual broadleaf weeds (24.6%), perennial grasses (18.3%), woody weeds (18.1%) and other annual grasses (9.5%). Only 3.5 per cent of farmers interviewed are concerned about vines.

The great majority of farmers (84.3%) check for weeds on a regular basis though most (65.3%) do so while conducting other on-farm tasks.

Most farmers consider that weed declaration makes no difference to checking for weeds, though it does make a difference for a small majority of WA interviewees, suggesting more effective declaration strategy and promotion in that state. Only 4.8 per cent of landholders indicate that the impending visit of an inspector makes them change their weed checking activity, which is in contrast to the more favourable perception of this impending visit amongst weed inspectors surveyed.

Farmers believe that weed authorities should focus on making sufficient information available to landholders on target plants rather than focusing on getting landholders to simply report suspicious plants to authorities, although 28.5 per cent suggest that both strategies would be useful. More farmers than inspectors (65.3%) believe that weed distribution information on private property should be made publicly available. However, NSW interviewees are less likely to agree with this than their counterparts, especially those in Queensland. Popular reasons for making the information available includes that it made landholders better informed and is in the community interest, while a relatively high proportion suggests that it is an invasion of privacy.

The majority (66.3%) of farmers concentrate on watered areas of the property, boundaries, traffic areas and previous known infestation areas when checking their farms for weeds. These are the areas where most new weeds are regularly found. Even when new weeds are rarely found in these areas, a high proportion of farmers believe that they are still worth checking. Few areas of a property were considered difficult to check.

Overall, 80.2 per cent of interviewees check for weeds on average every three months or less (at least four times per year). While year-round weed checking is not unusual amongst farmers, overall, 67.3 per cent of farmers check for weeds at particular times of year, a practice relatively more common in SA and WA, presumably due to climatic conditions, such as the distinct break of rainfall in the Mediterranean climates of southern SA and WA. The spring months appear to be the most common time for weed inspection, though the pattern varies on a state and territory and property type basis, depending on when weeds are growing rapidly, such as after rain.

Motor bikes and quad bikes are the most widely used (71.3%) mode of transport by farmers when undertaking surveillance for weeds, followed by passenger vehicles (57.6%). Farmers from Victoria check the largest percentage of a property overall (96%) while those from the NT check the lowest (71.6%). Of all property types, crop farmers check the highest overall percentage (96.5%) and horticulturalists the lowest (86.1%). Approximately half of the farmers believe their surveillance strategy is 'mostly effective' while the other half said that it was 'very effective'.

Having found an unknown weed, 74.8 per cent of farmers will ask a local professional for identification advice, while only 26.6 per cent will look the weed up in a book. Sending the weed away for identification is unusual behaviour amongst farmers. Curiosity, or wanting to know what the weed is, is the main motivation for having a weed identified, to a greater degree than concerns about spread, and possible economic losses.

When finding a new weed, 42.1 per cent of farmers will mark the site in the paddock with a stick or pole, while 36.8 per cent will make a record of it in a diary or notebook. The majority of farmers believe that impediments to reporting new weed discoveries include the cost of eradication, threat or fear of legal action, and concern over what other landholders might think.

Most farmers will either remove a new weed upon finding it or spray it as soon as possible afterwards, with only about a fifth finding out how to control the weed.

Farmers in general believe that, compared with 'professional' farmers, hobby farmers or rural retreat farmers are less likely to check for weeds, followed by absentee owners. Factors likely to encourage landholders to check for weeds included subsidising costs such as spray (17.1%), awareness and advertising (16.4%), and research and publicity into weed cost and impact (14.8%). On the other hand, factors that discourage them from checking for new weeds include cost (39.4%), lack of time or labour (17.1%) and laziness and apathy (11.4%).

Over half of all farmers rate the level of government commitment to weed control as 'low'. However, this percentage varies between states. For example, while 72.4 per cent of Victorian interviewees and 68.2 per cent of those from Tasmania rate the level of commitment as 'low', only 41.9 per cent of interviewees from SA do so.

The largest proportion of farmers interviewed (22.2%) have no suggestions for improving on-ground detection of weeds. However, the relatively high proportion of respondents indicating education and awareness campaigns and improved communication between weeds authorities and landholders suggests that many farmers feel inadequately informed with regard to weed control (an opinion shared by many weeds inspectors). The largest proportion of respondents overall (over 19%) indicated that updated local information or weed notification was a worthwhile initiative. A significantly higher proportion of cropping farmers, compared with the overall response group, are happy with the information on weed detection currently available.

Conclusions

On the whole, this research project has shown that Australian farmers are alert to new weeds, and have a reasonably high level of commitment to detection and control of such species, whether they be so called 'alert weeds', 'sleeper weeds', 'weeds of national significance', or simply weeds that are well established in Australia but spreading to new areas and properties. As a group, farmers therefore need to be encouraged, and equipped where needed, to be vigilant and effective weed spotters. This may be achieved through, amongst other things, training opportunities, greater extension and educational activities, increased resources devoted to weed detection, and greater cooperation between landholders and weeds authorities.

Weeds inspectors have also been shown to play a vital role in supporting and facilitating weed detection and control. While sometimes differing in opinion to the farmers, for example on the value of an inspection visit on weed control, the legally sanctioned surveillance of weeds by inspectors complements the generally voluntary approach adopted by farmers.

While certain questions in the surveys specifically called for suggestions to improve on-ground weed detection, the assumption made here is that the predominant approaches taken by farmers and weeds inspectors are most likely to be the more effective or efficient on-farm weed detection strategies. This assumption is based on the fact that, due to their long history of involvement with weeds, many farmers and inspectors will have determined the best management practice for weeds.

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

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

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NRMMC (2007). Australian Weeds Strategy: a national strategy for weed management in Australia. National Resource Management Ministerial Council, Australian Government Department of the Environment and Water Resources, Canberra.

Further information

The final full project reports on which this paper is based as well as electronic copies of the extension booklets arising from this research—'Weed detection on farms: a guide for landholders, and weed detection and control on small farms: a guide for owners'—can be accessed on the website of The Institute for Rural Futures, University of New England, at www.ruralfutures.une.edu.au or by contacting Professor Brian Sindel at bsindel@une.edu.au.

Engagement for the protection of biodiversity from invasive species: an approach in the Department of Sustainability and Environment

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Summary

The Victorian Government Weeds and Pests Initiative includes dedicated funding for engagement and communications activities to better outcomes in weed and pest management. The public land component of this project, undertaken by Department of Sustainability and Environment and Parks Victoria, funds a full time position to strategically and pro-actively plan for engagement and communications activities. The approach has been to use research findings on stakeholder perceptions of management of weeds and pests for environmental benefit to direct engagement and communications activities. At the same time project managers have been led through a common process to strategically and pro-actively plan for engagement and communications activities. As the Initiative is still current, results are pending a formal evaluation. However, one of the key learnings to date is the importance of strong local networks. Better partnerships between land managers, more collaborative works, and greater community involvement are linked to the strength of local network structures.

Introduction

Invasive species, including weeds, pose a significant threat to many of Victoria's natural, social and economic assets (Sinden *et al.* 2004). The scale of the threat, and the fact that weeds often move easily across the borders of land management areas, mean that there is a need for consistent and collaborative effort among the many different practitioners who manage weeds, across tenures and at a landscape level. Many government and non-government agencies now emphasise the need for partnerships between land managers across different land tenures, and engagement of stakeholders and community, to achieve better management outcomes (EWWG 2007, NRMC 2006, Williams and West 2000).

The emphasis on partnerships and engagement for better management outcomes is often expressed in policy documents designed to direct and guide actual management activities. However, the use of such approaches in actual project design and on-ground programs is varied. While the need for engagement and partnerships may be expressed, it may not be supported by adequate funding. Managers are sometimes reluctant to use valuable management funds for engagement activities and relationship building. Capacity and adequate skills in engagement are sometimes lacking. These issues mean the intent of government and non-government agencies to engage communities and build partnerships to better address weed threats is sometimes not transferred to on-ground management projects and programs.

The Victorian Government currently supports the Weeds and Pests Initiative (WPI) – a four-year program to tackle weed and pest threats on private and public land. The Department of Sustainability and Environment (DSE) and Parks Victoria manage a number of projects under this Initiative for biodiversity outcomes on public land. Scoping and planning work for the Initiative involved a great deal of discussion around the need for engagement in weed and pest management projects. Evaluation of the previous Weed and Pests Initiative revealed a need for dedicated funding and for strengthening of capacity and skills among on-ground managers. The result was a dedicated project for engagement and communications within the scope of the current Initiative.

Within the public land component of the Initiative, the engagement and communications project allowed for one full time person to focus on building understanding of stakeholders, strategically and pro-actively plan engagement and communications activities, and work with project managers to build capacity to deliver more strategic and purposeful engagement and communications activities. This paper outlines the approach taken in this project and some of the learnings gained.

Table 1. Stakeholder groupings.

Category	Stakeholder organisation/description	No. respondents
Head office	Parks Victoria (PV), Department of Primary Industries (DPI), DSE.	13
Peak body	Victoria Naturally Alliance, Victorian Catchment Management Council, Nursery Garden Industry Victoria, Victorian Farmers Federation.	9
Regional land managers	DSE, PV.	51
Other regional land managers and authorities	Catchment Management Authorities, DPI, Local Governments[A], Trust For Nature, Vic Roads, Greening Australia, Grampians Wimmera Water Authority, Indigenous groups.	57
Partners	Landcare, Friends of groups, Committees of management, Local Government.	111
Neighbours	Private landholders adjacent to public land.	82
Public land users	4WD, Field naturalist, Bushwalking groups, Surf life saving clubs, Campers, Lessees, Tour operators.	44
Education	Deakin/Forestech TAFE conservation students.	42
Total		409

[A] Local Government respondents are categorised as 'Other regional land managers and authorities' and as 'Partners' in this report. This is due to their wide role in pest plant and animal management.

The approach

Stakeholder information

The Engagement and Communications project for weed and pest management on public land began by commissioning Roberts Evaluation to research the perceptions of identified stakeholders. Roberts Evaluation conducted over 400 interviews to gather information on perceptions of threats from weeds and pests, Government management responses, and the position of different stakeholders within their local networks. Stakeholders were identified and prioritised by the Public Land WPI Steering Committee using a World Bank process to rank stakeholders that is commonly used at DSE (Holland 2007). Stakeholders were grouped into major groupings for the purpose of interview design (Table 1).

Interviews were designed specifically for each stakeholder group to address the following objectives:

1. The **assets people perceive to be under threat** from weeds and pests (pest plants and animals).
2. The current level of understanding held by key stakeholders of the **threat to biodiversity** from weeds and pests.
3. The extent of key stakeholder **awareness of Government weed and pest management** policies and programs on public land.
4. The level of key stakeholder **attitudes towards, and involvement in Government management programs** of weeds and pests on public land.
5. The **desired level of involvement of key stakeholders** in weed and pest management **activity and decision-making** on public land.
6. **Current versus optimal communication channels and engagement opportunities** for key stakeholders.
7. **Barriers to key stakeholders engaging** in weed and pest management on public land.
8. An assessment of stakeholder views regarding **improving weed and pest management** on public land within the current level of funding and if there were more or less resources
9. **The degree of influence** of key stakeholders in terms of their role in an organisation or community
10. **Recommendations for** the different elements of the study.

Data collected in the interviews was analysed using basic statistics, organisational network analysis (Krebs 2001), and an assessment of degree of influence.

The results from this research were used to identify the outcomes necessary to enable better engagement, partnerships and communication at the level of the policy unit responsible for invasive species at DSE (not at the local level). Outcomes have necessarily centred on building understanding of the Government approach to invasive species management and building the relationships necessary to achieve coordinated effort, among both internal and external stakeholders. The information gained from this research allowed for a better understanding of current relationships and gaps in networks.

Building capacity among project managers

The Engagement and Communications project for weed and pest management on public land had as a key priority to support project managers in planning for strategic and purposeful engagement and communications activities. Project managers possess a wide range of skills in engagement and communications, with some being highly skilled while others are more limited in their knowledge and capacity. Project managers also have limited time and funds available. As such, the process to plan for engagement activities needed to be simple but effective.

Project managers were initially brought together in a workshop to initiate planning for engagement and communications activities. The Engagement and Partnerships team from DSE facilitated the workshop and took project managers through a process to identify and prioritise their stakeholders and teach some of the fundamentals of engagement practices. The workshop also gave project managers a chance to interact and learn from each other's stories, successes and achievements.

The workshop was followed by one-on-one meetings between the Engagement and Communications project coordinator and project managers. These meetings began by assessing the desired outcomes of each weed or pest project and asking who needs to be engaged and how for each project outcome. The result for this was a simple plan for engagement and communications activities over the coming year, presented in table form. Activities were strategic in that each one was linked to a desired project outcome, and were proactive. With each project possessing a strategic plan for engagement and communications, the fundamentals were in place to be able to move forward in building further capacity and skills in engagement and communications to facilitate better management outcomes for biodiversity.

Networks and relationships

One of the focus points of the stakeholder research project was the strength and breadth of networks. The consultants found that collaborative work was most common where there were formal partnership arrangements. In regional areas the level of collaborative work often reflects the level of informal bonds between land managers from different agencies and community groups. Where there are weak links there is often not the mechanism for people to interact and to collaborate. Informal bonds are often characterised by personal relationships and are dependent on staff member's position in the local community and length of time in the job.

The importance of networks in establishing collaborative working relationships is one of the key learnings of DSE's work in engagement and communications for public land weed management outcomes. This finding has been reinforced at a recent series of internal DSE forums around Victoria. Discussions on weed and pest management activities at these forums suggested that where strong relationships exist between agencies and community groups at the local level there is more collaboration in on-ground work.

At this stage more thinking is needed around how to encourage and facilitate the strengthening of local networks. One option is to use a project or a focal area to put in place more formal and structured relationships such as working groups or supported community groups if there is enough community interest. There are a number of examples throughout Victoria where these exist. Each weed and pest project under the Weed and Pest Initiative public land component has a working group made up of different agency representatives. By way of example, in Mornington, representatives from State and local governments and infrastructure managers meet to prioritise potential areas for works and community grants to be directed for the best biodiversity outcomes. This collaboration enables work to be targeted to compliment other work occurring throughout the region.

Other formal groups exist throughout the State that are driven by other agencies and individuals outside of DSE. Landcare, Conservation Management Networks and Community Weed Groups are made up of multiple stakeholders collaborating to address weed and pest threats across different parcels of land and land tenures. However, there remain many local areas with no formal relationships in place that also lack strong informal bonds. Questions remain around how to best facilitate the strengthening of local networks in ways that are sustainable.

The Otway weed forum

To investigate potential mechanisms for strengthening networks a decision was made to run a pilot workshop for weed practitioners in the Otway region. The Otways were chosen because of the large number of practitioners concerned about weeds in the area, including a number of organised community groups. Parks Victoria and DSE manage a significant integrated weed management project throughout the Otways called 'Otway Eden'. Otway Eden prioritises new and emerging weed species for management and aims to protect identified biodiversity asset areas from the threats of new and emerging and established weeds. The region contains both coastal areas and inland plains and features significant private and public land values.

Representatives from several different agencies and community groups were asked to attend the workshop. Fifteen people attended while a further four people were interested but had other commitments. The aims of the workshop were:

- To encourage a level of coordination of weed work in the Otways that allows different groups/agencies to conduct work that is complementary and not undertaken in isolation from the management agendas of other groups/agencies.
- To build knowledge and understanding among different groups/agencies of where weed works are taking place.
- To set a platform for a broader Otways weed management group, pending the result and reception of the workshop.

These objectives were sufficient to entice people to attend but general enough to allow for a number of directions to be taken as a result of the workshop. The capacity for ongoing DSE support of a formal group was limited and so potential formal networks and relationships that could arise from the workshop needed to be driven and owned by participants themselves.

During the workshop participants were asked to present a snapshot of the group or agency they represented, their location of interest, their management priorities and approaches, and specific weed work they were currently undertaking. These were compiled after the workshop and distributed to all participants along with a spatial representation of where groups were operating and a contact list of all participants.

At the end of the workshop participants were asked if they saw a role for such a group for better weed management outcomes in the future. The majority of attendants felt that such a group did have a role, specifically that the group allowed them to seize the opportunity for networking and establishing relationships with fellow weed practitioners. An outcome of the workshop is that the Otway Eden project has agreed to support an annual forum where weed practitioners are able to share experiences and learnings from their work, and where people can meet and discuss with others their individual work objectives.

Conclusion

For engagement and communications activities to contribute meaningfully to weed management outcomes there needs to be adequate resources and capacity dedicated to pro-actively and strategically plan for engagement and communications objectives and activities. The work done under the Weed and Pest Initiative – public land component has helped to establish this groundwork for the public land Initiative projects.

A key learning from this has been the importance of networks and relationships at a local level to the establishment and effectiveness of collaborative work. The best way to effect collaborative work is to have formal relationships in place where work is done across different land parcels and tenures for a common goal.

The Otway Weed Forum was an exploration of how to pro-actively strengthen local relationships and networks in the absence of a formal common project. As this workshop was only recent, it is still too early to tell if relationships have strengthened and if the amount of collaborative work in the area has increased. The positive feedback from the workshop and the request that it be repeated annually is a good interim outcome that has the potential to result in further relationship building and ultimately, more collaborative work.

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Good Neighbour Program: managing weeds at the public/private land boundary

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Summary

Under the Good Neighbour Program public land managers undertake weed management at the interface of public/private land to reduce weed impacts on private land values. The program's Good Neighbour Tender is a pilot project that is giving private land managers the opportunity to bid to undertake that weed management on public land. Successful bidders who enter an agreement with the Department of Sustainability and Environment (DSE) will be paid to manage the weeds on the public land that adjoins them.

Introduction

Department of Sustainability and Environment and Parks Victoria manage in excess of 8.5 million hectares of public land in Victoria, and the shared public/private land boundary is around 60 000 kilometres. Weeds do not recognise the boundary between public and private land and since 1994 the Good Neighbour Program has focussed on managing the weeds on public land at the public/private land interface to protect private land values. The objectives of the Good Neighbour Program are to:

- Build positive relations with neighbours by reducing the extent of weeds and pests on public land;
- Demonstrate Government is a 'good neighbour' by controlling weeds and pest animals on the public and private land interface;
- Ensure weed and pest management on public land takes account of community priorities and actions;
- Support community-based programs occurring on adjoining private land; and
- Integrate weed and pest management with other natural resource management objectives.

Weed management under the Good Neighbour Program is usually undertaken by Department of Sustainability and Environment and Parks Victoria on the lands that they manage.

The Good Neighbour Tender (GNT) pilot is trialling, for the first time on public land, a market based approach for weed management on public land. This is a competitive process where eligible landholders in the pilot area can submit a bid for the management of nominated weeds on agreed sites in the pilot area. Successful bids are those that offer the best weed management outcomes for the investment.

Successful bidders will be offered a 'Good Neighbour Tender Site Weed Management Agreement'. Under the agreement successful bidders will be paid for managing the weeds on the public land that adjoins them. The agreements are for three years over which time the bidders will reduce the weeds to a level of not more than 5% of the original infestation by the end of the three year program.

There have been some other highly successful tender programs across parts of Victoria since 2001. These have been mostly on private land and relevant to native vegetation management and to achieving environmental outcomes. Developing a tender program for public land has involved unique challenges, and DSE will carefully evaluate all aspects of the trial.

The approach

Pilot area selection

An early step in designing the GNT was to select an area where the pilot could be run. In deciding the area, parameters included:

- Where there was likely to be community support for the approach;
- A history of landholder weed complaints;
- A variety of weeds in the area;
- A mixture of public land tenures – State forest, crown land, national parks; and
- A range of private land uses such as natural vegetation, agriculture and horticulture.

The pilot project needed a population density to achieve around 50 possible expressions of interest), and sufficient public land interface that the tender could be applied to. In addition, local 'champions' both landholders and agency staff who could lend support to the concept and an area where other 'auctions' such as RiverTender or BushTender were thought to be an advantage. Areas that were receiving bushfire or flood recovery funding for weed management were excluded.

The Kiewa, Barwidgee and Happy valleys in Victoria's north east met these criteria. The Mitta Mitta and Tallangatta valleys were also included in the pilot area following the February 2009 Beechworth fire.

Defining the 'site'

A GNT site, under the trial, is the public land 30 metres deep and bounded along its length by a private landholder's boundary. Thirty metres was selected as it would likely be manageable for the person undertaking the work, and likely to be able to be accessed from the adjoining private property. The latter was considered important as access to the GNT site may not be possible from the public land unless there was existing access such as formed tracks. A GNT bid covers weed management at a GNT weed management site.

Participant eligibility

One of the aims of the GNT pilot is to give landholders who adjoin public land the opportunity to manage the weeds on the public land that impact them. The tender recognises that there may be opportunities for neighbours or groups such as LandCare to work together at adjoining private property sites. It was also recognised that there may be occasions where a landholder does not want to participate themselves but is happy for another land holder to represent them.

Tender design

The GNT design considered: the weeds that would be available for treatment, the weed management activities, and terrain. These aspects are part of the metric that has been developed to differentiate between bids.

The weeds

In determining the weeds that would be available for treatment options ranged from all weeds on site, to only weeds on a site that the private land manager wants to treat (and not treating others), a list of weeds defined by the project– perhaps those posing the biggest risk or the most widespread, a long list – a short list.

While there was support for having all (possible) weeds on site available for treatment it was agreed that if there were a large number of species to consider then deciding between the bids would be more complex than is appropriate for this trial. In considering a shorter, defined list of weeds Good Neighbour Program records were examined to determine weeds managed under the existing program in Victoria's north east. The result was that eight weeds are nominated to be treated as part of the GNT pilot project. These are: *Eragrostis curvula* (African lovegrass), *Rubus fruticosus* (blackberry), *Genista monspessulana* (Cape broom), *Cytisus scoparius* (English broom), *Ulex europaeus* (gorse/furze), *Echium plantagineum* (Paterson's curse), *Nassella trichotoma* (serrated tussock), *Hypericum perforatum* (St John's wort), *Rosa* *rubiginosa* (sweet briar). Where these weeds are on a GNT 'site', they all must be treated; other weeds on the 'site' are not included.

Weed management
The likely methods of weed control are manual removal or spraying either by knapsack spray unit or high pressure spray unit. Minimum standards for weed control include:

- Reducing the infestation of weeds to a level of not more than 5% of the original infestation by the end of the three year program;
- Aiming to control weeds before seed set;
- Applying herbicide during optimum control period and according to the herbicide label;
- Control method and chemical choice is to be appropriate for protection of all native animals and plants on the site;
- Soil disturbance and damage must be minimised;
- Waterways should not be contaminated, appropriate herbicide for application near waterways and standing bodies of water should be used. Herbicide labels should be referred to for environmental warnings;
- Weed management activity at known cultural and historic sites is not permitted without express approval;
- Landholders and any employees or contractors under their direction must ensure that all weed control works are conducted according to safe minimum standards and in accordance with relevant legal obligations;
- The herbicide label should be read and understood prior to use. All herbicides must be applied according to the label recommendations. Safety equipment identified on the herbicide label is a minimum requirement;
- Approved, clearly visible signs must be placed to alert other public land users of chemical application in the area of the Good Neighbour Tender site; and
- Stagger the removal of weeds (especially woody shrubs) that provide native animal habitat where it may otherwise be absent.

Terrain
Terrain is used to describe how steep or rocky (or not) the GNT site is. It indicates how easy or difficult it would be to get around the site to do the weed management: could the site be traversed by two wheel drive vehicle, or would a four wheel drive, tracked machine (bull dozer) be used, would it be suitable to get around the site on foot? Terrain that varies across a site will be divided into zones. The terrain is described in each zone separately, a site may have only one zone or there may be multiple zones.

Metric development
A metric is used to determine which bids offer the best value for money and to ensure that bidders are not disadvantaged by the terrain or other site conditions.

The elements of the metric (assessed within each zone) are: the weed species; per cent cover of that species; weed arrangement, (scattered – clumped); proposed method of weed control; the terrain. The per cent cover of these same weeds is also assessed on the area of public land directly adjacent to the site and the private land adjoining the site. Weed management activities in the vicinity of the site such as those on adjoining properties or of LandCare groups is also noted.

The per cent cover of the weeds on the site (made up of zones) is the most important feature. This aspect is weighted in the metric to reflect the change that is expected due to weed management. For example: if there is a high per cent of weed cover on the site then there is a high degree of change to achieve no greater than 5% weed cover; if there is a low per cent of weed cover on the site then there is a lesser degree of change to achieve no greater than 5% weed cover.

The process

Expressions of interest
Landholders who adjoin public land in the pilot project area can register an expression of interest through the DSE Customer Service Centre. Expressions of interest close when the project considers that participation levels are sufficient.

Site assessments
The GNT Implementation Officer or Field Officer contacts each registered landholder to discuss eligibility, Occupational Health and Safety (OHS), insurance and WorkCover requirements of the tender and a (no obligation) site visit is arranged to assess the site and discuss weed management options with the interested landholder.

Site weed management plan
Following the site visit and in consultation with the local public land manager the GNT Field Officer prepares a draft Site Weed Management Plan and sends it to the landholder. The plan contains all of the aspects covered in the site visit and sets out the objectives of the plan and the obligations of the landholder in regards to: weed management; use of chemicals; insurance and licence requirements; OHS; protecting public land values; notifications; record keeping and reporting.

Bidding
Landholders can submit a sealed bid that nominates the amount of payment being sought by them to undertake the GNT Site Weed Management Plan. All landholders will have the same amount of time to consider the price that they will tender, and submitting a bid does not commit them to proceeding with the plan.

Bid assessment
All bids are assessed objectively by a tender assessment panel. Assessment is based on the weed management services being proposed, site terrain, site condition (including immediate surrounds); weed types and level of infestation, and site conservation values as described in the GNT Site Weed Management Plan.

Agreements
Successful bidders are offered a Good Neighbour Tender Site Weed Management Agreement based on the GNT Site Weed Management Plan. The period of the agreement is three years. Landholders who do not want to proceed do not sign the agreement, signing the agreement is binding and commits the landholder and DSE to meeting their obligations under the agreement.

Payments and reporting
At the commencement of the agreement 30% of the agreed sum is paid to the landholder. Further payments of 25% of the agreed sum are made to the landholder at the beginning of years two and three on condition that the agreed actions have been carried out and that satisfactory annual self reports are provided to DSE. At the end of year three a final payment of 20% is made to the landholder, 5% of this is for completing the agreed actions and providing the annual self report, and 15% is for meeting the reduction of weeds to 5% or less.

Evaluating GNT pilot
Evaluation of the pilot will investigate and analyse to what extent the approach is effective in terms of landholder support. What are the barriers to: expressing interest; undertaking a site visit; making a bid, or signing an agreement? Did the landholder get the bid price right – would they do it differently if doing it again? Is the landholder satisfied that the approach worked for them – are there other benefits to being involved that were not anticipated – were there other issues?

Is the approach a sound investment for government – is there reasonable return for investment in terms of weed management outcomes? Was the criteria about right, for example should the site width be greater, should it be set by the project or in consultation with the landholder? Is selecting the weeds for treatment the right way to go about it, is the metric about right?

Were the tools and process that were established to manage the pilot sufficient to support landholders and public land manager's participation in the pilot? To what extent were the objectives of the Good Neighbour Program met?

Conclusion

The GNT pilot is breaking new ground in terms of trialling a market based instrument on public land. There has long been anecdotal evidence that landholders would like to 'take care of the weeds just over the fence' and this tender approach is providing that opportunity. Public land managers take seriously their responsibilities for weed management on public land and managing weeds for the protection of public assets and for 'public good' is the focus of most weed management programs on public land.

The tender approach provides an opportunity for private land managers to manage weeds on public land and also provides the opportunity to ensure that this weed management does not impact negatively on the environmental or cultural assets of the public land or impact public land users.

It is important that government investigates ways to improve services and meeting obligations, and in terms of the GNT pilot, at this early stage… there are more questions than answers.

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Controlling wind blown fairy grass (*Lachnagrostis filiformis*) seed heads in western Victoria

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Introduction

Fairy grass or common blown-grass (*Lachnagrostis filiformis* (G.Forst.) Trin.) is an emerging indigenous weed in Australia that has extensively colonised areas of dry lake beds in western Victoria during the current drought. Whilst the plant is not of environmental concern, it causes many social problems where it grows in large populations close to townships. Large numbers of the plants' detached mature seed heads (panicles) disperse from the grass growing on lakebeds, subsequently lodging against nearby fences, railway lines, machinery and buildings. This accumulation of material initiates concerns with respect to the safety, fire hazard, and the general nuisance it provokes (Poussard 2004). Several control measures have been employed by management authorities to control blown fairy grass seed heads, but there effect in both in the short and long-term is unclear.

A study was undertaken to determine the effect of a number of control treatments on the cover of fairy grass and the total biomass of its inflorescences during the year of treatment and the following year, as well as on the viability of seeds produced. The treatments investigated were: slashing with removal and retention of slashed material; broadcasting seed of desired native species as competitors; glyphosate based herbicide at different concentrations; grazing; and burning.

Methods

The following treatments were applied to the bed of Lake Learmonth: non-selective glyphosate based herbicide (Roundup Biactive™) at 1.5 L ha^{-1}, and 3 L ha^{-1}, slashing (with both slashed material removed and retained), broadcasting native orache (*Atriplex australasica* Moq.) seeds at 3.5 kg ha^{-1}, broadcasting salt-marsh grass (*Puccinellia perlaxa* N.G.Walsh) seeds at 6 kg ha^{-1} and control. Seed broadcasting (14th June 2006) aimed to reduce fairy grass inflorescence biomass through competition with desired native species. Slashing and herbicide treatments were applied in late November 2006.

To determine whether fairy grass seeds remain viable after mature plants were treated with herbicide, seeds were collected two weeks after application. Seeds were tested for germination under the following conditions: 15/25°C, 12 h thermoperiods coinciding with 12 h dark/light cycles. Ungerminated seeds were tested for viability using tetrazolium chloride (Freeland 1976).

In addition, grazing was trialled on McCosslens Swamp with sheep at 3.5 dry ewes ha^{-1}. Eight 10 × 10 m grazing exclosure plots were established across the lake.

To examine the effectiveness of fire as a management tool, site colonisation of fairy grass and associated plant species was also observed following a controlled burn on Lake Learmonth in January 2008. Fairy grass seeds remaining in the seed bank after the fire were tested for germination.

Foliage cover (using the point intercept method) and seed head biomass of fairy grass were assessed two and twelve months after treatment to assess the effect of treatment in the short term and longer term.

Fairy grass foliage cover and biomass were analysed with univariate linear mixed effects models (LME). Following univariate techniques, multivariate data were analysed using the non-parametric Two-way Analysis of Similarities (ANOSIM2). A one-way Analysis of Variance (ANOVA) was used to compare seed germinability following herbicide application. All assumptions were tested and met prior to analysis.

Results

Herbicide

Herbicide treatments (1.5 L ha^{-1} and 3 L ha^{-1}) killed all fairy grass plants and non-target species. Although herbicide did not reduce the seed head biomass of fairy grass (Figure 1a), the seed heads failed to open fully and emerge from the leaf sheath, thereby reducing their capacity to disperse in the wind. Seeds from these plants subjected to herbicide were still able to germinate with mean total germination of 75 ± 3%. The tetrazolium test indicated that the ungerminated seeds could not be classed as viable (Freeland 1976). No significant difference in total germination was found between seeds collected from plants treated with glyphosate and control plants ($P = 0.280$).

The application of herbicide (3 L ha^{-1} and 1.5 L ha^{-1}) resulted in an increased fairy grass seed head biomass by 86–150% (Figure 1a, $P = 0.010$; $P = 0.022$) and foliage cover by 34–37% ($P = 0.007$; $P = 0.004$) one year after treatment. The SIMPER analysis showed that the mean foliage cover of prickly lettuce (*Lactuca serriola* L.) was reduced one year after herbicide application; contributing to 8.6–9.5% of the dissimilarity between the herbicide and control plots. Prickly lettuce had a mean foliage cover of 9.4 ± 0.3% in control plots and 2.4 ± 1.5% and 1.8 ± 1.2% in 1.5 L ha^{-1} and 3 L ha^{-1} herbicide treated plots respectively.

Slashing

Slashing significantly lowered seed head biomass (thatch both removed and retained) one month after treatment (Figure 1a, $P < 0.001$). However, these differences were not retained 12 months after the treatment was applied (Figure 1b, $P = 0.435$). Although the seed head biomass

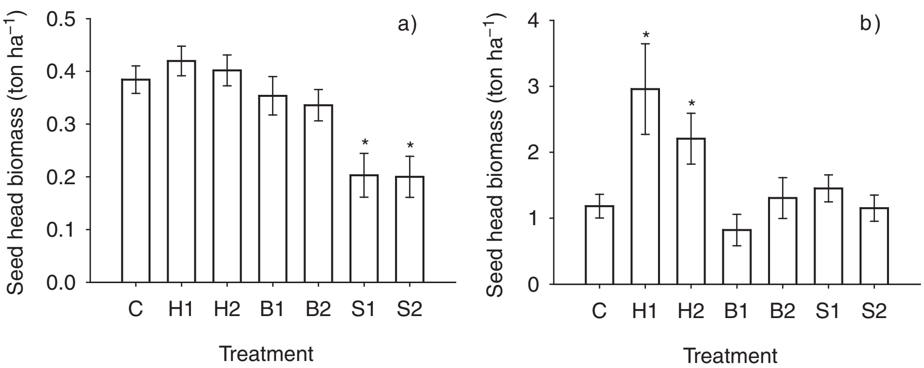

Figure 1. Main effects of treatments on fairy grass seed head biomass a) two and b) twelve months after treatment on Lake Learmonth. C = control, H1 = herbicide at 5 L ha^{-1}, H2 = herbicide at 3 L ha^{-1}, B1 = seed broadcasting of native orache, B2 = seed broadcasting of salt-marsh grass, S1 = slashing with thatch removed, S2 = slashing with thatch retained. Error bars represent ± standard error. * denotes means are significantly different from control.

was reduced by slashing, foliage cover of fairy grass was not reduced in the treatment year (P = 0.283) or the following year (P = 0.118).

Seed broadcasting
Little recruitment was observed from broadcast seed of both native orache and salt-marsh grass; fairy grass foliage cover and seed head biomass was not found to differ significantly in the year of treatment or in the following year with a seed broadcasting treatment (Figure 1a).

Grazing
Low foliage cover of fairy grass was found on McCosslens Swamp six months after the treatments were applied. Grazing did not significantly effect the plant community composition during this year (P = 0.121).

However, 18 months after the establishment of the grazing exclusion plots, higher fairy grass foliage cover and seed head biomass was found in grazed plots (Figure 2, P = 0.007). In addition to increased foliage cover, higher seed head biomass of fairy grass was found in un-grazed plots (P = 0.008) despite the low cover of fairy grass. The composition of the plant community also differed between the treatments (P = 0.001). Specifically, higher foliage cover of prickly ox-tongue (*Helminthotheca echioides* (L.) Holub.) was found in grazed plots, contributing to 53.6% of the dissimilarity between treatments. The remainder of dissimilarity was explained by fairy grass, which had increased abundance in grazed plots. These changes to the community composition were not retained in the following growth season.

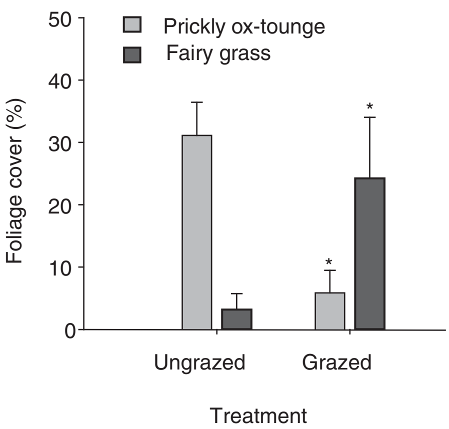

Figure 2. Main effect of treatment on foliage cover of fairy grass 18 months after treatment on McCosslens Swamp. Error bars represent ± standard error. * denotes mean was significantly different from ungrazed treatment.

Fire
Fairy grass plants were able to survive the controlled burn and persist into the following growth season. In addition, large numbers of fairy grass seed remained in the top 0–5 mm of soil (6.7–9.1 seeds cm^{-2}), with 30–41% of seeds remaining viable. Fire did not significantly affect seed viability (P >0.05).

Discussion
Herbicide and slashing effectively reduce the impact of blown fairy grass seed heads during the year of treatment. Herbicide is generally applied late season (late November-December) to control fairy grass. By this time, however, the seeds have reached maturity and are able to germinate readily. Additionally, such late application is likely to increase the seed bank on the lake as seed head dispersal is reduced. Late season herbicide also reduced the subsequent recruitment of the exotic prickly lettuce. Fairy grass was therefore able to re-invade the site in the year following treatment in greater abundance and with less competition from prickly lettuce; its foliage cover increased by 86–150% and seed head production increased by 34–37%, thus exacerbating the problem.

Whilst slashing was found not be effective in the long term, it was not found to be counter productive like herbicide treatments.

Grazing presented a different response to slashing, however. After 18 months of treatment, plant composition shifted, favouring fairy grass and disadvantaging prickly lettuce. This may be due to selective grazing.

Fairy grass was observed to be able to survive a fire event into the following growth season. In addition, large numbers of seed in the top 5 mm of soil were able to withstand the fire.

Conclusion
The results emphasise how management aimed at achieving short term goals, without considering its effect in subsequent years, are ineffective in the long term and can even be counterproductive.

Fairy grass is often only controlled once it has established and large numbers of its seed heads blow into township areas causing concern. A pro-active management approach, such as seed broadcasting of competitors prior to its establishment, may prove more effective and efficient in the long term on recently dry/drying lakes.

On lakes where fairy grass is already established, management should focus on speeding and directing plant succession towards a more desirable outcome (Sheley *et al.* 1996, Sheley and Krueger-Mangold 2003). Where herbicide is necessary, it should be applied prior to seed maturity and vegetation carefully mapped out to avoid killing non-target species.

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Compliance is more than a big stick: combining partnership building with enforcement to assist with Victoria's biosecurity

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Abstract

The Department of Primary Industries' Weed Alert Program uses a combination of stakeholder engagement and enforcement to form partnerships with industries that pose a risk of introducing high risk invasive weeds (State Prohibited Weeds). Weed Alert gains practice change from engaging with stakeholders to encourage them to adopt approaches that would be seen as 'best practise' for reducing the introduction of high risk weeds. Ownership is generally gained by industry through the creation of partnerships but when this fails or does not occur due to the lack of urgency, enforcement is used to assist with the process.

Introduction:

One of the key functions of the Department of Primary Industries, Weed Alert Program is preventing the introduction of State Prohibited Weeds in Victoria and managing the control effort when incursions of these weeds do occur.

Weed Alert uses a number of approaches to achieving the above function of which compliance is one. Weed Alert compliance operates on the principle that a balance of partnerships, education and enforcement is the best way to achieve this goal.

The Department of Primary Industries distinguishes compliance from enforcement in the following ways: enforcement is the action to prosecute specific breaches in legislation, while compliance includes the use of extension and education to encourage people not to offend first, and if that fails enforcement is used.

Partnership development and maintenance with key stakeholders is used by Weed Alert compliance predominantly to prevent offences from occurring in the first place and provides processes to reduce the chance of accidental breaches of legislation. By ensuring stakeholders understand their legal obligations, and by working together to develop codes of practise and/or procedures that work towards helping to protect Victoria's Biosecurity, many issues can be solved before offences occur. When that fails enforcement is used by Weed Alert compliance to deter prohibited events from occurring again. This also demonstrates to the broader community that Biosecurity is very important and a priority for the Victorian Government.

Engaging stakeholders and forming partnerships

By developing collaborative processes with key stakeholders (private and public) the stakeholders gain increased ownership in the risks weeds pose, a clear understanding across the groups as to what the processes are to reduce the risks, a greater understanding of what the Weed Alert Program does and why it takes the approaches it does. Partnerships also assist with information flow between groups beyond the development of any product/process.

The best outcome for the Weed Alert Program would be that the effort it devotes into developing and maintaining partnerships with key stakeholders is enough to ensure offences of the *Catchment and Land Protection Act 1994* do not occur. Two issues are that complacency occurs in some sectors when they feel there is no risk of punishment, and some stakeholders are difficult to engage when there is no perceived risk of punishment. Once an enforcement event occurs some stakeholders become more engaging.

Working with peak bodies and individual businesses is important to ensure they understand what DPI expects of them but equally important is the understanding Weed Alert can gain of how the industries work and what interventions can be implemented to reduce the risk of introductions of high risk weeds.

An example of the benefit of partnerships is the relationship that has developed with Nursery and Garden Industry Victoria (NGIV). A Code of Practice is being created to guide the industry on the best way to import plant material to ensure invasive plants are not accidentally imported. DPI is providing input into this document to help ensure that the Code of Practice will achieve what both DPI and NGIV require.

The businesses and industries that Weed Alert work with are, in general, very knowledgeable and enthusiastic about what they do thus are a valuable resource for Weed Alert.

Enforcement

The primary purpose of enforcement is not just to penalise offenders who breach legislation, more importantly, it is undertaken to deter the offenders from further offending, deterring others from breaching legislation, facilitate rehabilitation, to express denunciation and to protect the community (Department of Primary Industries 2000).

It is unfortunate in some circumstances that the community has to see compliance occurring to understand that the Government is taking an issue seriously. Further more, society does measure the importance of offences by the penalties imposed and the visible enforcement of those offences by Government. For example, society would generally acknowledge that the Victorian Police are taking speeding seriously over Easter by the introduction of the 'double demerit points' system and increased presence of Victorian Police vehicles and speed cameras. The Victoria Police effort to reduce the road toll during holiday period requires an increase to enforcement activities to remind the public not to speed.

What does Weed Alert use enforcement for?

Weed Alert undertakes compliance to protect Victoria from highly invasive plant species that are capable of being eradicated – State Prohibited Weeds. It does this by enforcing legislation that helps protect Victoria's Biosecurity:

- Prohibiting the trade of State Prohibited Weeds;
- Stopping the propagation and growing of State Prohibited Weeds;
- Ensuring control of State Prohibited Weeds is not compromised; and
- Prohibiting (and prosecuting for) activities that aid in the dispersal of State Prohibited Weeds.

Getting the balance right

Partnership and relationship building is the primary mechanism for DPI to gain practice change within industry and to protect Victorias assets. Unfortunately this alone has proven not to be fool proof and enforcement has been required to assist with protecting Victoria's Biosecurity.

This is partially due to some individuals who operate outside industry peak bodies, or those who believe their rights to grow any plant overrides legislation to protect Victoria from invasive plant species.

Kotter's eight-step plan for implementing change is widely recognised as a systematic approach to achieve change (Robins *et al*. 2008). The first step highlighted by the approach is to create urgency. This can be done by undertaking enforcement which demonstrates that society does not accept the behaviour. Combined with enforcement, extension material is disseminated to the stakeholders to reinforce why invasive plant importation and distribution is so dangerous to Victoria's socio, environmental and economic resources. The next few steps of Kotter's eight step plan can be interpreted as including the forming of partnerships, creating a vision and ensuring empowerment and ownership. The last step, reinforcement, involves both positive reinforcement via recognising good work undertaken by stakeholders, and penalising groups/individuals that diverge from the requirements by using enforcement.

Having good working relationships and partnerships can assist in making enforcement more effective in two ways:

1. As the stakeholders understand when and why DPI undertakes enforcement actions, they would generally publicly support the enforcement actions when they occur.
2. As the stakeholders have their own communication channels they act as a conduit to provide the message to more relevant parties that an enforcement event occurred, which helps to deter others from offending.

CASE STUDY – eBay and water hyacinth

The trade of species, via the internet, has steadily increased as technology improves. As a lot of trade is supplied from international groups it causes significant hurdles to prosecute suppliers, so enforcement is focussed on the importer (the person receiving the plants).

After two successful prosecutions of people who purchased water hyacinth on eBay, DPI developed a partnership with eBay to produce a process to stop the trade of declared noxious weeds. It is not without flaws but the new protocols adopted by eBay have greatly reduced the incidents of declared noxious weeds being advertised on eBay Australia.

CASE STUDY – Partnering with NGIV

Weed Alert has a close working relationship with NGIV. As the peak body for nurseries and garden industries they are a valuable network used to disseminate information and also to work with to improve current practices undertaken by their members. NGIV, with support from Weed Alert, have achieved some positive changes that have helped protect Victoria's assets from weed introductions into Victoria. These changes include the production of a 'Grow Me Instead' brochure (NGIA undated), voluntary removal of trade of some invasive species and shared displays at the Melbourne International Flower and Garden Show. Like most peak bodies, NGIV's views are not always accepted by all members and non-members within the greater industry. While NGIV agrees that some species should not be traded due to the risk they pose, some growers still persist in propagating and trading in these species. It is these few individuals that use most resources in the enforcement effort.

Conclusion

In conclusion, to achieve practice change within industries whose general practices pose a risk of invasive weed species being introduced into Victoria, Weed Alert works with the key stakeholders to develop partnerships. The purpose of the partnership is to increase ownership of the issue, develop processes in cooperation to address the issue and to develop an open exchange of information.

Enforcement is generally required when dealing with groups or individuals that are difficult to engage, and therefore initiate practice change. Barriers to engagement include; lack of representation by formal body, and/or their apathy, ignorance or deliberate disregard to the legislation and their requirements regarding invasive plants in Victoria.

Enforcement is also used as a tool to create urgency within an industry that otherwise thought were above having to work within weed legislation.

Acknowledgments

I would like to thank the Weed Alert staff for their dedication to reducing the risk that new and emerging invasive pest plants pose. I would also like to thank Neil Smith for his assistance in producing this paper and Ryan Melville for his good work with negotiating with eBay.

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Blackberry control is more than science: understanding community engagement in pest management

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The methods for controlling blackberry are well established, however, blackberry continues to be a significant issue for many land managers. This highlights that there are a variety of socio-economic factors inhibiting on ground change. Community-led approaches have a proven record (see for example Hickey and Mohan 2004, Saul 1997) in providing a holistic approach to natural resource management.

The Victorian Blackberry Taskforce (VBT), a multi-agency taskforce, is charged with providing direction to the community and government for blackberry control. A significant role is facilitating and supporting community-led projects. Based on the VBT experiences, this paper outlines some lessons and principles for meaningful engagement with communities for effective pest management. The North East Blackberry Action Group and Far East Community Blackberry Action Group formed in 2005 and 2008 respectively, have been used as case studies to begin to explore the complexities around a community-led response for managing blackberry.

Approach

This paper is aimed at sharing insights to groups or individuals involved in pest management programs that have participation from the community. Based within the social science discipline, the paper will argue that blackberry control is more than science. Rather than viewing blackberry management as a purely technical based issue, it begins to address blackberry management as a socio-economic issue.

The methodology draws on an iterative approach, emphasising community based land management (Furze *et al.* 1996) and grounding social reality from the various perspectives and experiences of communities.

A framework, outlining the community-led approach has been developed to provide context for the community partnership program. Brief case studies are used to highlight the socio-economic components of blackberry management, and how the community has addressed their issues within their area. As the focus of the paper is on the human actor element, learning's based on their experiences will be provided. These are supported through a variety of key academic literature.

A brief background: blackberry

European blackberry, belonging to the *Rubus fruticosus* aggregate, was first introduced into Australia in the 1830s. Similar to the introduction of many pests into Australia, the origins of its introduction can be traced back to the cultural needs of the earlier settlers, with plantings occurring in Sydney gardens to produce hedgerows, and provide fruits for jams and pies. In 1851, the Government Botanist in Victoria, Baron von Mueller, and the first Curator of the Gardens at Melbourne University, Alexander Elliot, recommended that blackberry be planted to control soil erosion along creek banks. With its preference as a plant for erosion control, assistance from the earlier settlers, combined with its invasiveness, blackberry's status as a pest grew exponentially.

Currently blackberry covers significant tracts of land across Victoria, and is considered to have established to its climatic limits. It has created significant concern for both public and private land managers, with boundary fences between properties often being points of contention.

Blackberry infestations have significant detrimental effects on the landscape. It reduces productivity of primary industries, particularly grazing and forestry, degrades natural environments, hindering the provision of eco-system services, provides a harbour for vermin and hinders the recreation and ascetic value of regions. Under the *Catchment and Land Protection (CaLP) Act 1994* blackberry is declared as noxious and in Victoria is categorised as a Regionally Controlled Weed and responsibility for its control lies with the land owner (Melville 2008).

There are a variety of control measures available for land managers to manage blackberry, such as slashing, mechanical removal, grazing, fire, herbicide application and biological control. Although a variety of options exist to effectively manage blackberry, it still remains prevalent across much of the state, indicating that blackberry control is more than science. There are a variety of socio-economic barriers inhibiting its control. That is, farming and pest management are framed within a wide variety of social, economic, cultural, perceptual and situational reasons (eg Vanclay and Lawrence 1995, Vanclay 2004)

The community-led approach: a way forward

> '*Never doubt that a group of concerned citizens can change the world… indeed it is the only thing that ever has*.'
>
> Margaret Mead, Anthropologist

Incorporating local people and communities into natural resource management has become a global conservation and development orthodoxy. It has brought with it a rethinking of conservation, natural resource management and landscape protection and where it works well, has facilitated a more inclusive approach to searches for sustainable futures (Furze *et al.* 2008). The community-led approach, being facilitated by the Victorian Department of Primary Industries (DPI), has emerged to encourage greater participation of community for the management of widely established invasive plants, namely, blackberry, gorse and serrated tussock.

The approach has evolved in Victoria from a desire by communities to take increasing control of weed issues that are of greatest concern to them. It has effectively created a process by which the efforts of the people themselves are united with those of governmental authorities to improve the economic, social and cultural conditions of communities (Setty 2002, Kenny 2006). The unity between government authorities and community has been identified as essential (Green 2008, Rossouw 1996) for the longevity and success of such programs.

The Victorian Blackberry Taskforce (VBT) acts to mediate and facilitate relationships between community groups and government (refer Figure 1). It is comprised of five community members from across Victoria, and representatives from DPI (research and policy), Department of Sustainability and Environment and Parks Victoria. The position of Chair is held by a community member, and the Executive Officer to the VBT is provided by the DPI. In addition to providing clerical and leadership responsibilities for the VBT, the Executive Officer is involved with supporting the community partnership groups.

platform to seek alternative funding to address other land management issues. One particular project which has gained success has been the establishment and re-generation of native species in areas previous uninfested by blackberry.

A documentary has been produced capturing the north east experience from the perspective of the community (Ruralia 2008) and is currently being used to share the north east experience with other interested communities[1].

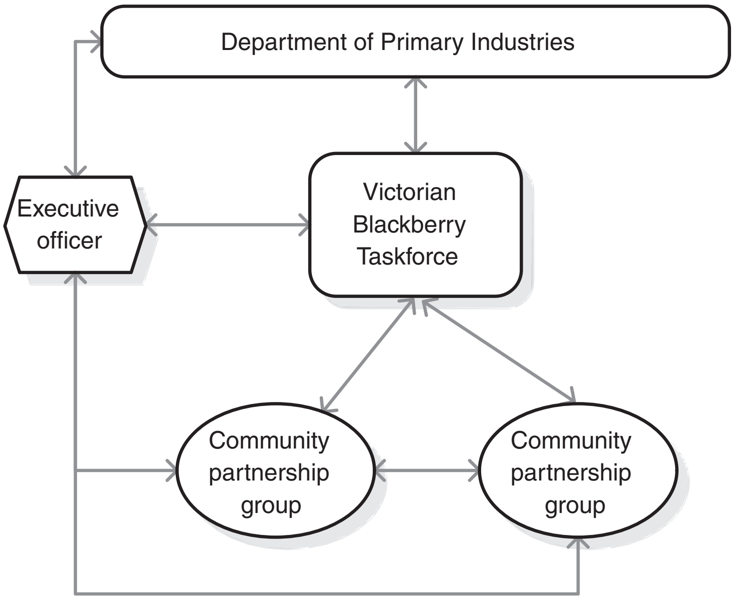

Figure 1. Basic conceptual model outlining the Victorian Blackberry Taskforce as a mediating structure.

Reflections from community-driven projects

North East Blackberry Action Group

The North East Blackberry Action Group (NEBAG) was formed in February 2005 as a result of community desire to address the impacts of blackberry on agricultural productivity and biodiversity in north east Victoria. The region is home to some of the most pristine natural regions of Victoria, and also is the birthplace of the Murray River. However, much of the private and public land has large infestations of blackberry.

Initially, members of the local Landcare network lobbied State government to provide support in the form of a Pest Management Officer. The request was unsuccessful due to changing priorities placing a greater focus on new and emerging weeds. For private land managers in the Upper Murray, blackberry was a clear and visible threat and perceived by them as a higher priority because of their impact on the landscape values and on farm profitability.

Blackberry due to its visibility and vigorous spread across usable farmland was locally-identified as a significant issue in terms of lost productivity, landscape values and biodiversity conservation – it was seen as an economic issue (lost farm productivity), a socio-cultural issue (lost landscape values) and an ecological issue (lost biodiversity). Even without government support, blackberry still remained an important multi-dimensional issue within the community. A pivotal point in the group's establishment and success was persistence in developing partnership approaches for blackberry management with the community and other stakeholders.

A meeting of key stakeholders including Landcare representatives, public land managers, local government representatives, the plantation industry and Vicroads identified the need for the establishment of a group to manage blackberry. A facilitator was used to help draft a basic action plan. This formal process and the development of an action plan consolidated the vision of the group and also allowed a reality check in the form of recognition that blackberry will never be eradicated from the region, but that it could be managed. The group found this important as a realistic goal for their objectives.

Attracting funding became easier due to the collective nature of the group and investors seeing significant value in supporting community led action for pest management. The consolidation of ideas, structure and sense of direction by the group has since manifested into community enthusiasm for the management of blackberry and ability to lobby agencies for future funding.

The group have managed to attract funding from various sources, which have gone towards funding a Project Officer who is employed a few weeks a year to map infestations and develop work contracts with land managers. This structure has also meant greater effort via public land managers to coordinate their weed control activities with the group.

Today, NEBAG has achieved significant success in the management of blackberry and their strong on-ground focus has ensured growing respect from those land mangers not directly involved in the group.

Blackberry is still an issue within the region, but the group has provided a platform to seek alternative funding to address other land management issues.

Far-East Gippsland Blackberry Action Group

Unlike the Upper Murray region, the far East Gippsland landscape is better described as containing vast tracks of public land, interspersed with pockets of free hold land. It contains several sites of national and international significance, having high eco-system values of old growth forests and diverse vegetation communities (East Gippsland Shire Council 2008). Blackberry infestations occur frequently on both freehold and public land.

Members from the Far East Victoria Landcare (FEVL) heard about the VBT's community partnership approach in 2008. With blackberry listed as a priority by all Landcare groups, the Landcare network organised a variety of community meetings in which the community-led approach and other communities' experiences in managing blackberry were shared.

There was initial interest from several communities; however, there was also some reluctance from community members in establishing a community-led project as it seemed too large for their communities to successfully manage. With support of FEVL, a coalition of these communities was established, known as the Far East Community Blackberry Action Group (FECBAG) with membership open to both non-Landcare and Landcare members. An action plan was then facilitated for the region.

The Goongerah region was selected as a pilot area for FECBAG as previous work has been initiated by community through the development of a local blackberry management plan. Previously, the community was exploring using the compliance services offered by DPI to assist them with their management plan, however, when presented the option of a community-led approach, the group believed a voluntary compliance approach would be a more appropriate option for their region.

The demographics of the pilot region comprise a variety of non-traditional agricultural drivers. Blocks sizes maybe described as 'lifestyle' size, with a large

[1] The NEBAG documentary can be viewed online at www.vicblackberrytaskforce.com.au/documentary.

percentage of residents being strongly embedded in an environmental ethos - passionate about their natural surroundings, and politically active in organising grass roots action.

A local action plan was then facilitated for the pilot region with a local pilot project steering committee reporting to FECBAG.

Seeding funding was provided by the VBT and a Project Officer was then employed. The group's Project Officer worked together with private landholders to manage their blackberry infestations, and also assist the group in working closely with government agencies to coordinate on ground works. This commitment and coordination of public works has encouraged efforts from private land managers to manage their blackberry infestations.

The FECBAG Project Officer works with freehold land managers to establish formalised three-year property management plans. Face-to-face engagement by the Project Officer has been well accepted and has often transformed an overwhelming problem into manageable steps. Difficulty in locating some absentee land managers has posed a problem as they are not living in the community and are unaware of their legal responsibility to control blackberry. Where some landholders are reluctant to commit to a written management agreement, due to the formality of the process and the binding implications, the Project Officer continues to negotiate with them. Others believe an agreement is unnecessary because their independent initiatives are already successful. Where this is the case, it is acknowledged. Compliance may eventually be necessary for land managers who are unwilling to acknowledge responsibility and take voluntary action.

Since the initial investment from the VBT, the group has explored other opportunities for co-investment into their project. Funding was sought and received from a not-for profit organisation for FECBAG to continue to provide funding for the Project Officer. The group also successfully lobbied the local catchment management authority for funding to be used as incentives for on-ground work.

FECBAG have initiated and convened workshops with key government land managers to improve coordination of works and communication. In the future they plan to expand their program into other valleys in the region, which contain demographics of a mixture of traditional agricultural and lifestyle drivers.

Reflections from the approach

In order to reduce the impact of blackberry, or other widely established weeds, private land managers who live, own land and work directly with the problem have a major role to play in collaboration with the broader community, industry and government who have land management responsibilities. Both the Victorian Blackberry Taskforce and other community groups provide platforms to bring both affected and effective people together to exercise their self-determination, share power within decision making, share their experiences and learn from different perspectives.

There have been a variety of lessons learnt, both from community and the VBT, these include:

Community-led approaches are collective

A community-led approach promotes collective action rather than individual land managers operating in isolation. Typically, a compliance driven approach emphasises individual responsibility, and may set up frequent oppositional attitudes and actions between government agencies and local communities. Initially, within the NEBAG area, land managers with significant infestations were reported as seeing no way forward in regards to their blackberry problem. They received very little encouragement from external parties and neighbours to take affirmative action, being cast as a 'bad land manager' resulting in despondency to the situation (DPI 2008). Through greater inclusion of community members, and also negotiation with key agencies, focus has shifted from land managers with severe infestations being 'their problem' towards blackberry being 'our' problem. It is this form of collective action which is necessary if head way is to be made against blackberry, which fails to delineate at the fence line.

Community-led approaches cater for diversity

Communities are not homogenous, and neither are blackberry infestations. Centrally designed programs and projects often fail to capture the nuances and diversity that exist across communities. Tailoring to individual requirements and regional issues is an important aspect of the community led approach. Farmers come from different demographic backgrounds and they may have:

- High or low levels of cash liquidation;
- Different levels of education;
- Different values towards the landscape and sustainability (prefer organic over chemical control);
- Highly productive operations or more less-economically viable land;
- Agricultural drivers or they maintain a strong environmental/lifestyle focus for their property;
- Received the farm through generational transfer or a recent purchase and are not familiar with appropriate land management practice;
- Varying access to information and knowledge; and
- Strong farming experience or low knowledge of agricultural practice.

To further complicate the socio-economic dynamic, blackberry infestations vary across the landscape, with some properties bordering dense blackberry infestations, inheriting blackberry infestations from previous land owners, having high infestations on extremely steep country or may have undulating landscapes with small pockets of infestation. A community-led approach allows for proper representation of these needs, allowing the groups and project officers to cater for this diversity in working with land managers. For example, the NEBAG has blackberry infestations on steep hill slopes, with access to spraying chemicals being reported back to the group as a barrier for control. The group addressed this issue by using external funding to offer incentives to construct access tracks in a cost sharing approach, with the group remunerating the land manager for half of the cost of a constructing a track by bulldozer. This successful approach has constructed 25 kilometres in previously inaccessible land, allowing land managers to access blackberry infestations with spray units. Also, the flexibility of the project officers to negotiate the issues, not simply as a technical problem, but within a broader socio-economic context of the farm has been essential for achieving on-ground results.

Community-led approaches are trusted

Whether based on perceived or real experiences, there can often be a growing divide between government departments and community. This is by no means a new phenomenon. Botterill and Mazur (2004) cite a variety of studies which indicate declining trust of individuals and communities towards scientific based public institutions. One of the key learnings from the community groups is that because the project is managed by the community there is a greater level of trust, and therefore their commitment to blackberry management is higher. In addition, the project officers are well received by individual landholders because they are not associated with a government department or selling a particular product.

Community-led approaches build capacity

With more directed government funding into widely established weeds, communities require the skills and knowledge to respond for a long-term solution. The community-led approach lends itself towards building capacity of the individuals and community to improve their understanding of roles and responsibilities of invasive pests and the management of widely established weeds. That is, communities have the capacity and understanding about managing pests and ability (Chaskin *et al.* 2001) to help promote or sustain their landscape. It is important to note within this discussion that people cannot be developed; they can only develop themselves with external parties playing a supporting role.

Capacity building from the program can be witnessed at both an individual, organisational and leadership level. Individually, farmer's technical capacity to manage blackberry has increased through developing and improving technical knowledge of blackberry management. Reports from the Project Officer in the NEBAG region indicated some land mangers using inappropriate chemical practices for managing their blackberry, such as dirty water and cocktail mixtures of chemicals, which resulted in despondency due to poor kill rates. In addition to providing best practice advice, the group established chemical trial sites to showcase the various mixtures of chemical groups, and their effectiveness for controlling blackberry, which can differ across species.

Within both regions, the groups have demonstrated their leadership and organisational capacity. That is, individuals and the groups are building their skills, commitment and confidence, as a collective to motivate both their communities and other stakeholders towards achieving goals. Both groups have, and continue to convene meetings and develop action plans. The groups have also address their on-going sustainability through seeking funding to address blackberry issue within their region, with FECBAG attracting a four-fold increase in funding from their initial investment by the VBT.

Community-led approaches need to integrate community and government priorities

Community and government need to work together to achieve results. Green (2008) metaphorically describes this as marching to different rhythms, the steady grind of state machineries contracting with the ebb and flow of civil society activism. The Victorian Blackberry Taskforce acts as a mediating body between various government departments and the community to facilitate partnerships. Through participation of the various government and community representatives at the state-wide level, community interests are able to be presented and government priorities communicated in a mediated environment. However, the relationship between government agencies and farmers can also be contested and problematic.

For community led approaches to be successful power in decision making needs to be shared, that is communities play a key role in identifying the problem and developing the solution. Shared decision making between government and community is one of the key ingredients for success of this program and contributes to the community taking ownership of the issues and having more control of their future. Land managers must be able to identify problems, reflect on solutions as they see them and not as selected by outsiders. They do, however need the ability to accept the assistance and guidance from others. Friere's (1976) work highlights that the control and reflection of knowledge determine our ability to act, that is our control over decision making must also include control over problem posing, and time for reflection. Forcing issues onto community, which they have not identified, or failing to involve communities in project development will, more likely than not, result in on-ground failure, or fail to achieve significant results when community are included. This can often be difficult for government, as engaging community can be perceived as an arduous process, with key outcomes that have already been negotiated. If engagement becomes tokenistic, post decision making, or is perceived as tokenistic, social actors will become disenfranchised (Lockie and Vanclay 2006).

In assessing ways in which inclusive or participatory approaches have contributed to the goal of sustainability, policy makers and natural resource managers have tended to emphasise specific economic and strategic outcomes (Furze *et al.* 2008). Such measures do not necessarily align with community expectations of success, and is often a source of frustration. A land manager, from the Upper Murray region comments on a documentary as saying 'It doesn't matter how many little maps we put out with red dots all over them, that is really secondary. We won't kill any blackberries by covering them with paper reports, we need to spray them and kill em' (Ruralia 2008). Land managers and their communities have longer term priorities that may differ from long term goals of government. There are opportunities, which the groups are pursuing, to address longer term landscape scale change, managing life after blackberry. Continuing to support locally-based networks and structures to develop a strategy for coordinating and improving their landscape is critical. It is important that State government involvement in such programs continues to remain flexible and supportive of community partnerships, maintaining fiscal accountability, without over burdening communities 'terms of reference' with government requirements. If pursued, there is a significant risk of programs resulting in failure through shear frustration, contributing to community burn-out (Furze *et al.* 2008).

Conclusion

To provide long-term changes in the management of blackberry, those who live and work directly with the issue have a major role to play with government and other land managers. The community-led approaches being facilitated by the Victorian Blackberry Taskforce provide an example of the success such approaches can achieve if meaningful engagement occurs. Communities are complex and these approaches allow communities to begin to address this complexity. In addition, it allows the promotion of collective action and contributes to the capacity of communities. The successful integration of government and community priorities remain critical to the on-going success of the program.

Acknowledgments

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Utilising waterbody drawdown to suppress submerged aquatic weeds

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Abstract

Control of submerged aquatic weeds is notoriously difficult and specialist techniques are required to effect control. Drawdown (water level lowering) is one method that is used in Victorian impoundments. This paper will focus on preliminary results of in-lake efficacy assessments of a recent winter drawdown of Lake Mulwala against dense waterweed (*Egeria densa*). Initial findings (five months after refilling) indicate that winter drawdown, without significant frosts, can rapidly decrease density and height of weed beds over very large areas. The duration of control is unknown and may be short-lived. A high proportion of root crowns and stems survive in exposed moist sediment or where protected by overlying mounds of stranded vegetation. Therefore, upon refilling, regeneration can occur from at least three sources; 1) *in situ* propagules exposed on the lakebed, 2) propagules drifting in from unexposed in-lake areas, or 3) propagules drifting in from upstream areas.

Introduction

Lake drawdown or water withdrawal is a recognised technique used to manage invasive submerged macrophytes. The objective of a drawdown is to retard macrophyte growth by destroying reproductive structures through drying or freezing conditions (Cooke 1980).

Dense waterweed (*Egeria densa* Planch. – other common names include; egeria, leafy elodea, oxygen weed) is a submerged, freshwater perennial herb native to South America. It has been introduced, mainly through the aquarium trade, and become weedy in many countries around the world (Global Invasive Species Database 2009). It does not produce seed outside of its natural range and is entirely reliant upon vegetative reproduction. Short stem fragments that contain a 'double node' readily develop into new plants (Cook and Urmi-König 1984).

Evidence suggests that dense waterweed has been abundant in Lake Mulwala since the mid-1990s. Weed problems in the lake in the early 1990s were caused by floating pondweed (*Potamogeton sulcatus* A.Benn.), but since that time dense waterweed has displaced floating pondweed (Shane Papworth, G-MW, personal communication) and is now the dominant species in the lake. Surface reaching beds of dense waterweed create barriers to boat traffic, entanglement risk for swimmers and are visually offensive. The plants also detach and block the inlet screens to the hydropower station at Yarrawonga Weir and form piles of decomposing and at times malodorous weed on the shore. Some degree of control has been achieved in the past through drawdowns and harvesting.

This paper describes a study to determine the effect of a winter 2008 partial drawdown on dense waterweed in Lake Mulwala. The results presented here are from five months after refilling and so do not demonstrate the long–term efficacy of the drawdown. An additional, full drawdown has occurred in winter 2009 that is the subject of a similar study that we will report on in the future.

Methods

A winter drawdown was initiated at Lake Mulwala on 24 April 2008. Dewatering was conducted slowly over a two month period and the water level was held at a low level of ~122 m AHD (Australian Height Datum) for 14 days, 2.9 m lower than operating level.

In-lake submerged vegetation assessments
Early drawdown and post-drawdown vegetation assessments were made using two methods, 'shoreline profiles' and 'basin point-intercepts'.

Shoreline profiles were aligned approximately perpendicular to the shoreline and extended to the maximum extent of the shoreline aquatic plant bed. At each of these profiles submerged vegetation communities were described by underwater observations made by snorkelling. Species present, visual estimate of cover, height of plants, depth of lake bed and distance from shore were all recorded continuously along the length of the profile.

Basin point intercept sampling was carried out according to the methods of Madsen (1999). Thirty-eight point intercept stations were established at 100 or 200 m intervals along three transects across the main, lower basin of the lake. These transects extended from the maximum extent of one shoreline profile and continued to the maximum extent of another on the opposite side of the lake (Figure 1). Plant data was recorded as above.

Results

General observations
A total of 10 submerged aquatic plant species were recorded in Lake Mulwala during this study, eight of which were native (Table 1). A profile sketch of the lake bed, associated vegetation and water depths

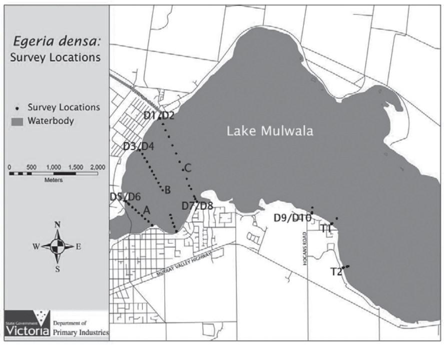

Figure 1. Vegetation sampling locations conducted within Lake Mulwala.

Table 1. Submerged aquatic plant species recorded growing in Lake Mulwala during this study.

Scientific name	Common name	Native/exotic
Egeria densa Planch.	dense waterweed	exotic
Elodea canadensis Michx.	Canadian pondweed	exotic
*Hydrilla verticillata (*L.f.) Royle	hydrilla/water thyme	native
Vallisneria gigantea Graebn. / *Vallisneria americana* Michx.	ribbonweed	native
Potamogeton ochreatus Raoul	blunt pondweed	native
Potamogeton sulcatus A.Benn.	floating pondweed	native
Potamogeton crispus L.	curly pondweed	native
Chara australis R.Br.	charophyte / stonewort	native
Chara muelleri[A]	charophyte / stonewort	native
Nitella pseudoflabellata R.Braun	charophyte / stonewort	native

[A] tentative identification due to poor specimens.

across Transect C (see map, Figure 1) is reproduced at Figure 2. None of the central areas of the lake bed that support dense waterweed were exposed. This was also observed at Transects A and B and is likely to be representative of what occurred over most of the lake.

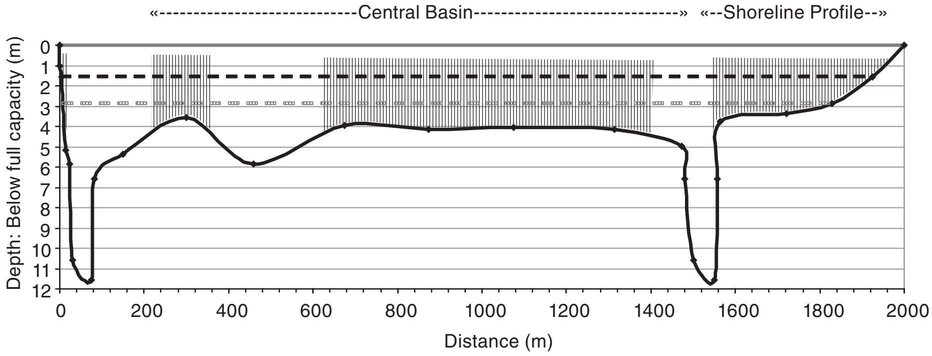

Figure 2. Stylised profile of Transect C that crosses Lake Mulwala from the Mulwala Canal (left side of profile, D1 – 0 to 40 m) to the Yarrawonga Yacht Club (right side of profile, D8 – 1600 to 2000 m). Hatching represents stands of dense waterweed and associated species. Lower dashed line represents maximum drawdown level, 2.86 m below full capacity (122.025 m AHD).

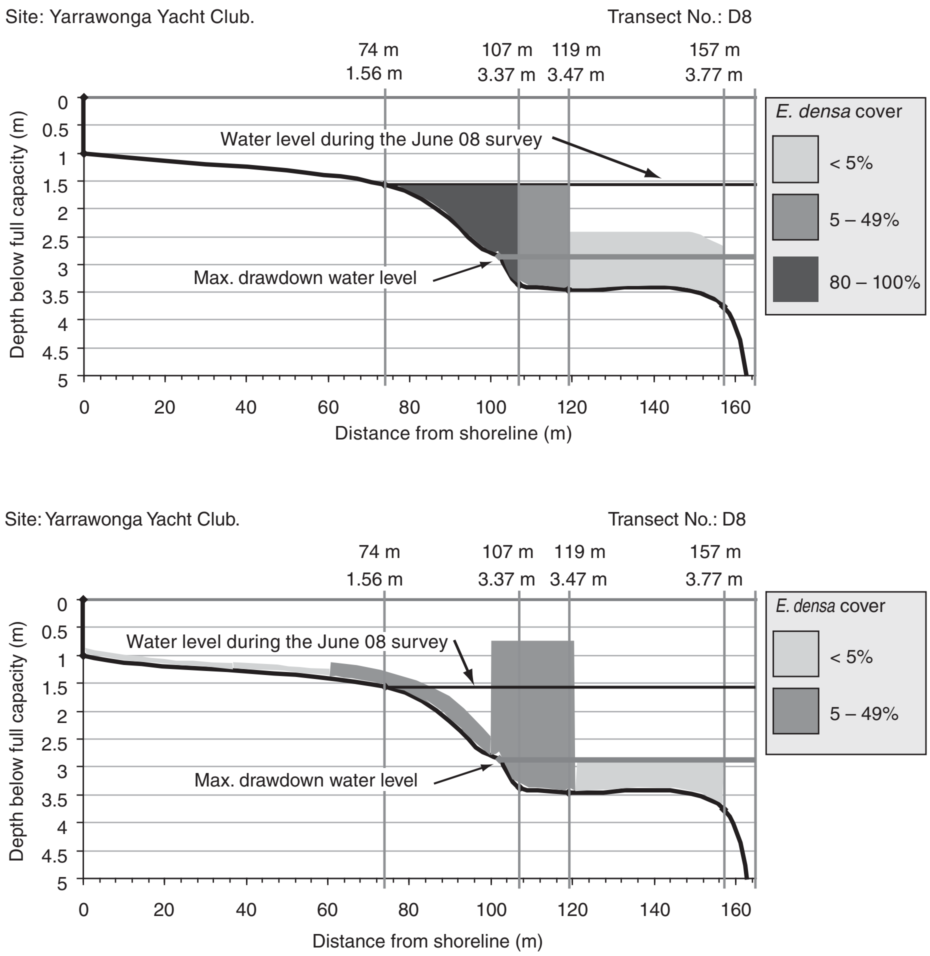

Figure 3. Profiles of the dense waterweed (*E. densa*) present before (top) and after (bottom) drawdown at the Yarrawonga Yacht Club shoreline profile (D8). Other submerged aquatic plants were present at low densities but are not shown for clarity. Water level during the June 08 survey is shown, 1.6 m below full capacity (123.324 m AHD). Red line represents maximum drawdown level, 2.86 m below full capacity (122.025 m AHD).

In-lake submerged vegetation assessments
Approximately 50% of the shoreline weed beds were exposed at maximum drawdown. Profiles of the lake bed and associated vegetation were drawn for each of the shoreline areas before and after drawdown and example profiles for the Yarrawonga Yacht Club are reproduced in Figure 3. Dense waterweed was much less abundant and shorter after drawdown than before in the area of the lake bed that was exposed. In contrast, dense waterweed abundance remained unchanged in the areas that were not exposed. In the after-drawdown survey (December 2008), there was often a clear demarcation observed in the dense waterweed community along a line representing the maximum drawdown depth. Overall, there was a 63% reduction in dense waterweed cover in the drawdown areas (Figure 4). In comparison, there was a 22% reduction in cover beyond the drawdown where the weed was not exposed.

Only one of the basin point intercept stations was exposed during the drawdown so weed control was not achieved at the basin sites. Dense waterweed was present at 50% of the stations. Five additional native species were recorded far less frequently at the stations (blunt pondweed, floating pondweed, curly pondweed, hydrilla and *Chara australis*). All of these co-occurred with dense waterweed, except for *C. australis*, which was found in an area of low dense waterweed abundance. As well as being present at the greatest number of stations, dense waterweed had the greatest cover of the species recorded. Where present, its cover ranged from 50 to 100% cover, by contrast cover for the native species was always low (<5%).

Discussion

The primary aim of water level drawdown for the management of submerged weed biomass is to expose the plant to dry/freezing or dry/hot conditions to destroy the plant's vegetative and reproductive structures. (Cooke 1980). Frosts were not recorded at Lake Mulwala while the dense waterweed was exposed. However, despite the lack of frost and short duration of exposure (14 days), the results presented here indicate that sufficient desiccation occurred to achieve a moderate reduction in dense waterweed abundance where it was exposed.

The real effectiveness of the drawdown cannot be determined after such a short period (five months after refilling), particularly given that the post assessments were conducted in mid-spring and that dense waterweed biomass usually doesn't peak until late autumn. A subsequent assessment of the dense waterweed was carried out in May 2009, ten months after the lake was refilled. Although these data have not yet been fully analysed, observations indicated that the effect of the June 2008 drawdown was still apparent at some sites where there remained clear demarcations in dense waterweed

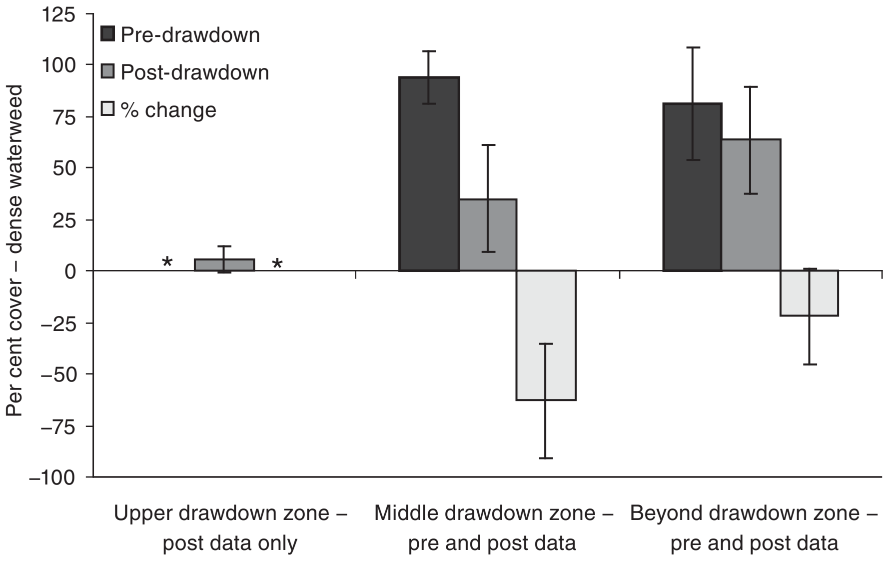

Figure 4. Average per cent cover of dense waterweed at all of the shoreline profile sites before and after drawdown and the resulting change in cover. * = no data collected. Error bars = ± one standard deviation.

abundance or height corresponding to the maximum drawdown level.

It has been suspected that mounds of dense waterweed stranded on the shore as the water level recedes provide a mechanism from which rapid re-establishment of dense waterweed can occur (Clayton 1996, Barrat-Segretain and Cellot 2007). They both report that where thick weed beds are exposed, typically only the surface stems are damaged and these act as a blanket preventing desiccation of material lower in the mounds, resulting in subsequent rapid regrowth. Collections of plant material taken to test this during the drawdown at Lake Mulwala supported these observations (Dugdale *et al.* 2009). It was found that ~20% of stem fragments collected from the bottom of the mounds were viable and that none of the exposed stem fragments collected from the top of the mounds were viable. In addition, 33% to 76% of the crowns collected were viable, depending on time of exposure (position on shoreline) (Dugdale *et al.* 2009). These data provide two separate mechanisms from which re-establishment can occur; from protected stem fragments or from crowns, while re-establishment does not occur from surface exposed stems. An additional mechanism from which re-colonisation will occur is from stem fragments drifting into the drawdown area. This was likely to be much more important after the winter 2008 drawdown because only a small proportion of the weed bed in the lake was exposed.

The native species present in the lake all produce seeds and/or have specialist reproductive and storage structures that can tolerate desiccation. Fluctuating water levels are a somewhat natural occurrence in south-east Australia so these species are evolved to cope with periods of no water (Boulton and Brock 1999). Lake Mulwala contains a diverse native plant community that may have persisted because of the history of drawdowns in the lake, which could reduce the competitive advantage of the dense waterweed over the over the less troublesome native species. The interval between drawdowns required for this to occur is unknown. However, where dense waterweed has invaded shallow lakes similar to Lake Mulwala, it has completely displaced almost all other submerged vegetation from the ~1 m depth down to 6 to 10 m depth (e.g. Tanner *et al*. 1990, Wells and Clayton 1991, Wells *et al*. 1997, Champion 2002, Carrillo *et al*. 2006).

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Alternative control methods for aquatic alligator weed in Victoria

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Abstract

Alligator weed, *Alternanthera philoxeroides* (Mart.) Griseb., is a serious weed that has invaded a wide range of habitats from tropical through to temperate regions in Australia and overseas. In Victoria it is declared a State Prohibited Weed and, as such, is a target for eradication. To date, control using herbicide has been the predominant method used to eradicate the plant; however, when controlling aquatic infestations, herbicide choice is limited to a few products. This trial investigated alternative techniques that might preclude the need for herbicide and reduce chemical input to water bodies. Manual removal was shown to be highly effective in most situations eliminating both above- and below-ground biomass in one treatment. Steam burning provided a rapid knockdown of most alligator weed, but substantial regrowth, particularly from waterborne stems, demonstrated that its use would be limited to reducing the volume of vegetative material prior to undertaking other control works.

Introduction

Alligator weed, *Alternanthera philoxeroides* (Mart.) Griseb., is an amphibious, perennial herb native to South America. It has been present in Australia for more than 60 years (Sainty *et al.* 1998) and known to Victoria for over 10 years (Gunasekera personal communication), and is one of a number of species in Victoria legislated to be eradicated. Chemical control has been the most common method used to treat infestations, but with the aquatic form of the weed, herbicide choice is limited to a few products. With increasing concerns about the environmental impacts of using herbicides, particularly on or near waterways, alternative control methods are worthy of further study. In this trial, four methods were selected and reviewed for their potential to effect control of aquatic alligator weed: fire, geotextile barrier, steam burning and manual removal. From a preliminary review steam burning and manual removal methods were selected for field trial in Victorian waterways. Fire was eliminated as a control technique due to the risks to public health and the potential threat of creating a wild fire. Use of geotextile barriers was also discounted from the field trial as information on this technique to control amphibious weeds is lacking. This is the first year of the trial and the results and discussion are preliminary.

Materials and methods

Trial sites and assessments

Two field trials were established, one to test manual removal at Merri Creek (near Normanby Ave., Thornbury), the other to test steam burning at Patterson River (National Water Sports Centre, Riverend Road, Bangholme). As a benchmark, additional patches in both water bodies were treated with herbicide, or left untreated and used as controls.

At each patch the cover of alligator weed was assessed by measuring its maximum length and width and approximating it to a geometric shape (Figure 1). The total cover of alligator weed, defined as the vertical projection of all plant material onto the ground surface, was estimated by eye. A cover scale was used to ensure estimation within all patches was repeatable. A metric was developed to quantify the area covered by green alligator weed at each patch. This was simply a calculation of the area of the geometric shape of the alligator weed patch multiplied by the percentage cover of the green (foliar) alligator weed within that area. Treatments and assessments were undertaken at various times within the period October 2008 to May 2009.

Steam burning

Nine patches of alligator weed growing along the northern shore of Patterson River were selected and treated in accordance with Table 1. An industrial, large-volume

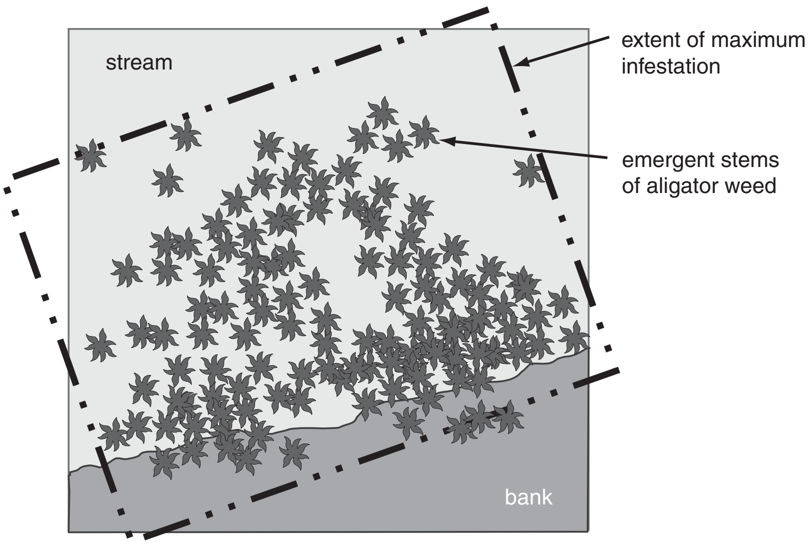

Figure 1. Visual indication of maximum area of infestation along with an approximated geometric shape.

Table 1. Site and treatment details for patches of alligator weed in Patterson River.

Patch	Treatment	Date of first treatment	Patch size (m^2)	Time to carry out treatment once on site (mm:ss)	Total treatment time per m^2
PR 1	herbicide	25 Nov 08	21.7	06:04	17 s
PR 2	herbicide	25 Nov 08	9.0	02:38	18 s
PR 3	herbicide	25 Nov 08	18.8	03:12	10 s
PR 4	herbicide	25 Nov 08	21.4	03:00	8 s
PR 5	steam	4 Feb 09	9.0	17:00	113 s
PR 6	steam	4 Feb 09	11.0	10:00	55 s
PR 7	steam	4 Feb 09	8.0	07:30	55 s
PR 8	steam	4 Feb 09	13.1	13:00	60 s
PR 9	control	–	11.8	–	–

steam generator was used, which produced steam and superheated air under pressure at a claimed output temperature of 120–140°C. Steam was applied to plants via a hand-held nozzle. A netting barrier was constructed around each of the patches to prevent alligator weed fragments from entering or leaving the treatment area. The time taken to treat patch was recorded. Four patches were selected and treated with herbicide to establish a basis for comparison, and a further site left untreated and used as a control.

Manual removal

Eleven patches of alligator weed growing along the banks of Merri Creek were selected and treated in accordance with Table 2. All patches were marked with a star picket at their upstream extent and a netting barrier constructed around each of the herbicide-treated patches to prevent alligator weed fragments from entering or leaving the treatment area. Manual removal was conducted by experienced staff from Thiess Services. A floating barrier with a suspended netting skirt was positioned to encircle the patch against the bank to capture plant fragments released during treatment. The barrier was left in place for several days after which the site was re-examined and any additional plant material found was removed. All above-ground alligator weed was removed first, followed by stems that were traced back to the substrate with the roots being dug up by hand or with mattocks. All alligator weed and detached sods and soil were immediately placed into bags and removed off-site. The time taken to remove the alligator weed from each patch was recorded.

Results and discussion

Steam burning

Four patches at Patterson River in which alligator weed was growing both terrestrially and in open water were treated by steam burning. The first of these (PR5) received what the operator considered a full treatment. After this, the steam generator malfunctioned and patches PR6 to PR8 did not receive proper steam treatment – the unit produced mostly hot water rather than steam. Despite this limitation, in all patches many leaves discoloured and stems wilted, resulting in a rapid knockdown of alligator weed overnight. However, where growth was dense, upright emergent stems collapsed during treatment and provided a protective cover for underlying stems, some of which remained green and turgid. Regrowth was observed from these stems as well as from root material in the soil. In open water areas, all of the prostrate stems and leaves remained green and healthy and produced new growth. From observation during treatment, the prostrate stems floating on water were pushed underwater by the force of the steam jet and thus protected from exposure to high temperatures.

The discoloured, wilted stems did not fragment nor was any regrowth observed. Most of this material, however, was on areas of exposed substrate and not subjected to any form of disturbance. Water movement during a flood event may break up such material into fragments, but the viability of such fragments, if they are produced, is unknown. A study in China demonstrated that dry stems of alligator weed (≤25% moisture content) lacked reproductive capacity, but those that are withered (≥33% moisture content) can sprout new roots and shoots (Liu and Yu 2009). In that study, though, stems had not been exposed to high temperatures by heat treatment.

Despite such a rapid knockdown, the duration of control was very short-lived relative to herbicide treatment. Extensive regrowth was observed 13 days after treatment (DAT) and continued to increase. By 35 DAT the area under foliar cover was, on average, back to 68% of the original size (Figure 2). In contrast, regrowth in herbicide treated areas did not return to half the original size until 84 DAT (Figure 3). At 97 DAT, it was recorded that in some steam treated plots the area under foliar cover was lower than expected due an increase in water level reducing the measurable area for those patches. On average then, the level of recovery is understated and would be expected to more closely follow the growth level observed in the control patch (i.e. patches would have returned their original size).

Steam burning may have achieved better control if multiple treatments had been applied. Regardless, regrowth was so rapid that more than three applications would have been required in a growing season. Re-treatment in the trial was prevented due to external factors. The lack of subsequent treatments did not detract greatly from the experiment as it was designed to test if steam burning was effective in reducing biomass rather than eradicating infestations.

Table 2. Site and treatment details for patches of alligator weed in Merri Creek.

Patch	Treatment	Date of first treatment	Patch size (m^2)	Time to carry out treatment once on site (hh:mm:ss)	Total treatment time per m^2
MC 1	herbicide	5 Feb 09	5.9	00:04:30	46 s
MC 2	control	–	1.2	–	–
MC 3	control	–	6.8	–	–
MC 4	control	–	7.0	–	–
MC 5	manual removal	untreated	0	0	0
MC 6	herbicide	5 Feb 09	5.8	00:02:20	24 s
MC 7	manual removal	4 Mar 09	8.5	36:00:00	4.2 h
MC 8	manual removal	2 Mar 09	4.0	02:00:00	0.5 h
MC 9	manual removal	19 Feb 09	2.9	32:00:00	11 h
MC 10	herbicide	5 Feb 09	0.9	00:00:50	56 s
MC 11	manual removal	12 Feb 09	2.3	16:00:00	7 h

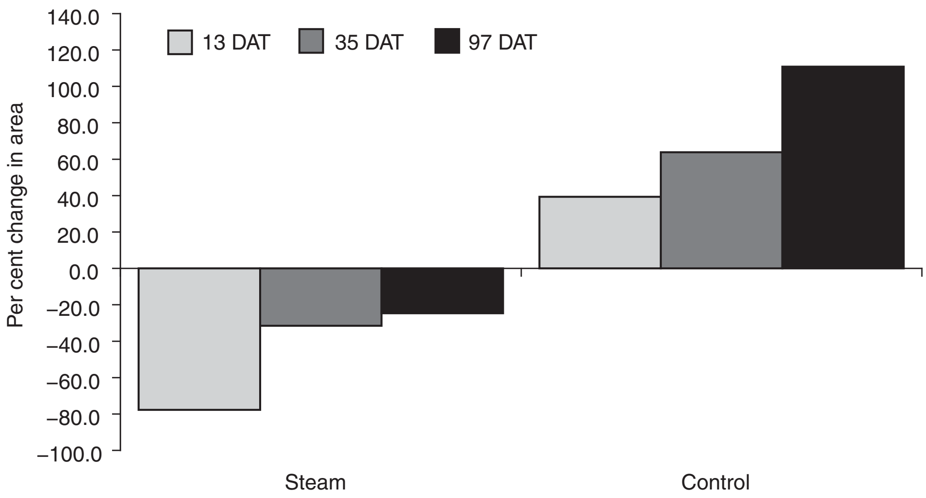

Figure 2. Mean percentage change in foliar area for patches treated using steam burning.

In comparison to herbicide treatment, steam burning has a number of limitations. Within this small trial, steam treatment took more than five times as long as herbicide treatment. Additionally, a large supply of clean water is required (about 600 L), as well as petrol and gas to operate the compressor and boiler respectively. A comparative cost of steam and herbicide treatments was not undertaken, but indicatively, one local government authority in Western Australia that uses steam burning to control weeds on paths and kerbing reports that steam treatment is almost three times more costly than herbicide treatment (Froese 2008).

Manual removal

Manual removal of alligator weed in Merri Creek was undertaken over a three week period (Table 2), starting at the highest point in the catchment (MC 11). Crews of differing sizes were employed in the task, but in all cases, the work was supervised by an experienced weed specialist and undertaken by people experienced in alligator weed manual removal.

A mean reduction in area of 100% was achieved (Figure 4). Patch MC5 is excluded from analysis as the work crew did not get to treat this site.

Control effort using manual removal compared with herbicide treatment is greater by more than two orders of magnitude. At this site, the average time to treat one square metre of alligator weed with herbicide is 30 seconds in contrast to manual removal, which took 345 minutes. While this time difference may seem extraordinarily excessive, it should be kept in mind that to have the same level of efficacy as manual removal, herbicide treatment needs to be repeated three times per year for possibly six years or more (van Oosterhout 2007).

Herbicide treatment of alligator weed proved effective in reducing the amount of foliar alligator weed to similar levels found in manual removal. However, it should be noted that in contrast to manual removal, much of the below-ground biomass remains in place and is likely to regrow. This indicates successive within-season treatments over several years are required to exhaust plant reserves and achieve eradication of the patch of alligator weed.

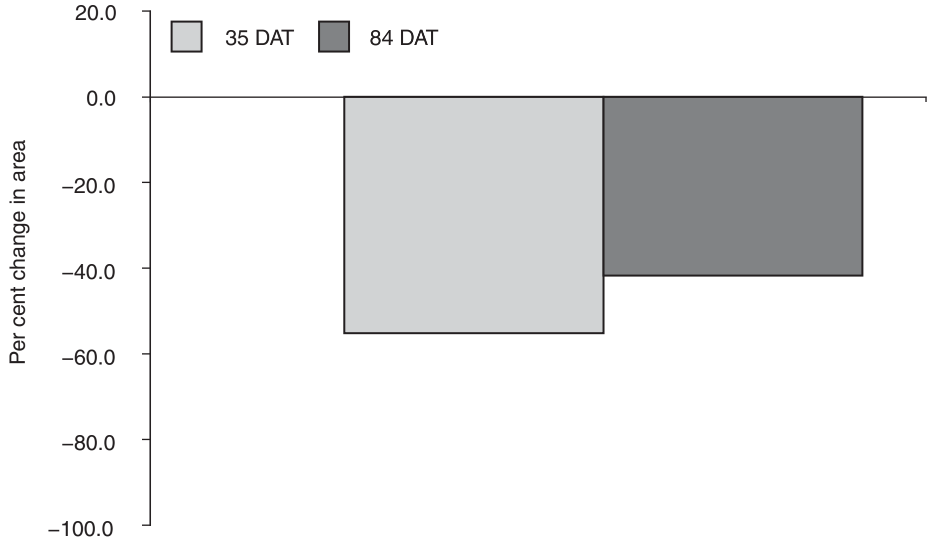

Figure 3. Mean percentage change in foliar area for patches treated with herbicide in Patterson River.

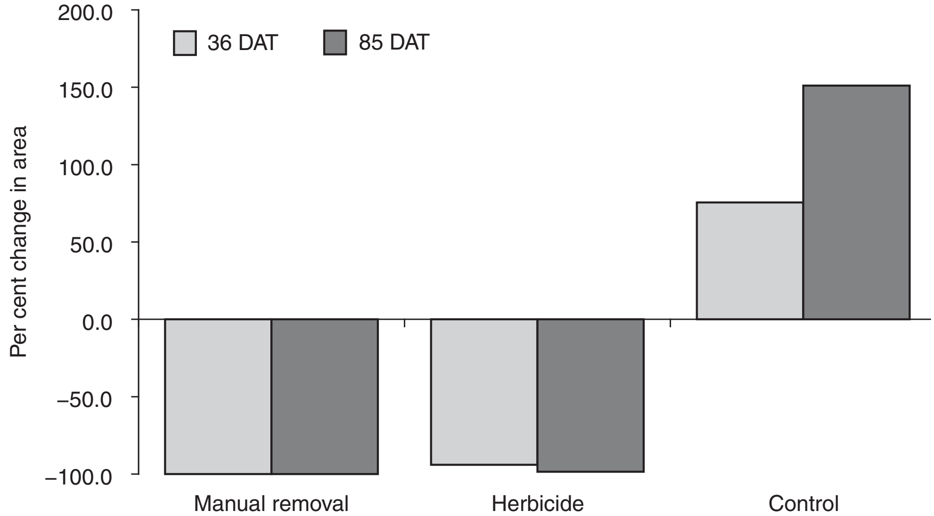

Figure 4. Merri Creek manual removal and herbicide treatment: change in area over time.

Conclusions

We conclude that steam burning provides a rapid though short-term knockdown of alligator weed biomass, which minimises the potential for dispersal. Within this trial no stem fragments were observed, which is a significant advantage over herbicide treatment (see Clements *et al*. this volume). The short-term nature of the treatment though, suggests that a secondary control method, such as manual removal, is needed and should be implemented as soon as possible after initial treatment. As an aid to manual removal, steam burning significantly reduces the volume of material to be removed, which may in turn improve productivity. Steam burning is more labour intensive than herbicide treatment, yet achieves less control. Its greatest advantage is that no herbicide is introduced to the water body and that few, if any stem fragments appear to be produced.

From this initial trial, manual removal appears to be effective in eradicating individual infestations. With appropriate hygiene controls to capture and dispose of released fragments, easy site access and working from the upper-most infested part of the catchment down it may be possible to extirpate alligator weed from the catchment. Although results from this trial are preliminary, they demonstrate manual removal is more effective with one treatment than herbicide, albeit more resource-intensive. Future assessments during the next growing season will verify the degree of success. As with steam treatment, manual removal eliminates the risks associated with adding herbicides to the water body.

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Weed classification using unmanned aircraft and machine learning algorithms

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Abstract

In 2007 the Australian Centre for Field Robotics (ACFR) at the University of Sydney developed a robotic helicopter for unmanned detection and spraying of invasive aquatic weeds (alligator weed and salvinia) funded by Land and Water Australia. In 2008, a second unmanned aircraft was developed for the detection of woody-weeds (parkinsonia, mesquite and prickly acacia) in Northern Queensland funded by Meat and Livestock Australia. This paper reviews the design of these aircraft, their subsequent field trials, and initial work towards classifying and mapping weeds based on computer vision techniques and machine learning algorithms.

Introduction

Unmanned aerial vehicles (UAVs) are robotic aircraft designed to be operated by computers rather than an on-board human pilot. They are equipped with sensors to measure important flight control variables such as position, airspeed and heading. Software algorithms then fuse the platform's sensor measurements, make control decisions to pilot the aircraft, and then drive the aircraft's mechanical control surfaces via electronic actuators.

UAVs have historically been limited to military projects because of high platform costs, safety concerns, and the need for specialised operating personnel. As the technology is maturing, UAV operations are now appearing in civilian applications such as agriculture and ecological research (Cox *et al.* 2004, Dossier 1999, Herwitz 2002, Rango 2006).

Two of the ACFR's UAVs, a fixed wing and a rotary wing UAV, have been used to acquire high resolution imagery over terrestrial and aquatic weeds during field trials in 2008 and 2009. This type of imagery provides a valuable source of information for weed detection that can be used alone, or to complement other sources such as multispectral satellite imagery in the assessment of weed infestations.

Like satellite and manned aerial surveys, UAVs are able to reach locations that are inaccessible by land. They can also be used to collect data over large areas (although the length of an individual flight is limited). Unlike manned aircraft and satellites, UAVs can be operated at particularly low altitudes to obtain a very high spatial resolution. For example, at an altitude of 100 m above ground, the ACFR's J3 Cub UAV can record tri-chromatic colour imagery at a spatial resolution of approximately 4 cm $pixel^{-1}$. On the other hand, GeoEye-1, the world's highest-resolution commercial colour imaging satellite, is limited to 41 cm $pixel^{-1}$ panchromatic imagery, or 1.65 m $pixel^{-1}$ multispectral imagery (Madden 2009). The high spatial resolution of the acquired imagery means that fine detail such as foliage texture can be resolved, providing visual information that would be otherwise unavailable. Because flight control is automated, UAVs can repeatedly and consistently fly adjacent paths that would be difficult and repetitive for a human pilot. This autonomy was particularly beneficial in recent Julia Creek flight trials, where the FUAV covered larger areas than would be feasible with remote control piloting, spending much of its flight time beyond visual range of the operators. Although the current aviation safety rules in Australia require qualified UAV operators to attend any deployments, we envision that in the future UAVs will be operated in the field without specialised personnel, providing a reliable and flexible source of information.

The imagery acquired has also enabled research work towards robust autonomous classification algorithms, and probabilistic mapping of weeds. This strategy of autonomous data collection and data interpretation is expected to be a valuable resource in the assessment and management of weed infestations.

Robotic aerial platforms

The aerospace research group at the ACFR has been working on industry UAV projects for over a decade. While much of this experience has transferred to the new weed focused UAVs, the airframes, navigation systems, control systems, payload sensors, ground stations and communications systems were all selected specifically for the challenges of weed surveillance.

For the 2007/08 LWA project, a robotic helicopter (RUAV) was built using a modified design of UAV Vision's G-18 model. Being rotary wing, the platform can stop and hover, enabling it to operate close to the ground and spray weeds on the water. The system has a maximum take-off weight of 15 kg, of which approximately 5 kg is payload including a camera system and an off the shelf spray system. The RUAV is depicted in Figure 1a during a flight demonstration in Pitt Town, NSW, in August 2008 where it was used to record imagery of salvinia, communicate with a ground station, and conduct targeted aerial spraying of the aquatic weeds.

For the 2008-present MLA project, a fixed wing (FUAV) platform was configured using the airframe of a 1/3 scale model J3 Cub. The fixed wing form is well suited to collecting aerial imagery over large areas as the aircraft can efficiently cover long tracks. The system has a take-off weight of 27 kg, including approximately 3 kg of fuel and 6 kg of payload. It is shown in Figure 1b taking off for image acquisition during trials at Julia Creek, Queensland, in July 2009, during which it successfully collected over seven hours of geo-referenced imagery while communicating with a ground station via radio link. These tests involved seven flight plans, five at 100 m altitude to achieve 4 cm $pixel^{-1}$ resolution, and two at 500 m to achieve 20 cm $pixel^{-1}$ resolution over a larger area. Each flight was at 25m s^{-1} (90 km h^{-1}) for approximately 70 minutes.

The aircraft are fitted with computer flight controllers for following straight line

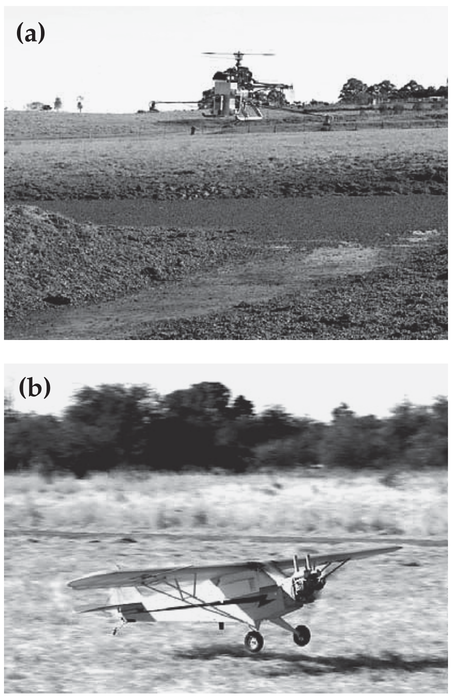

Figure 1. (a) The RUAV above sprayed salvinia at the Killarney Chain of Ponds and (b) the FUAV taking off during the 2009 Julia Creek image acquisition.

paths to geo-referenced waypoints (based on inertial/GPS navigation), as well as communications systems that allow the aircraft to transmit and receive information from a ground station. To improve the robustness and safety of field operations, both UAVs have been configured for multiple modes of operation including manual control, semi-autonomous, and autonomous flight modes so that, in the event of a safety concern, trained operators can take control and intervene.

For the vision payloads, a number of cameras (colour and multispectral units) were considered in terms of image quality, spatial resolution, spectral resolution, frame rate and compatibility with the aerial platform capabilities. Initial investigation indicated that classification could be achieved with three colour channels given sufficient resolution, so both the RUAV and FUAV were equipped with Hitachi HV-F31 3CCD cameras with a maximum video resolution of 1024 × 768 pixels in RGB colour. This 3CCD model was selected to avoid artefacts associated with a Bayer filter, and the images were logged in a lossless file format at 3.75 frames per second by an on-board computer during the flights. In addition to camera hardware, navigation measurements including GPS and inertial sensor readings were also logged so that the images could be geo-referenced from the position and attitude of the platform.

Machine learning for classification

Because a large quantity of image data is potentially collected in every flight (about 13 500 images per hour), it is highly desirable to employ a computationally efficient algorithmic model to classify weeds present in the imagery and produce a map of their distribution. Towards this goal, we have approached the processing in three main steps: images are rectified using navigation data to form a mosaic, visual information is used to classify weeds based on their appearance, and then the classifications are used to build weed probability maps.

To classify weeds autonomously, a set of p visual features are first extracted at locations over the image. The features may be extracted at a lower resolution than the raw colour data, but must capture the local appearance of the image by quantitatively describing patterns in luminance, chrominance, and texture at different scales. An example of extracting $p = 6$ feature dimensions from a colour image (at 1/8th the resolution of the captured image) is depicted in Figure 2. Ideally, visual features should remain similar for different occurrences of the same class.

The extracted features contain some important visual information from the image, but a classification algorithm is required to learn a mapping between these features and the likelihood of membership of a class. For this role, we have explored a number of supervised machine learning algorithms including Support Vector Machines [Suykens99], Adaptive Logistic Boosting with decision stubs [Friedman00], and Gaussian Process Classification [Rasmussen06]. These algorithms learn from a set of training examples consisting of a both a feature set and its corresponding true classification (which must be manually segmented prior to training). Figure. 2 depicts a typical training example.

We have built feature sets and manually segmented training examples for a number of datasets including imagery of alligator weed and salvinia infestations, and land containing a mixture of woody weeds, Mitchell grass and native eucalyptus trees. A number of learning algorithms have been tested on these datasets (with example results presented in Figures 3–5).

Logitboost (Friedman 2000) is a multi-class, probabilistic form of boosting, where many versions of a weak algorithm are trained, and their unreliable classifications combined such as to produce a much more reliable classification. In this case, the weak algorithms used were decision stumps (that produce one of two outputs depending on whether a threshold value is met in one of the features). With the latest set of p = 12 features, this implementation has been able to satisfactorily segment eucalyptus and prickly acacia from background detail. Further work is needed to discriminate between woody weeds of similar visual structure (such as mesquite and prickly acacia).

Conclusion and future work

Two UAV platforms have been developed at the ACFR for detecting terrestrial and aquatic weeds in inaccessible regions. A robotic helicopter was demonstrated in 2008 where it acquired imagery of salvinia and conducted targeted aerial spraying. A robotic fixed wing aircraft has recently been deployed to collect imagery at Julia Creek, Queensland, for the purpose of monitoring woody weeds over large areas of relatively inaccessible terrain. These scenarios have both demonstrated the potential of UAVs as a cost-effective strategic tool for the detection and management of weeds in the future, and have also provided datasets for further exploratory research work into machine learning for classification and mapping.

Initial results have been obtained for the training of robust and effective classifiers based on image feature extraction and

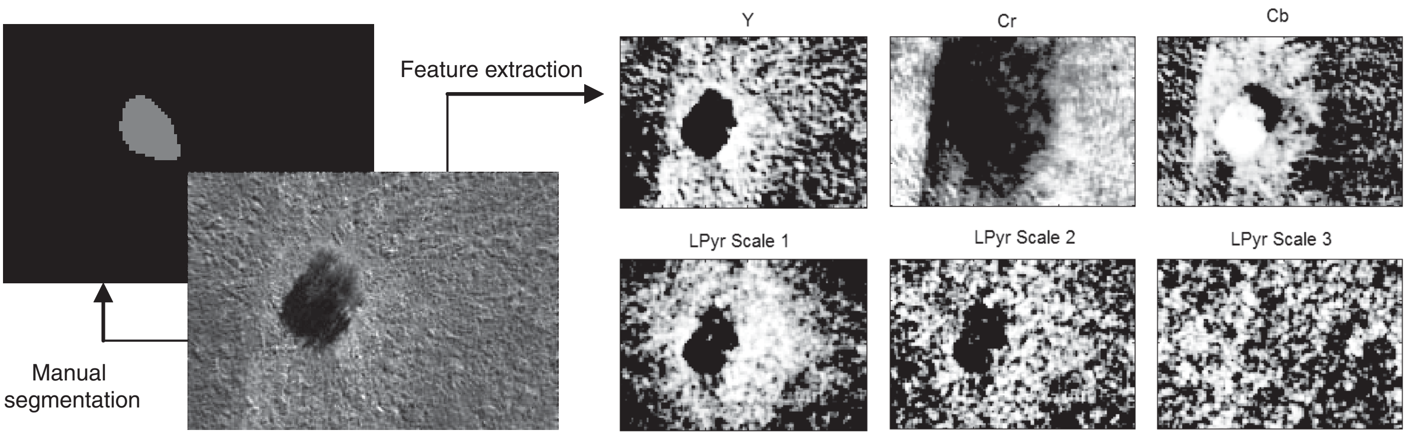

Figure 2. Feature extraction and manual segmentation are required to build a training example for a supervised learning algorithm. Left-centre – geo-rectified colour image of a prickly acacia bush surrounded by Mitchell grass. Left – manual segmentation provided by human input. Right – feature representations. The top row is response in luminance and chrominance (red and blue). The bottom row is a multi-scale texture decomposition based on Laplacian pyramids to measure image intensity gradients at different scales.

machine learning algorithms. These learning algorithms provide an elegant solution to the classification problem as they learn directly from examples without requiring prior modelling or heuristics. Example results were presented for the segmentation of the weeds salvinia, alligator weed and prickly acacia from their environments based on appearance in high resolution colour images.

Beyond this research, we are extending the machine learning to build a probabilistic classification model that accounts for relationships between different types of data, incorporates spatial relationships such as clustering, is more resilient to uncertain classifications and is able to propagate stochastically over gaps in spatial coverage.

Figure 3. Classification of alligator weed based on maximum separation margin. The output provides a probability that the image depicts alligator weed. Here the support vector machine algorithm has been trained to determine a hyper-plane which divides the weed/non weed classes with maximum separation (Euclidean in the feature dimensions). Once the algorithm is trained, this hyper-plane becomes the detection model, and any new data that is obtained can be quickly classified by its direction and distance to the plane.

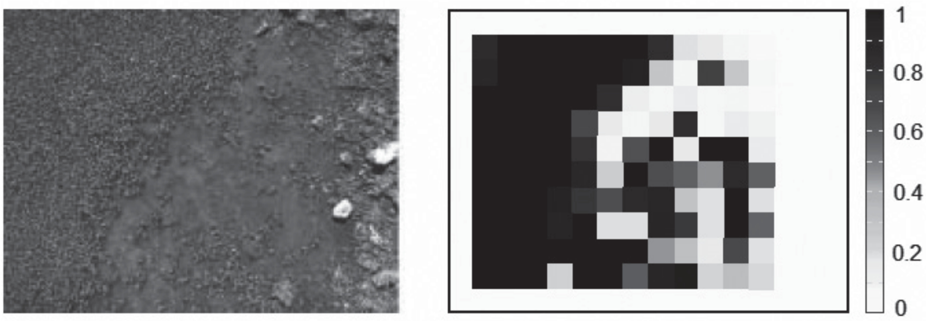

Figure 4. Classification of salvinia (sprayed) using a Support Vector Machine approach similar to Figure 2. The classification represents the class probability of salvinia (against non-salvinia).

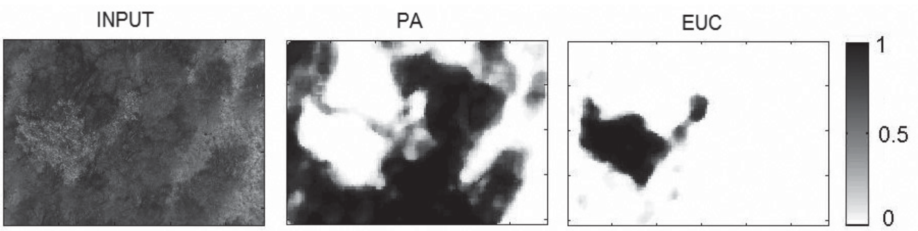

Figure 5. A multi-class classification of prickly acacia, and eucalyptus, against non-trees (grouping shadows, mud and grass) using the Logitboost algorithm with decision stumps. The PA plot shows the likelihood that a pixel belongs to the prickly acacia class, EUC us the likelihood that the pixel belongs to a native eucalyptus, while any mud, shadows or Mitchell grass should appear as low values in both.

Acknowledgments

We would like to thank both Land and Water Australia and Meat and Livestock Australia for funding our UAV projects and recognising their potential. We would also like to thank Andrew Petroeschevsky from NSW DPI, Luke Joseph from Farm and Dam Control, and Sunwater for their valuable contribution. We also acknowledge the ACFR aerospace group technical staff for their hard work on the UAV systems. Finally, we thank the Australian Research Council for their support.

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Impact of herbicide on alligator weed fragmentation and fragment viability in aquatic situations

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Abstract

Alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb.) is subject to an eradication program in Victoria, Australia. In aquatic situations the herbicides glyphosate (glyphosate isopropylamine salt) or metsulfuron-methyl are used. Anecdotal observations suggest that herbicide application results in the production of many alligator weed stem fragments and that some of these are viable and capable of colonisation. We applied herbicide to alligator weed growing in containers (glyphosate, metsulfuron-methyl and dichlobenil) and in the field (glyphosate and metsulfuron-methyl only) and collected the resulting stem fragments. A high proportion of the field-collected fragments were capable of regeneration (70%), regardless of the herbicide used. A much lower proportion of stem fragments collected from the container trial were viable and varied between herbicides (40% for metsulfuron-methyl, 2% for glyphosate and 1% for dichlobenil). We also found that glyphosate produced more than twice the number of stem fragments (382 m^{-2}) compared to other herbicides, in contained situations. We speculate that the stem fragments remain viable because of incomplete herbicide coverage and propose that improved application techniques may eliminate this problem.

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Oxalis compressa: should we be more aware of this weed in Victoria?

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Abstract
The distribution of *Oxalis compressa* in north-west Melbourne is much greater than was previously realised and it may commonly be mistaken for *O. pes-caprae*. It is too late for eradication. It tends to occur where there is an absence of intense competition, such as sites that are heavily mown or have considerable bare soil. Like the closely related *O. pes-caprae*, it appears to be sterile and only produces vegetatively in Victoria. However, the presence of all three style morphs means that the possibility of sexual reproduction cannot be ruled out at this stage. We conclude that in the absence of seed production, an overlap in habitat with *O. pes-caprae* and poor competitive ability, management of the two species as if they are one would have few negative repercussions.

Introduction

Oxalis compressa L.f. has been present in Australia for many years, including a single site in Western Australia (J. Dodd personal communication) and several locations in South Australia (Australia's Virtual Herbarium 2006). We found it growing in great abundance at Broadmeadows in 2007. In Victoria, *O. compressa* had been known only from a single site (a research station in Heidelberg). Most weed researchers and practitioners, even in these regions, appear unaware of its existence. From a casual inspection, its flowers can be easily confused with its close relative *Oxalis pes-caprae* L. (soursob), abundant throughout southern Australia. Its leaves are very distinctive, being broader, hairy and with very flattened, hairy petioles, compared with the shiny, hairless leaves and cylindrical petioles of *O. pes-caprae*. Like *O. pes-caprae*, *O. compressa* was probably imported as garden ornamental.

Given its similarity to the more widespread *O. pes-caprae*, how much of a threat does *O. compressa* pose? Should steps be taken to eradicate it from Victoria? How widespread is it currently? Does it have similar habitat requirements? How similar is its life history? We conducted a preliminary investigation into some of these questions. In addition, we made measurements to characterise differences in floral structures between the two species.

Methods

Distribution

We used a GPS to record locations of plants at Broadmeadows Valley Park. Transects were walked at 90° to the valley, with transects about 75 m apart. Waypoints were recorded whenever a patch or a plant of *O. compressa* was crossed. Using maps of Melbourne, we identified potential locations up and down this catchment and visited them to record presence/absence. We also drove around the northern suburbs, examining patches of *Oxalis* close to the roadside. Casual observations were made on the types of habitat in which it was present and the relative distributions of the two species within sites.

Life history

In Australia, *O. pes-caprae* reproduces only asexually by the production of bulbils. We excavated plants to examine whether bulbils were present. We also searched populations for evidence that seed capsules were swelling, as an indication that viable seeds may be forming. We took flowering plants from the field and grew them in a glasshouse to see whether they set seeds. Finally, we searched the literature to see whether there was any record of the life history or ecology of the species.

Floral structures

Measurements were made of petiole length and width, scape height, flower number per scape, and number of scapes per rosette; sample size was 20 ramets, chosen at random and widely-spaced. Each flower was removed and petal length, sepal length, and the lengths of both rows of filaments were recorded. Comparisons between species were made using t-tests. In its native South Africa (Rottenburg and Parker 2004), *O. pes-caprae* is tristylous (exhibits three different flower morphs, differing in length of the style). Throughout Australia and in many other invaded regions only the pentaploid, short-style

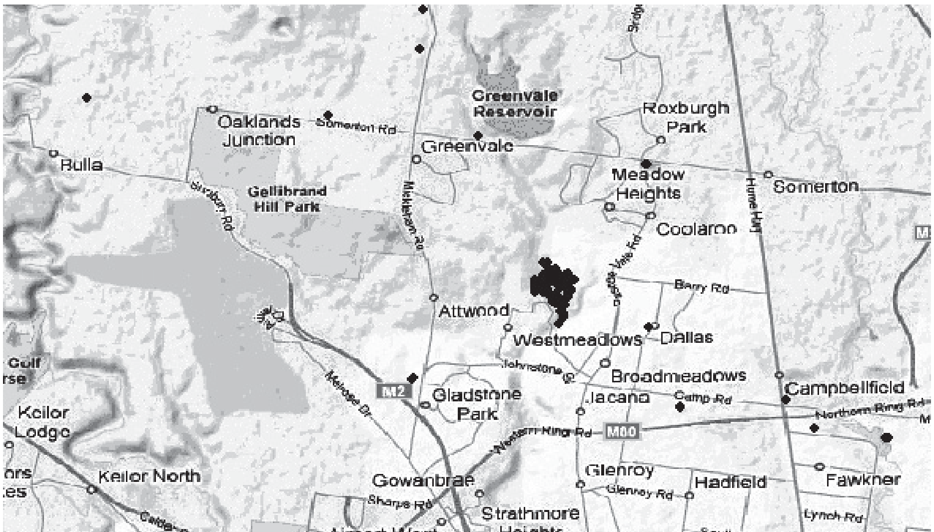

Figure 1. Distribution of *Oxalis compressa* in north-west Melbourne (shown by black symbols). The dense cluster of points is the detailed survey in Broadmeadows; other areas were less intensively searched. Source of base map: Google Earth 2006.

morph has been recorded (though in the western Mediterranean other morphs may be present: Castro *et al.* 2007). Initial observation in Broadmeadows found only the short-styled flower morph, though other morphs were present in herbarium specimens from South Australia (V. Stajsic personal communication). A photograph from Western Australia was also of the short-style morph. We therefore examined four populations, counting the number of each morph within samples of 20 random inflorescences at each. This would also give an indication of whether successful pollination could occur.

Results

At Broadmeadows, *O. compressa* tended to occur in short grass (such as sports fields) and other situations in which competition from other plants was low. Often this coincided with shallow soils, such as along roadsides. Where it co-occurred with *O. pes-caprae* it was of shorter stature and was over-topped by the other species. *O. compressa* was widely distributed throughout north-west Melbourne (Figure 1), but with greatest abundance around Greenvale and along the Moonee Ponds and Merri Creek systems (and their tributaries). There was a sharp northern edge to its distribution, coinciding with the edge of housing developments and recreation facilities. Although it was found along road verges in more built-up areas, it was most often seen in parks.

There was no difference in petal lengths between *O. compressa* and *O. pes-caprae*; *O. compressa* sepals were slightly longer (4.9 mm vs. 4.4 mm), while filaments were slightly shorter (long filaments 7.0 vs. 7.8 mm; short filaments 3.2 mm vs. 4.4 mm). Scape heights were considerably shorter, on average, in *O. compressa* (76 mm vs. 156 mm) and there were fewer flowers per inflorescence (mean 2.7 vs. 5.1; range 1–5 vs. 1–16); the number of inflorescences per rosette was similar (5.9 vs. 6.0). Petiole lengths of *O. compressa* were half those of *O. pes-caprae* and widths were double (2.8 mm vs. 1.3 mm).

Though mid-styled plants were the most abundant (48.3%), 38.3% were short-styled and 13.3% were long-styled. The proportions appeared to differ among populations, but this was not determined formally.

Conclusions

Oxalis compressa appeared to be restricted to less competitive conditions than *O. pes-caprae*, though they are often found at the same sites. It was frequently found in mown areas, especially recreation fields, and in the bottoms of valleys (where sports fields are often sited). This may indicate that council or contractor machinery may be spreading *O. compressa*; earth-moving machinery used in bulldozing sites may also have been important. Other possibilities for dispersal are water, mud on footwear (sports and walkers). Occurrences along roadsides may again suggest a link with machinery, or this may be just the availability of uncompetitive habitat. If there was a desire to stop the species from spreading, then a focus should be on vehicle hygiene and restricting movement of soil.

No evidence was found of *O. compressa* setting seed, but we did not monitor sites throughout the flowering season. The presence of all style morphs indicates that, at least morphologically, cross-pollination could occur, though there may still be other barriers to the production of seeds (e.g. sterility due to chromosome number). More extensive observations and perhaps hand-pollination are needed before the lack of seed production can be concluded with certainty.

There seems to be little to suggest that *O. compressa* will become a worse weed than *O. pes-caprae*. Perhaps, then, the difference between the species is more of taxonomic than practical interest and the two could be managed as one. It is likely that the same herbicides would be effective, with similar timings. It is already too late for eradication of the species.

Acknowledgments

We thank Graham Brodie for his assistance in GIS mapping and Roger Cook and Juliana Riotto (Hume City Council) for local knowledge.

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New Zealand starweed (*Plantago triandra* subsp. *masoniae*) in Victoria: ecology, impacts and recommendations

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Abstract

New Zealand starweed (*Plantago triandra* subsp. *masoniae*) was first recorded in Australia in 2001 in a bowling green, which it subsequently dominated. It has since been recorded at a small number of sites, where it has mostly been eradicated. Although found early, the decision was taken by the State government not to eradicate it. The bowling club failed in its attempts to control it and now faces high costs for green renovation. The Royal Victorian Bowls Association (RVBA) has also taken no action, despite the threat it poses to valuable greens in this and other States. Other turfgrass industries could also be impacted. Should someone be taking responsibility for its containment or eradication?

Ecology

New Zealand starweed (*Plantago triandra* subsp. *masoniae*) is a small, herbaceous species native to New Zealand. It was first recorded in Australia from a bowling green in Melbourne in 2001. Since then it has been found at just a handful of turfgrass sites around the city. There is little documented information on its ecology. It forms flat rosettes of about 3 cm in diameter and produces single capsules on the end of short scapes that bend over to release around 20–30 seeds at the edge of the rosette. The seed heads are produced in early autumn and seeds are released during the cooler months of the year. The small seeds, less than 1 mm in diameter, are sticky and can be easily attached to shoes, clothing, bowls and turf management equipment. It was probably spread to Australia by bowlers, since Australian players often take their bowls on holiday, some play in tournaments internationally, while New Zealand bowlers also come here.

Plantago triandra subsp. *masoniae* is a successful invader on bowling greens because of its ability to withstand intensive management techniques and still reproduce. Constant watering prevents it from drying out and exposure to high light conditions maximises its growth rate, suppressing preferred turf species. Starweed will initially be restricted to small patches on a green, but it will spread rapidly through human traffic, through rollers and in lawn clippings. It may also spread to other greens in this way, through home-and-away matches and greenkeeping contractors. After coring, waste material is taken to the tip or spread on gardens, potentially spreading the weed to non-turf sites. A report by the New Zealand Sports Turf Institute gave the quantity of sieved seed from starweed greens in New Zealand as between 5–20 kg (Ormsby 2005, p. 30). It can re-grow from small fragments after hand-removal (MacCartney 2002).

Impacts

Weeds affect the aesthetic appeal of a green, with most greenkeepers being proud of the appearance of their product. More importantly, they affect the direction and speed of bowls. While speed naturally varies through the season, patches of weeds will alter the course of a bowl, making accurate play more difficult. However, once a green is dominated by Starweed, the playing behaviour becomes less erratic and players report enjoying it as a surface. Herbicide costs during early invasion of a green would be minor and plants could be removed by hand. Even so, the original bowling club was unable to eradicate it. Once it is out of control, upwards of $100 000 would be needed to completely re-lay the green to remove the seed bank (and re-invasion may still occur), while a cost of up to $200 000 would be required to replace the live green with a synthetic one. Over time, however, the running expenses for a synthetic green will be much less. Although clubs are steadily converting to synthetic greens to reduce maintenance costs and to ensure year-round bowling, many bowlers prefer to play on grass with its different playing characteristics.

The overall impact on bowling greens if Starweed were to spread is difficult to quantify because of the huge variation in the factors needing to be considered: size of club, size of green, labour (volunteer or professional), chemicals and the benefits contributed to health (both mental and physical), safety and the environment (Aldous 1999). However, such an analysis could be done.

Management

Continuous awareness is needed for early stages of invasion of a green. Hand-removal is often ineffective as it can re-grow from small pieces (MacCartney 2002). Selective broadleaf herbicides containing MCPA, bromoxynil, propyzamide and oxadiazon may be effective in controlling starweed. To stop movement between greens, hygiene of equipment is especially important and machinery should not be transported between sites. Lawn clippings should be disposed of responsibly. Club members, associates and general players have the potential to spread the seed if they do not clean playing equipment during pennant and after general play. Shoe-washing baths were proposed at the original site in Melbourne, for home and visiting players, but this was not implemented.

Responsibility

When its identification was first confirmed by the National Herbarium of Victoria, a report was made to the State government (J. Reid personal communication). It would appear, however, that a decision was taken not to eradicate the incursion, on the grounds that it would not have a significant benefit to industry or to the natural environment. Whether or not a formal benefit-cost analysis was ever made is unclear. However, bowling is a major competitive and recreational sport. In Australia, there are about 2000 bowling clubs with approximately 3200 greens (Aldous 1999). Other flat turf sports are a part of a multi-billion dollar turf industry. Early intervention at the source club would therefore have had a considerable public good.

At the present time no one seems to be taking responsibility for the weed. It should not be the responsibility of the most-infected club to spend their scarce resources to protect others from starweed. State government has decided that it is not worth eradication even though it would still be feasible; the RVBA has not made it a priority and has not conducted any awareness campaign amongst its member clubs of bowlers (the chair of its greens committee had not heard of it (J. Drummond personal communication 2008), though the previous chair had); the wider turfgrass industry has no program in place to prevent its spread. Individual greenkeepers are aware and information spreads by word-of-mouth. Action to stop new incursions would need to be preventative, with bowling bodies advising their members to observe good hygiene when returning from New Zealand and observing their home greens for new plants. The small sizes of seeds would make inspection at ports of entry by AQIS difficult.

Recommendations

This weed appears to be under-appreciated by all organisations except a single club. This is likely to continue until the species spreads more rapidly (if it does), by which time eradication will not be possible. Thus, the case of this diminutive plant mirrors the history of weed management! When we had the chance, we should have eradicated the outbreak with only modest costs. The RVBA needs to reassess the threat posed by the weed, as does the wider turfgrass industry. This could be prompted by an application by the affected club to the RVBA for a grant to cover the costs of green renovation/replacement; the RVBA might also help to find the funding for this from external sources. The decision by the State government, which does not appear to be transparent, should be reviewed through a formal cost-benefit analysis; this could also be the basis for decisions by the other organisations. If one of these bodies identifies it as a threat, eradication (green replacement) at the affected club should be funded by them. Even if no expensive action is taken at the club, awareness through participants of the sport, encouraging them to demonstrate some responsibility for monitoring and minimising outbreaks through hygiene, will reduce the rate of spread of the species.

Acknowledgments

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Technology tackling weeds in South Gippsland – www.southgippslandweeds.com.au

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With increasing number of people relying on the internet for information, the establishment of a regionally specific website that is both informative and interactive , was the next step forward for the South Gippsland Landcare Network (SGLN) – Community Pest Plant and Animal Program.

South Gippsland Water have been sponsoring projects for the South Gippsland Landcare Network for a number of years and the 2007/2008 sponsorship included the development of the South Gippsland weeds website. The website was designed locally by a web design company called Loud Mountain.

The focus of the website is to provide the user with an easy to use, up to date and visual method of identifying weeds in our local area and how to control them. With a range of people purchasing land in South Gippsland, many with little knowledge of our local weeds species and the damage they can cause, identification in the first incidence is vital.

Since the site was launched in November 2008, it has received 2193 unique visits with an average of about 300 per month. The feedback received from landholders, State and Local Government agencies within and outside our region has been extremely positive.

A member of the public was heard to say 'that's cool' as the features of the website were launched. Who would have ever thought weeds would be cool!!!

The weed gallery section of the website has a series of high quality photos in different growth stages and identifying parts of the plant. Currently 52 weed species are featured on the website, each with multiple photos at various growth stages and links to control methods and details on the type of weed eg: environmental, noxious, regionally controlled. These photos are updated regularly as new specimens are located. The majority of the photos have been taken by Martin Chatfield (SGLN Pest Plant and Animal Officer) locally so they represent how the weeds look locally. Examples of these photographs will be displayed as part of the poster.

Bi monthly weed talk articles which feature in the Foster Mirror (a local newspaper) are also on the site for people who may have missed the paper or need to check the details of the weed they had seen in the past.

'Weed of the month' highlights a different weed each month and one that is of particular interest for that month eg, time to spray, easily identifiable or a new weed recently seen in the area.

The website has been designed to be interactive with visitors to the site being able to ask questions of the Pest Plant and Animal Officer (PPAO), request a site visit, or even upload a photo of the weed they need identified and the PPAO will get back to them. Since the launch approximately 20 photos have been sent in for identification and assistance with control.

The benefit of the website for our absentee landholders is they can visit the site while at home, collect all the information they need and be ready to tackle the problem next time they visit their property.

The Control section provides users with methods on how to control and what chemicals are available. Chemical labels for the most commonly used chemicals are also on the site, thus eliminating that annoying problem for landholders of remembering what rate to use and where they put the chemical sheet when they peeled it off the drum. Now they can print it off whenever they need to. The chemical labels also have the safety information, something that is vitally important when dealing with any chemicals.

The site also details the type of weed as defined under legislation eg: regionally controlled and the level of responsibility of the landholder for control.

With a range of SGLN's range of weed information sheets available to download and print, suggestions for alternatives to environmental weeds in 'plant me instead', a range of frequently asked questions (FAQ) and links to other weed and pest information, the South Gippsland Weeds website has it all. The site is regularly updated and maintained by SGLN staff courtesy of sponsorship of South Gippsland Water.

'A website has been set up by Martin Chatfield. This is a really useful site. It tells you all you ever wanted to know about weeds, including specific control methods and excellent identification photos. You can find out when is the best time to control. If you have not seen it log on now to www.southgippslandweeds.com.au and surprise yourself!' taken from Community Weeds Taskforce report by Mike Carnell tabled at the SGLN AGM on 10th August.

Effect of low rates of flupropanate for control of Chilean needle grass seedlings

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Abstract

Low rates of flupropanate have been shown to control serrated tussock seedlings while doing little damage to desirable pasture species (Campbell 1997). The aim of this project was to investigate whether similar results can be obtained using low rates of flupropanate to control Chilean needle grass (CNG) seedling while doing minimal damage to beneficial pasture species. The recommended rate of flupropanate to control mature CNG is 1.5–3 L ha^{-1} (Taskforce 2006). The trial was conducted on a public river reserve (Casey's Weir Midland Hwy) with dense CNG infestation on a clay loam soil. Plots 4 m × 3 m were laid out as a randomised complete block design with four replications. In an attempt to remove mature CNG and promote CNG seedling germination, all plots received a blanket application of glyphosate and specific treatments of trash removal or trash conservation during May 2007 (Figure 1). Low rate treatments (0.25 L ha^{-1} and 0.75 L ha^{-1}) of flupropanate were applied during July 2007 and were compared to untreated controls (Table 1).

Pasture composition was assessed using a 1 m × 1 m basal point comb that has 10 1 m rods each marked at 10 cm intervals. Plant species touching or intercepting these 100 point locations on the comb were recorded. Chilean needle grass seedling counts were taken using a 32 cm × 32 cm quadrat. Plot assessments and visual assessments were completed prior to any treatments (2/5/07) and after treatments (4–5/6/07, 7/9/07, 16/10/07, 7/1/08, 7/11/08). Pasture composition data was angularly transformed and seedling data was logarithmically transformed prior to statistical analysis.

The low rates of flupropanate did not affect the cover of CNG, with or without trash cover. Plots sprayed with flupropanate had significantly more perennial desirable grasses and significantly less annual grass species than unsprayed plots. Where flupropanate was applied, the rate of application, or trash removal did not have an affect on the pasture composition (Table 2). The application of flupropanate at the given low rates did not affect the germination of CNG seedlings, irrespective of trash removal (Table 3).

Effect of flupropanate on CNG seedlings

Very few CNG seedlings germinated during the observation period. This may be attributed to the transient nature of CNG seed banks (large amounts of unviable seed/unsuccessful germinants) (Williams 2005) or to the application of glyphosate, as a means of killing the mature CNG tussocks prior to the application of flupropanate. Glyphosate is known to kill mature C004EG plants although it is does not control subsequent CNG seedlings (Bourdot 1988, Nufarm 2005, Gaur *et al.* 2006). The application of glyphosate to kill mature CNG tussocks, together with dry seasonal conditions, may have limited seedling germination and growth. The observation period (14 months after spraying) was timed to ensure that sufficient rainfall and time had elapsed to allow for flupropanate

Figure 1. Casey's Weir – replication 1 plot 3 (5th June 2008) four weeks after application of glyphosate – replications 1 and 2 close, replications 3 and 4 far.

Table 1. Treatments for CNG07-1.

Treatment	Glyphosate rate 510 g a.i. L^{-1}, 100 L ha^{-1} water (3/5/07)	Trash cover	Flupropanate rate 745 g a.i. L^{-1}, 165 L ha^{-1} water (5/6/07)	CNG physiological growth stage
1	2.5 L ha^{-1}	trash	None	–
2	2.5 L ha^{-1}	trash	250 mL ha^{-1} (186g a.i. ha^{-1})	seedling
3	2.5 L ha^{-1}	trash	750 mL ha^{-1}a (558.75 g a.i. ha^{-1})	seedling
4	2.5 L ha^{-1}	no trash	250 mL ha^{-1} (186g a.i. ha^{-1})	seedling
5	2.5 L ha^{-1}	no trash	750 mL ha^{-1} (558.75 g a.i. ha^{-1})	seedling

Table 2. Effect of flupropanate and trash on average cover of pasture components during the period from September 2007 to October 2008 (significant differences (P >0.05) shown in bold).

Pasture component	Angularly transformed					Back transformed			P-values	
	[1] No flu no trash	[2] Flu trash	[2] Flu no trash	SED 1 vs. 2	SED 2 vs. 2	No flu no trash	Flu trash	Flu no trash	Between combinations presented	Any flupropanate level effect
Chilean needle grass	7.3	6.1	3.7	1.82	1.49	2	1	0	**0.13**	0.20
Perennial desirable grasses	11.8	26.2	20.3	4.88	3.98	4	19	12	**0.037**	0.67
Annual grasses	43.1	30.4	34.7	2.78	2.27	47	25	32	**0.0022**	0.63
Broadleaf plants	1.0	7.6	2.6	1.95	1.59	0	2	0	**0.0072**	0.61
Litter	41.8	44.0	46.45	2.36	1.93	44	48	53	**0.17**	0.19

Table 3. Effect of flupropanate and trash on the average number of seedlings m^{-2} over the period August 2007 to October 2008.

Logarithmically (base 10) transformed					Back transformed			P-values	
[1] No flu no trash	[2] Flu Trash	[2] Flu no trash	SED 1 vs. 2	SED 2 vs. 2	No flu no trash	Flu trash	Flu no trash	Between combinations presented	Any flupropanate level effect
0.49	0.59	0.64	0.209	0.171	3.1	3.9	4.4	0.13	0.20

activation (Taskforce 2006) given the soil type, whilst allowing for CNG germination.

The CNG seedlings that did grow were not affected by flupropanate application at levels up to 750 mL ha^{-1} (558.75 g a.i. ha^{-1}) irrespective of trash removal. These findings are aligned with other trials where low rate applications of flupropanate have been used, although trash removal had not been investigated (Gaur *et al.* 2006). Removal of trash prior to the spraying of flupropanate did not seem to affect the level of CNG seedling control. This finding is in contrast to previous observations where flupropanate residual activity has been maintained in areas with trash (Grech 2007).

Flupropanate application at or below 750 mL ha^{-1} (558.75 g a.i. ha^{-1}) was insufficient to control germinating CNG seedlings in a clay loam soil, with or without pasture trash. Pasture composition of sprayed plots 14 months after application had more desirable perennial grasses and less annual grasses

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Disclaimer

Integrating herbicide wipers for the management of Chilean needle grass (*Nassella neesiana*)

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Abstract

A carpet herbicide wiper mounted on the linkage of a tractor was used to apply herbicide to 5 m × 20 m plots of phalaris and cocksfoot pasture infested with Chilean needle grass (CNG) during the spring of 2005 and 2006. The wiper was driven at 8 km h^{-1} and operated at 20 cm above ground level as both single and double passes (two passes in opposite directions). The herbicides used through the wiper were glyphosate (RoundUp PowerMax 1:2 water) and flupropanate (Taskforce 1:20 water) as well as a mixture of both of these. These two chemicals were also boom sprayed onto equivalent plots at label rates (RoundUp PowerMax 4 L ha^{-1}, Taskforce 2 L ha^{-1}) as a comparative application technique and compared to an untreated control. Certain plots at the trial site were grazed by sheep prior to wiping in 2005 to selectively graze down the desirable grass species but this was not repeated in 2006. Herbicide wiping treatments that contained only glyphosate were the only treatments to be re-applied in spring 2006.

Plots wiped with either glyphosate or flupropanate had less CNG than the control plots. Plots wiped with both glyphosate and flupropanate as a mixture did not have less CNG than the control plots and appear to have had an antagonistic effect. Plots that were boom sprayed with either chemical, separately or in combination, had significantly less CNG basal cover than the control plots. Double pass wiped plots generally had the same amount of CNG basal cover as their corresponding boom spray treatment plot (excluding the glyphosate and flupropanate combination). Plots wiped with a single pass (any chemical or combination) had less desirable perennial grass basal cover than double pass plots. Boom spray plots (excluding the glyphosate and flupropanate combination) and double pass wiper plots generally had more desirable perennial grass basal cover than the control plots. Grazed plots had more CNG basal cover than ungrazed plots (all combinations of single pass wiping, double pass wiping and boom spraying). Grazing did not effect any other pasture composition measures. Plots wiped with glyphosate had nearly no viable panicle seeds. Boom spray glyphosate plots had no viable seed in the spring of application yet had recovered seed production by the second spring. Other than using much less herbicide in wiping, there was no significant difference between double wiper application and boom spraying using glyphosate.

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