# 18th NSW WEEDS CONFERENCE


Monday 12th to Thursday 15th October 2015
Multi-Function Centre, Cooma NSW

COOMA-MONARO SHIRE COUNCIL

## Weeds - the Future:
## *"Innovation and Adaptation"*

THE WEED SOCIETY OF NEW SOUTH WALES INC.

# Conference Program

## Monday 12 October 2015 - Ex-Services Club – Vale Street Cooma

5:00pm –8:00pm   Registration Open
6:00pm – 8:00pm   Welcome Reception

## DAY 1   Tuesday 13 October 2015 - Cooma Multi-Function Centre

7:00am – 8:15am   Registrations open

### Opening Sessions – Changes in the Weed World

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| **CHAIR** | **Peter Smith** |
| 8:30am | Welcome to Country – Community Elder – Jandemarra Wall |
| 8:35am | Conference Welcome – Mayor - Cooma-Monaro Shire Council |
| 8:40am | **Opening** – Bruce Christie, DDG Biosecurity NSW DPI |
| 8:50am | **Keynote Speaker** – James Litchfield, Hazeldean. Celebrating 150 years of Merino and Angus breeding on the Monaro |
| 9:10am | Keynote Speaker – Andy Sheppard - CSIRO – 100 years of continually successful weed biological control in Australia |
| 9:30am | Changes in the weed world – Dr Andrew Sanger - DPI |
| 9:50am | Applying Rational Regulation. Changing Noxious Weeds Act and NSW Biosecurity Act – Michael Michelmore – NSW DPI |
| 10:10am | Question & Answer Session |

### 10:20am   Morning Tea and Trade Display

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| **CHAIR** | **John Cahill** |
| 11:00am | NSW Invasive Species Plan 2015-2022 – What's New – Jane Frances - NSW DPI |
| 11:20am | NSW Weeds Review Implementation within Local Land Services – Brett Miners - Hunter Local Land Services |
| 11:50am | Overview of the Biosecurity Information System – Mary Malin - Biosecurity - NSW DPI |
| 12:20am | Question & Answer Session |

# 100 years of continually successful weed biological control in Australia

**Andy Sheppard[1], Jim Cullen[1] and Bill Palmer[2]**

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[2] Biosecurity Queensland, Department of Agriculture, Forestry & Fisheries, Ecosciences Precinct, GPO Box 267, Brisbane, Qld 4001

Biological control of weeds started in Australia in 1903 when the Queensland Department of Agriculture and Stock imported *Dactylopius ceylonicus* cochineal (ex Brazil via India/Sri Lanka) to work on as a potential biological control agent for *Opuntia vulgaris* (Barbary fig) but the culture died out before any releases were made. Then in 1913-1914 Department of Agriculture and Stock imported three more *Dactylopius* spp., *Cactoblastis cactorum* and a disease of *Opuntia*. In 1914 *D. ceylonicus* was released in Queensland and quickly led to the successful control of *O. vulgaris.* In the same year the moth *Epinotia lantana* and the fly *Agromyza lantanae* were released on lantana (ex Mexico via Hawaii) but did not achieve any control. From 1921 to 1940, 19 other insect agents were released against seven *Opuntia* spp. and 12 of these agents established. The major success of the *Cactoblastis* moth complemented by *Dactylopius opuntiae* led to the world renowned successful control of *Opuntia stricta* (prickly pear) over 25M ha of Queensland and NSW. Since then Australia has run 73 weed biological control programs (69 on weeds exotic to Australia) against weeds of agriculture, the environment, recreation, amenity and health. Of these 58 were fully developed programs. In summary 14 have been very successful, 11 seasonally or regionally successful, 11 programs were unsuccessful and 22 programs are still ongoing and too early to assess. That is a confirmed success rate of 69% programs and included targets like salvinia, rubber vine, bridal creeper and Paterson's curse. A 2006 independent evaluation also showed that for an annual investment of $4M a year since 1903 weed biological control has returned, not including environmental benefits, an annual benefit of $95M to the $4.4 Billion a year financial problem weeds cause to Australian agriculture. The 1970s through to the 1990s saw the most weed biological control programs in Australia. Since then activity and capability have gone into serious decline. This paper will tell the story of 110 years of weed biological control, a century on from the first effective release, and look to the future around opportunities and capacity to deliver.

# The New NSW Invasive Species Plan 2015-2022 - What's New?

**Jane Frances, Manager Special Projects NSW DPI**

## Introduction

The Invasive Species Plan 2015-2022 (the Plan) aims to outline mechanisms to prevent new incursions, contain existing populations and adaptively manage widespread invasive species. The overall goal is to foster and support a cooperative culture where everyone contributes to minimising the impacts of invasive species in NSW. The Plan also seeks to clarify roles and responsibilities of partners and stakeholders in NSW.

The Plan builds on and further develops the principles of its predecessor (the NSW Invasive Species Plan 2008-2015), and continues to adopt four goals:

1. Exclude – prevent the establishment of new invasive species.
2. Eradicate or contain – eliminate, or prevent the spread of new invasive species.
3. Effectively manage – reduce the impacts of widespread invasive species.
4. Build capacity – ensure NSW has the ability and commitment to manage invasive species.

The Plan provides a state level framework for the coordinated and cooperative management of invasive species. It complements other existing strategies, in particular the NSW Biosecurity Strategy, the Australian Pest Animal Strategy, the Australian Weeds Strategy and the National System for the Prevention and Management of Marine Pest Incursions. It also provides links to regional and other plans, as well as various species-specific plans, both those that are in preparation as well as those already in existence.

## Process to Develop the Plan

In early 2014 NSW DPI appointed a Project Manager to coordinate and oversee the review of the NSW Invasive Species Plan 2008-2015 (ISP1) and the development of the NSW Invasive Species Plan 2015-2022. The first task was to establish a Working Group with membership composed from key agencies, partners and stakeholders with an interest in invasive species. The NSW DPI Project Manager chaired the Working Group and members from National Parks and Wildlife, Local Lands Services, Local Council, Crown Lands, Weeds Officers and NSW Farmers participated. NSW DPI also provided representatives with expertise in weeds, vertebrate pests, plant and aquatic biosecurity management.

At its first meeting the Working Group commenced a review of ISP1. They were determined that the new Plan would maintain the clarity and concise nature of ISP1, while including updates on novel control techniques and new management initiatives at the national and state levels. To achieve this, the Working Group sought input from a broad range of people active in invasive species management and research. The Working Group developed an extensive list of key contacts and distributed a questionnaire to them as a mechanism to seek input from technical experts, practitioners and stakeholders. In particular, the questionnaire sought comments on strengths and weaknesses of ISP1, and suggestions for case studies for inclusion in the new Plan.

The Working Group was particularly keen to try to keep interested parties informed of progress in developing the Plan. A number of updates were prepared and distributed by working group members to their networks and posted on line. NSW DPI also sought comment on an early draft from its Invasive Plants and Animals staff, prior to releasing the document for public consultation. All comments received were assessed and the draft Plan was amended where appropriate prior to its finalisation and endorsement by the Minister for Primary Industries.

## So what is new?

Key differences between this Plan and the Plan it replaces (the 2008-2015 NSW Invasive Species Plan) include that the new Plan:

- clearly defines roles and responsibilities in invasive species management,

- explains the invasion curve,

- describes the need for and use of prioritisation, risk assessment and monitoring,

- includes contemporary case studies, and

- clarifies implementation, monitoring and reporting against the Plan.

Each of these changes are now outlined is detail.

## Roles and Responsibilities

A wide range of organisations and people are involved in invasive species management in NSW. The Plan recognises the variety of roles that exist, and attempts to consolidate these efforts through better coordination and communication between organisations and individuals.

The Plan describes in some detail the roles and responsibilities of key Government and community groups, and includes the following table which provides a generic illustration of these roles and responsibilities.

**Table: Representation of roles and responsibilities**

| Role or Activity | Responsibility | | | |
|---|---|---|---|---|
| | Occupier (rural /urban) | Community or local council | State government | Federal government |
| 1. On-farm biosecurity | Primary | None | None | None |
| 2. On-farm pest control | Primary | None | None | None |
| 3 Backyard management | Primary | Shared | None | None |
| 4. Public land management | Primary | Shared | Shared | None |
| 5. Commercial production (eg agriculture, horticulture etc) | Primary | None | None | None |
| 6. Legislation | None | None | Primary | Shared |
| 7. Stakeholder awareness | Shared | Shared | Shared | None |
| 8. Hands on/field activities (eg treatment, spraying, trapping) | Primary | Shared | Shared | None |
| 9. Diagnostics/identification | Primary | Shared | Primary | None |
| 10. Domestic market access | Shared | None | Primary | None |
| 11. Export market access | Shared | None | Shared | Primary |
| 12. Training and engagement | Primary | Shared | Shared | None |

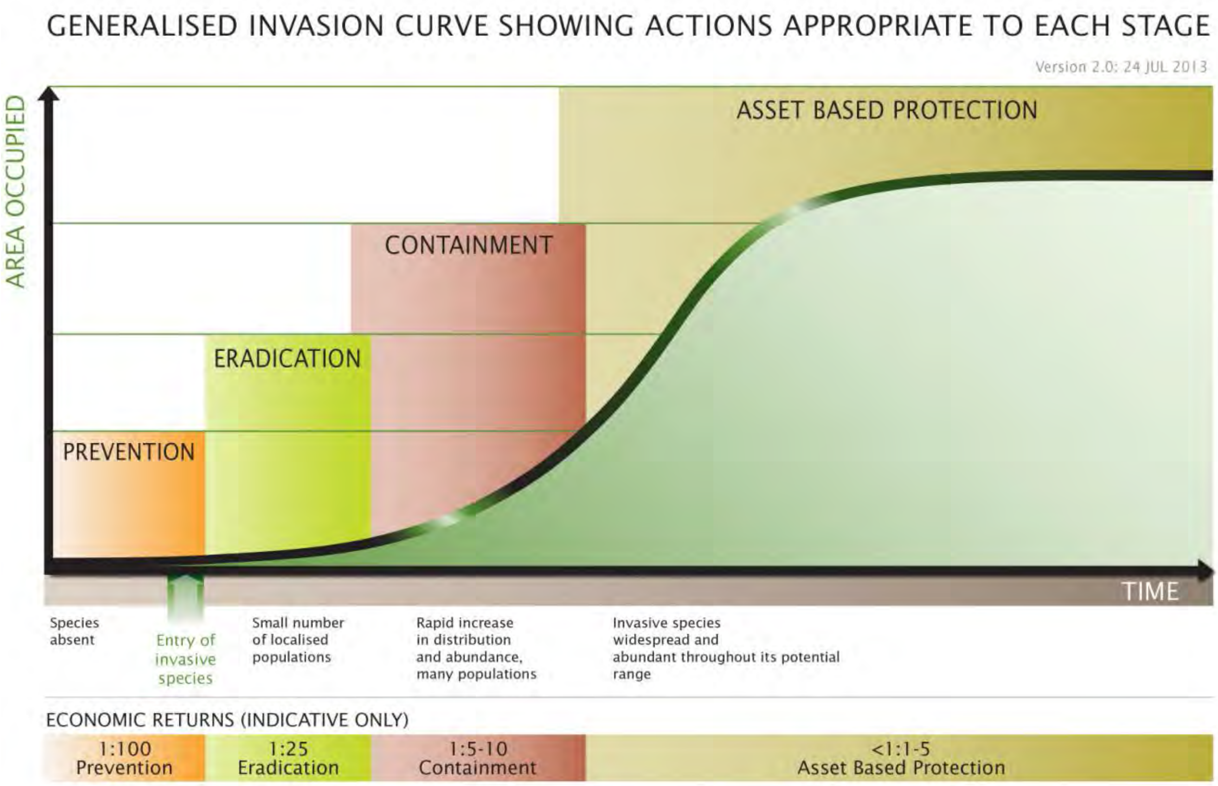
Key to colours

- (dark green) Means this group has primary responsibility
- (light green) Means a shared responsibility
- (pale green) Means no responsibility

## The Invasion Curve

Biosecurity Victoria developed a graphic representation, known as the Invasion Curve, which has been widely adopted by invasive species practitioners throughout Australia, and is included in the Plan (with Biosecurity Victoria's permission). The generalised invasion curve illustrates changes over time if pests and diseases successfully invade new areas and the different actions appropriate to counter invasion at each stage. The return on investment for different stages in invasive species management is also shown, along the bottom axis.

**Figure: Invasion Curve, sourced from Biosecurity Victoria, Department of Primary Industries, Victoria**




The invasion curve highlights that the most cost-effective approach to invasive species management is achieved through preventing the entry of new threats. Unfortunately however, prevention is not always possible. The next highest return on investment in the management of invasive species is achieved by early intervention and eradication, which is really only possible when a small number of localised populations of the pest have invaded. If early intervention is unsuccessful and/or the pest spreads, eradication is no longer a feasible goal.

Full landscape management of widely established pests is the least cost-effective approach, and is the major reason why widespread pests should be risk-assessed to focus effort and investment on the identification and protection of significant environmental, economic and social assets.

## Prioritisation, Risk Assessment and Monitoring

Invasive plants and animals are among the most serious threats to the NSW natural environment and primary production industries. However, as with all things, the resources (both human and financial) available to address the risks and impacts of invasive species are limited, and activities and investment must be prioritised.

Invasive species management can be classified under four approaches: Prevention, Eradication, Containment and Asset-Based Protection. These four approaches are aligned with the invasion process from arrival to widespread establishment (as illustrated in the Invasion Curve).

The most effective way to minimise the impacts of invasive species is to prevent their initial incursion in the first instance. This requires being able to identify high risk species, thoroughly assess their potential invasiveness and implement effective barriers to prevent their establishment. The risks posed by an incursion of a novel invasive species (animal or plant) is informed by data on whether it has invaded other countries, information on its native range, preferred habitat, suitable climate and how well this matches conditions in NSW and Australia. Formal risk assessment techniques for invasive species estimate likelihood (including of successful reproduction, establishment and spread) and consequences (including environmental and economic impacts and social considerations).

New incursions can colonise areas rapidly and successful control will be highly dependent on a timely and rapid response. The challenge in the initial stages of establishment is to ensure early detection, reporting and rapid action by developing and deploying effective and efficient ways to eradicate or contain the introduced species before it becomes widespread. This usually results in a species-led approach.

Once widespread, the eradication of pest animals and plants over wide areas of different land tenure is rarely practical. Priorities for the control of these species must be determined and resources focussed in areas where the benefits of control will be greatest. A strategic or site-led approach is needed, leading to the largest reduction in impacts while protecting priority assets. Assets may be environmental, primary production or community (human health, infrastructure or cultural). A prioritised approach to invasive species management ensures maximum benefit from finite resources.

The NSW Weed Risk Management system is a tool developed to assist managers in NSW to determine priorities for weed management. The system uses a series of questions to score weed risk (invasiveness, impacts and potential distribution) and feasibility of coordinated control (control costs, persistence and current distribution). These scores help prioritise weed management, whether that involves eradication, containment or asset protection actions.

The NSW Government controls and regulates the introduction of some non-indigenous animals into NSW and the movement and keeping of those animals within the state. The system used in NSW for assigning non-indigenous animals into risk categories is primarily based on an assessment of three factors:

1. The risk that an escaped or released individual would harm people;
2. The risk that escaped or released individuals would establish a wild free-living population in NSW; and
3. The risk that the species would be a pest if a wild population did establish

NSW DPI manages a licensing and permit scheme for the keeping and movement of some non-indigenous animals that are deemed to be in the higher risk category.

In NSW, the Saving our Species program sets the main priorities for protecting threatened species from the impacts of pest plants and animals. It assigns threatened species to different management streams so the individual requirements of each species can be met. Strategic priorities are also outlined in threat abatement plans and the Biodiversity Priorities for Widespread Weeds.

The Biodiversity Priorities for Widespread Weeds, published in 2011, followed three initial steps:

1. Identifying the widespread environmental weeds within each region;
2. Identifying the native biodiversity (including threatened species) most at risk from these weeds;
3. Ranking sites and targeting weed management to sites where action would lead to the greatest protection of those native biota most threatened by weeds.

The community also has a role in prioritisation. Landholders also have limited resources and face significant impacts from a variety of invasive plants and animals, the extent of which varies between species and from region to region. Landholders who share concerns over the impacts they face from invasive species can achieve significant impact reduction through collaborating with their neighbours and coordinating agreed control efforts (sometimes referred to as the "tenure neutral" approach). Efforts to control wild dogs demonstrate the benefits of collaborative efforts.

At all levels (local, regional, state and national) and at all stages of invasion (prevention, eradication, containment and asset protection), monitoring invasive species management activities is required. Monitoring measures the effectiveness of our actions in reducing the impacts of invasive species and provides data on return for investment. Using this information, invasive species programs can be reviewed and evaluated, and investment of resources (human and financial) realigned as/if required.

## Case Studies

As with ISP1, the case studies in the new Plan once again describe options and outline successes in invasive species management. A number of novel emerging techniques are also outlined. The Case Studies have been chosen to illustrate each of the four Goals of the Plan (Exclude, Eradicate or Contain, Effectively Manage and Build Capacity). Examples of Case Studies included in the Plan and the Goals they illustrate are:

*Goal 1 Exclude:*

- *Case Study 1 - Efforts to keep tilapia out of the Murray Darling Basin*

Tilapia (*Oreochromis spp.*) are an internationally recognised pest fish that originate from the warm waters of southern Africa. They have established wild pest populations that dominate native fish communities in parts of Queensland, including catchments that lie directly adjacent to the Murray Darling Basin. The case study describes the NSW & Queensland governments' collaborative efforts to keep tilapia out of the Murray Darling Basin.

*Goal 2 Eradicate or Contain:*

- *Case Study 4 – Bitou bush management: protection of environmental assets*

Bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata*) is a South African invasive shrub that was inadvertently introduced to Australia, then deliberately planted on the NSW coast in the 50s and 60s to stabilise coastal sand drifts and revegetate dunes following mining. Now Bitou is listed as a Weed of National Significance (WoNS), a noxious weed, and as a Key Threatening Process under the NSW *Threatened Species Conservation Act 1995*. This case study describes the protection of environmental assets at risk from Bitou bush through the development and application of the Bitou Threat Abatement Plan.

*Goal 3 Effectively Manage:*

- *Case Study 5 – Coordinated control of wild dogs*

The Brindabella/Wee Jasper wild dog control group was formed in 2000 to address predation on livestock in the area, and was the first NSW group to develop a tenure neutral approach to wild dog and fox control. This case study describes the development of their wild dog control plan and demonstrates that for pest animal control to work everyone has to accept some of the problem and also be part of the solution.

*Goal 4 Capacity Building*

- *Case Study 6 – Novel emerging techniques in invasive species management: integrated aerial surveillance, thermal imaging and mapping pilot project*

The Northern Inland Weeds Advisory Committee coordinated weed management in the New England and North West regions, an area comprising 100,000km² and including 10 Local Control Authorities. Since 2010, new weed incursions of tropical soda apple and alligator weed have occurred in various locations within the region, often occurring in inaccessible and remote areas. This case study describes integrating new technology, including unmanned aerial vehicles, thermal imaging and a proven existing mapping system (Weedtr@cer) for the detection and surveillance of high risk invasive weed species.

## Implementation, monitoring and reporting against the Plan

The NSW Invasive Species Plan is a strategic document that will help prioritise and direct invasive species management programs, funding and resources for NSW. The Plan acts as a starting point to develop new action strategies while embracing existing strategies that are complementary to the Plan's objectives.

Agencies, stakeholders and community groups all have a role to play in implementation of this Plan. For example, this Plan is seen as a vital document for planning and works programs regarding weed management in NSW, and Local Control Authorities will ensure it is incorporated into Weed Action Program initiatives for 2015-2020 and beyond.

NSW DPI has a well-established formal stakeholder consultative framework at which invasive species management issues are discussed, including the Pest Animal Council and the State Weeds Committee (formerly the Noxious Weeds Advisory Committee). Committees such as these allow key stakeholders, including peak industry bodies, Local Control Authorities, public and private land managers and non-government organisations, to have a say in policy direction and priority setting. Many of the representatives on these committees also have an active interest in broader invasive species management. NSW DPI will coordinate reporting against implementation of this Plan in consultation with the NSW Pest Animal Council, the State Weeds Committee and similar groups that are involved in invasive species management in NSW.

## Conclusion

The development of the NSW Invasive Species Plan 2015-2022 has been a collaborative effort, with contributions from key agencies, partners and stakeholders with an interest in invasive species. It is sincerely hoped that this Plan continues the successes and usefulness of its predecessor in fostering and supporting a cooperative culture where everyone contributes to minimising the impacts of invasive species in NSW.

# NSW WEEDS REVIEW:
# IMPLEMENTATION BY LOCAL LAND SERVICES

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**SUMMARY**
The NSW Government has made a commitment to strengthen and maintain biosecurity measures in the state. The NSW Biosecurity Strategy 2013-2021 aims to protect NSW from biosecurity threats including animal and plant pests, diseases and weeds. The strategy has been developed with a focus on shared responsibility. Local Land Services (LLS) will play a key role in collaboration with other organisations such as the NSW Department of Primary Industries (DPI).
The weeds review of 2013 presents a unique opportunity and responsibility to improve weed management in NSW. The LLS has been tasked with facilitating the replacement of the existing 14 regional weed advisory committees with 11 statutory regional weed committees comprising Local Control Authorities, public and private landholders, and community members aligned with LLS boundaries. The establishment of these committees is a high priority because they will assist regional planning requirements under the proposed NSW Biosecurity Act and support implementation of Weed Action Program funds.

**Keywords:** Weed, reforms, implementation.

**INTRODUCTION**
The Minister for Primary Industries, Katrina Hodgkinson asked the Natural Resources Commission (NRC) to undertake an independent evaluation of the effectiveness and efficiency of weed management arrangements in NSW with a view to inform the further development of the proposed NSW Biosecurity Act, and other relevant strategies under the NSW Biosecurity Strategy.
The NRC was asked to:

- assess (based on existing data) the distribution and abundance of weeds across NSW and their impacts and likely trajectories;
- evaluate current regulatory and institutional arrangements across both public and private tenures;
- evaluate weed management programs funded by the Australian and NSW Governments;
- identify and assess viable alternative weed management arrangements; and
- provide advice on potential transitional arrangements for the future implementation of the NSW Biosecurity Act and NSW Biosecurity Strategy.

In May 2014, the NRC submitted a final report detailing recommendations and findings for its review of weed management in NSW. The submissions and consultation highlighted the impact that weeds have on a range of stakeholder groups and provided useful insights that directly informed the final recommendations.

The NSW Government provided a comprehensive response to the recommendations of the weeds review (Annexure 1 – lists those relevant to LLS and DPI). This paper will provide an update on implementation of the recommendations for formation of regional weed committees by Local Land Services.

**PRINCIPLES**

The LLS is implementing the NSW Weed Review using the following principles:

- Provision of state level guidance to ensure consistent and transparent committee operations and reporting without impacting the autonomy of regional weed committees;
- Utilise an effective partnership with Local Government and DPI in implementation of weed reform;
- Encourage accountability for cross tenure weed management in NSW at all levels, and ensuring this is open for scrutiny;
- Identify relevant opportunities for greater consistency and collaboration between LLS Regions, with the development of Weed Management Strategies and Regional Weed Committees; and
- Recognise success of reforms will be highly dependent upon partnerships and collaboration between local government, LLS and other land managers.

**COORDINATED RESPONSE**

LLS has established a Weeds Cross Regional Team (CRT) to ensure a coordinated approach to implementation of the relevant weeds review recommendations.

The CRT is working towards the following objectives:

- Support the effective transition to new weed management arrangements;
- Work effectively with external stakeholders at state scale to implement NSW Weeds Review;
- To provide consultation with regions in the development and implementation of a consistent approach;
- Support Regional Boards to be informed and engaged with the Weeds Review implementation process;
- Ensure consistent and coordinated regional weed management planning and delivery; and
- Ensure consistent state-wide reporting under the new weed management arrangement

The cross regional team liaises closely with the State Weeds Committee (and its predecessor, the NSW Weeds Advisory Committee) to ensure LLS closely aligns with DPI and local government in progressing the weed reforms.

LLS has taken a deliberate approach to build on success as of the past and achieve a balance between the benefits of a consistent approach across the state with the need for regional diversity. One of the main mechanisms to achieve this balance has been the establishment of a community of practice involving the LLS leads in weed reforms from each region.

**REGIONAL WEEDS COMMITTEES**

The Weeds CRT, based on advice from the weeds community of practice, has developed a model terms of reference.

These model terms of reference have sought to effectively blend the terms of reference for a

Community Advisory Group (under the LLS Act) with a typical constitution of a Weeds Coordinating Committee (more closely aligned with local government approaches to governance). The development of the model terms of reference has drawn heavily on the experience and knowledge of people involved with existing weeds coordinating committees.

The model terms of reference has built upon an initial charter for regional weeds committees which was jointly developed by DPI, LLS and local government and circulated with the guidelines for the Weed Action Program (2015-2020). The model terms of reference explicitly acknowledge local negotiations will result in a range of approaches for sub-committee and working group structures to be established under Regional Weeds Committees. Each LLS region has been encouraged to support those negotiations at an early stage to achieve a successful transition to the new Regional Weeds Committee and to build on the success of previous efforts in the area of coordinated weed management.

**NEXT STEPS**

Coordinated implementation of the regional weed committees is a first important step in implementing the NSW Weed Reforms. Further detail on the next steps and proposed timing will be presented at the conference.

Table 1: Government response to the NRC Weeds Review

| Recommendation Number | Detail recommendation | Level of Support | Government Response |
|---|---|---|---|
| 1. - Promote shared responsibility for weed management across the whole community | (c) build community-wide shared responsibility for weed management through improved education, capacity-building and cooperative community-based responses | Supported | The government supports a community-wide shared responsibility for weed management. The DPI has an excellent relationship with local government and has invested significantly in building its capacity to undertake community based weeds management programs. The establishment of LLS has potential to complement existing arrangements and may allow these programs to be extended to the broader community and industry. |
| 2. - Provide consistent and transparent state level leadership and accountability | (c –iii) commissioning independent audits of Local Control Authorities (LCAs), LLS and the DPI against standards and implementation of agreements and plans, and taking action where necessary | Supported in Principle | The government agrees with the need for effective and on-going evaluation of weed programs. There is statutory provision for audits of state and regional plans in accordance with the Local Land Services Act 2013. |
| 3. - Ensure consistent and coordinated regional planning and local delivery | (a) confirm and support local level service delivery by LCAs and define LCA statutory functions | Supported | |
| | (b) replace the existing 14 regional weed advisory committees with 11 statutory regional weed committees comprising LCAs, public and private landholders, and community members (similar to the Bush Fire Management Committee model) as subcommittees to LLS, and aligned with LLS borders | Partially Supported | The Government will establish regional weed committees under the Local Land Services Act 2013, with terms of reference similar to the role of Bush Fire Management Committees under the Rural Fires Act 1997. Membership will ensure that all major stakeholders have a say, and a primary responsibility will be to prepare and report on regional weed plans. |
| | (c) provide a legislative basis for tasking the regional weed committees with developing regional plans and priorities for widespread weeds and surveillance | Supported | The planning provisions of the Local Land Services Act 2013 coupled with provisions within the proposed Biosecurity Bill will require regional committees to develop risk-based strategic plans for weed management. These plans will be unambiguous, enforceable, tenure-blind, and inclusive of all relevant stakeholders. |
| | (d) ensure all regional plans are based on best available local knowledge, research and technology, and promote behavioural change and adoption of integrated land management practices | Supported | |
| | (e) encourage state bodies and the Australian Government to align | Supported | |

| Recommendation Number | Detail recommendation | Level of Support | Government Response |
|---|---|---|---|
| | funding with regional priorities identified in these strategic plans | | |
| | (f) ensure legislation allows for integration of pest plant and animal services and that LLS and LCAs work together to realise opportunities for efficiencies | Supported | The establishment of LLS presents opportunities to realise efficiencies in local service delivery. The proposed Biosecurity Bill will allow for authorised officers to exercise powers to conduct pest plant and animal services. |
| 5. - Improve management of high-risk pathways | (e) appoint LLS to coordinate management of declared aquatic weeds within each region | Supported | The government supports this role at the regional level. It should also be noted in most cases management and control of aquatic weeds requires specialist knowledge and equipment. It is important that broad oversight and technical input into these projects is provided at the state scale. |
| 6. - Improve accountability and enforcement at all scales | (b) require the State Weeds Committee to developed state-wide service delivery standards for LCAs. The Committee should commission independent audits of LCAs against these standards, with LLS given the resources and mandate to assume the LCA's surveillance responsibilities, if the LCA is not meeting their obligations. LCAs would not be relieved of responsibilities to manage their own land or roadsides | Supported | Independent audit provisions for state and regional plans are available under the Local Land Services Act 2013.<br>Plans will be developed based on broad consultation and with regard to available resources |
| | (c) require the State Weeds Committee to commission audits of LLS and DPI's performance in weed management, and the extent to which funding has been allocated in line with strategic priorities | Supported | Independent audit provisions for state and regional plans are available under the Local Land Services Act 2013. |
| 8. - Ensure effective implementation of reforms | (b) allow for each LLS region to establish a position for a regional project officer to oversee implementation of weed management programs within its region | Supported | The government supports the establishment of this role by either using existing weeds expertise within each of the LLS or the absorption of the current regional project officers who are largely funded through the NSW Weeds Action program. |

| 12.30pm | Lunch and Trade Display |
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**Mid-Afternoon Sessions**

| | Agronomy – Marquee | Conservation Symposium Auditorium |
|---|---|---|
| CHAIR | Dean Lynch | Hillary Cherry |
| 1:40pm | Invasive Grass Species via DNA barcoding – Aisuo Wang - NSW Trade and Investment | An Introduction to the forum: Managing Weeds for Conservation of Biodiversity in NSW – Stephen Johnson NSW DPI & Peter Turner OEH and NPWS |
| 2:00pm | Pasture activities on the Central Tablelands highlight the importance of plant recognition – Clare Edwards, Phil Cranney and Carol Rose-Central Tablelands LLS and NSW DPI | Effective Weed Management – from theory to reality – Tim Scanlon, OEH and NPWS |
| 2:20pm | The application of compost to improve soil quality as a management tool to control the noxious weed African Lovegrass in the Monaro region of NSW – Greg Bender, Australian Soil Management | Cabomba control for the protection of the Ramsar listed Myall Lakes – Terry Inkson - Great Lakes Council |
| 2:40pm | Another herbicide to replace Flupropanate – Resistance in Serrated Tussock - Tony Cook - NSW DPI | Using pathogens to biologically control environmental weeds: Updates – Louise Morin, CSIRO |

| 3:00pm | Afternoon Tea and Trade Display |
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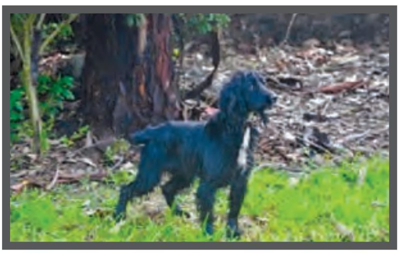

# Identification of Invasive Grass Species via DNA Barcoding

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## Abstract

Early intervention and mitigation of invasive grasses in Australia is often confounded by problems of species mis-identification. Field identifications can be erroneous through lack of taxonomic expertise or facilities to accurately distinguish invasive grasses from native varieties. Here we report the utility of DNA barcoding as a genetic method for assisting in the identification of high profile invasive grasses present in Eastern Australia. A total of 606 grass specimens, including four major invasive grass species [*Nassella neesiana* (Trin. & Rupr.) Barkworth (Chilean needle grass), *Nassella trichotoma* (Nees) Hack. ex Arechav. (serrated tussock), *Eragrostis curvula* (Schrad.) Nees (African love grass), and *Hyparrhenia hirta* (L.) Stapf (Coolatai grass)], and a variety of native species were sampled across a broad geographic area. Up to 18 genetic markers (including 17 chloroplast markers and one nuclear marker) were screened for their efficiencies as potential DNA barcodes for identifications of weeds species. Preliminary results indicate that five genetic regions (ITS, *matK*, *atpF*, *ndhK* and *petL*) displayed some facility in separating particular species from others, but no single gene was suitable as a universal standalone DNA barcode region for accurate identification of all the surveyed species. Our future work will focus on these five genes to improve their PCR success rate across species, and to determine if multi-locus DNA barcode profiles can be used to distinguish all species in specific genera.

**Key Words:**

Chilean needle grass, serrated tussock, African love grass, Coolatai grass, genetic identification

## Introduction

Invasive grass weeds impose one of the biggest threats to our agricultural industry. Each year, millions of dollars are lost due to the decreased productivity of grazing land and livestock caused by weeds (Sinden *et al*., 2005).

Many invasive grasses, especially at seedling stages, are very similar in appearance to our native grasses, and frequent misidentifications occur which result in delayed mitigation of new invasive grass outbreaks, or unnecessary local eradication of similar looking native species (Wang *et al*., 2014).

Identification of grasses is primarily based on morphological examination of floral material using well researched diagnostic keys. In many cases, accurate identification of focal pest weeds in Australia requires advanced taxonomic expertise and availability of specimens containing diagnostic feature(s) present at particular stages of the growth cycle. Alternative methods of accurate grass species identification are needed to remove the dependency on availability of suitable growth-stage samples for analysis, to reduce the burden of identifying extensive collections placed on taxonomic experts, and ultimately to provide a comparative means to check key-based identifications made by officers in the field. DNA barcoding (Hebert *et al*. 2003), is a universal genetic method for identifying specimens to species based on diagnostic DNA sequence content at one or more gene regions. The method relies on initial provision of diagnostic DNA barcode libraries of taxonomically described biota (Gopurenko *et al*., 2013), and when available, can be used to accurately and rapidly identify samples to species, even from trace amounts or degraded sample tissue (DeWaard *et al*., 2010; Pradosh & Sankar 2013).

Currently, we aim to develop libraries of diagnostic DNA barcodes for genetic identification of the key invasive grasses and other morphologically similar native grasses present in eastern Australia. Once developed, this method could be used as an alternative laboratory based species identification tool in grass survey programs, and will be especially useful in instances where field identifications of suspected weed presence requires rapid and independent verification. The following are some preliminary results from this project.

## Materials and Methods

A total of 606 samples of 59 grass species were examined for the DNA barcode library. Material included field sampled specimens (N = 368), Nursery specimens of native seeds (N = 50), herbarium specimens from the Australian National Herbarium in Canberra (N = 84) and the National Herbarium of Victoria (N = 74), and DNA samples from the Instituto Multidisciplinario de Biología Vegetal, Museo Botánico de Córdoba Argentina (N = 30). Particular emphasis was given to sampling of four major weeds species: *Nassella neesiana* (N = 92), *Nassella trichotoma* (N = 85), *Eragrostis curvula* (N = 79) and *Hyparrhenia hirta* (N = 23). Each specimen was allocated a unique specimen ID for DNA analyses.

DNA was extracted from leaf or seeds of grass specimen (< 1 mg) using a Corbett Research 1820 X-tractor Gene robotic system, following protocols reported by Gopurenko *et al.* 2013.

We screened 17 chloroplast gene regions (*atpF, cemA, G3pdh, infA, matK, ndhK, petA, petL, psbK, rbcL, rpl16, rps14, tRNA-Leu, tRNA-Ser, tRNA-Thr, trnH* and *YCF6*) and the nuclear ribosomal ITS intergenic spacer regions to determine levels of PCR fidelity across genera and species of collected grasses. Further we identified levels of intra/interspecific sequence difference among taxa at each gene region to determine their facility as DNA barcodes. Pairwise estimates of intra and interspecific percent sequence difference were estimated using K2P character weighting in MEGA6.0 (missing nucleotide was compensated using the pair-wise deletion option). PCR, bi-directional sequencing, sequence assembly and other molecular laboratory procedures followed Gopurenko *et al.* (2013) with the exception of primers used in PCR.

Specimen sequences were aligned for each gene using ClustalW (Larkin *et al.* 2007) as implemented in BioEdit (Hall 1999). Sequence alignments were imported into MEGA 6.0 (Tamura *et al.* 2013) and analysed as genetic distance trees using the neighbour-joining (NJ) method. Pairwise distances among sequences in NJ trees were adjusted as per the Kimura two-parameter model, and statistical support for all nodes in trees were estimated by bootstrap replication (N = 1,000 replicates).

Gene trees were examined for presence of species monophyly (single genetic clade inclusive of all specimens at a single species only) or species paraphyly (multiple clades among specimens in a species, where some clades are more closely related to other species). We used this as a starting criterion, to determine the utility of the separate gene regions to provide accurate DNA barcode species identifications.

## Results and Discussion

Preliminary results indicate five of the 18 surveyed gene regions are potentially useful for development as DNA barcodes for identification of native and invasive grasses in Australia. The five prominent genes examined in this project are discussed here.

### *matK*

*matK* and *rbcL* are two cpDNA gene regions that have been recommended by the Consortium for the Barcode of Life (CBOL) for universal use as standard plant barcodes (CBOL Group, 2009). While *rbcL* did not show much separation capacity in our results (data not shown), *matK* appeared to be useful for accurate DNA barcode identification of many (but not all) of the grasses. *matK* PCR success among surveyed species varied from 50 to 86 % (Table 1). Eleven out of 18 species surveyed (*Anthosachne scabra, Aristida behriana, Austrostipa elegantissima, Cymbopogon refractus, Digitaria brownii, Eragrostis curvula, Microlaena stipoides, Nassella neesiana, Nassella trichotoma, Paspalidium sp.* and *Themeda triandra*) were each monophyletic in the *matK* NJ tree (Figure 1); though several of the species were poorly sampled. Several of the sister species were however separated by minimal genetic distances (ie. *Nassella* species), and it remains to be seen in our future work if monophylly at those species is consistent across a broader sample.

**Table 1: Preliminary PCR success rates of *matK* gene regions at surveyed grasses. Evidence of species monophyly or paraphyly at each gene as indicated (* = native Australian grass, all other species are invasive to Australia)**

| Species | No of specimens | PCR success rate (%) | Results of Phylogenetic analysis |
|---|---|---|---|
| *Anthosachne scabra** | 9 | 86% | Monophyletic |
| *Aristida behriana** | 3 | 50% | Monophyletic |
| *Austrostipa densiflora** | 6 | 50% | Paraphyletic |
| *Austrostipa elegantissima** | 4 | 83% | Monophyletic |
| *Cymbopogon refractus** | 4 | 50% | Monophyletic |
| *Dichelachne sp.** | 4 | 67% | Paraphyletic |
| *Digitaria brownie** | 8 | 50% | Monophyletic |
| *Eragrostis curvula* | 79 | 80% | Monophyletic |
| *Microlaena stipoides** | 40 | 73% | Monophyletic |
| *Nassella neesiana* | 92 | 50% | Monophyletic |
| *Nassella trichotoma* | 85 | 50% | Monophyletic |
| *Paspalidium sp.** | 4 | 67% | Monophyletic |
| *Poa labillardieri** | 10 | 33% | Paraphyletic |
| *Poa sieberiana** | 8 | 63% | Paraphyletic |
| *Rytidosperma caespitosum** | 5 | 50% | Paraphyletic |
| *Rytidosperma pallidum** | 8 | 83% | Paraphyletic |
| *Rytidosperma sp.** | 4 | 83% | Paraphyletic |
| *Themeda triandra** | 5 | 50% | Monophyletic |

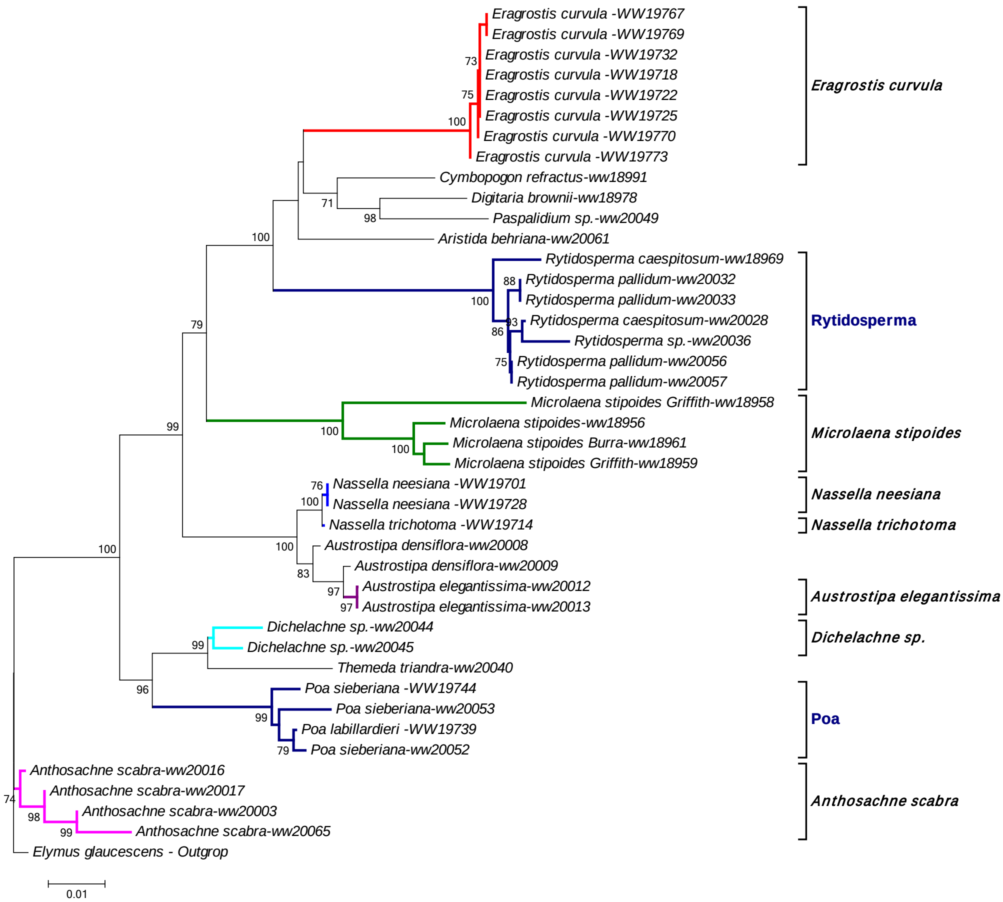


**Figure 1: NJ trees constructed on the sequences of *matK* across species of *Anthosachne, Aristida, Austrostipa, Cymbopogon, Dichelachne, Digitaria, Eragrostis, Microlaena, Nassella, Paspalidium, Poa, Rytidosperma* and *Themeda*.**

## *atpF, ndhK and petL*

*atpF* is one of the non-standard chloroplast markers tested in this study. We obtained a range of PCR success rates (33 to 100 %) with this marker across 25 surveyed species. Thirteen out of 25 species surveyed (*Austrostipa variabilis, Austrodanthonia richardsonii, Digitaria coenicola, Nassella leucotricha, Hyparrhenia hirta, Chloris virgata, Microlaena stipoides, Anthosachne scabra, Austrostipa elegantissima, Bothriochloa macra, Cymbopogon refractus, Eragrostis cilianensis* and *Eulalia aurea*) were each monophyletic in the NJ tree (Figure 2). While several monophyletic species were poorly sampled, *Hyparrhenia hirta*, an important invasive weeds species in eastern Australia, was well represented by 11 specimens. The clear separation of this weed from other weeds species by this marker reveals the potentials of *atpF* as a DNA barcode.

Except for *atpF*, other two non-standard chloroplast markers also displayed some levels of identification capacity at particular species (Appendix). For example, all subgroups of the native *Microlaena stipoides* were clustered as a single monophyletic clade by each of these genes, and *Anthosachne scabra* was proved to be monophyletic by *petL*.

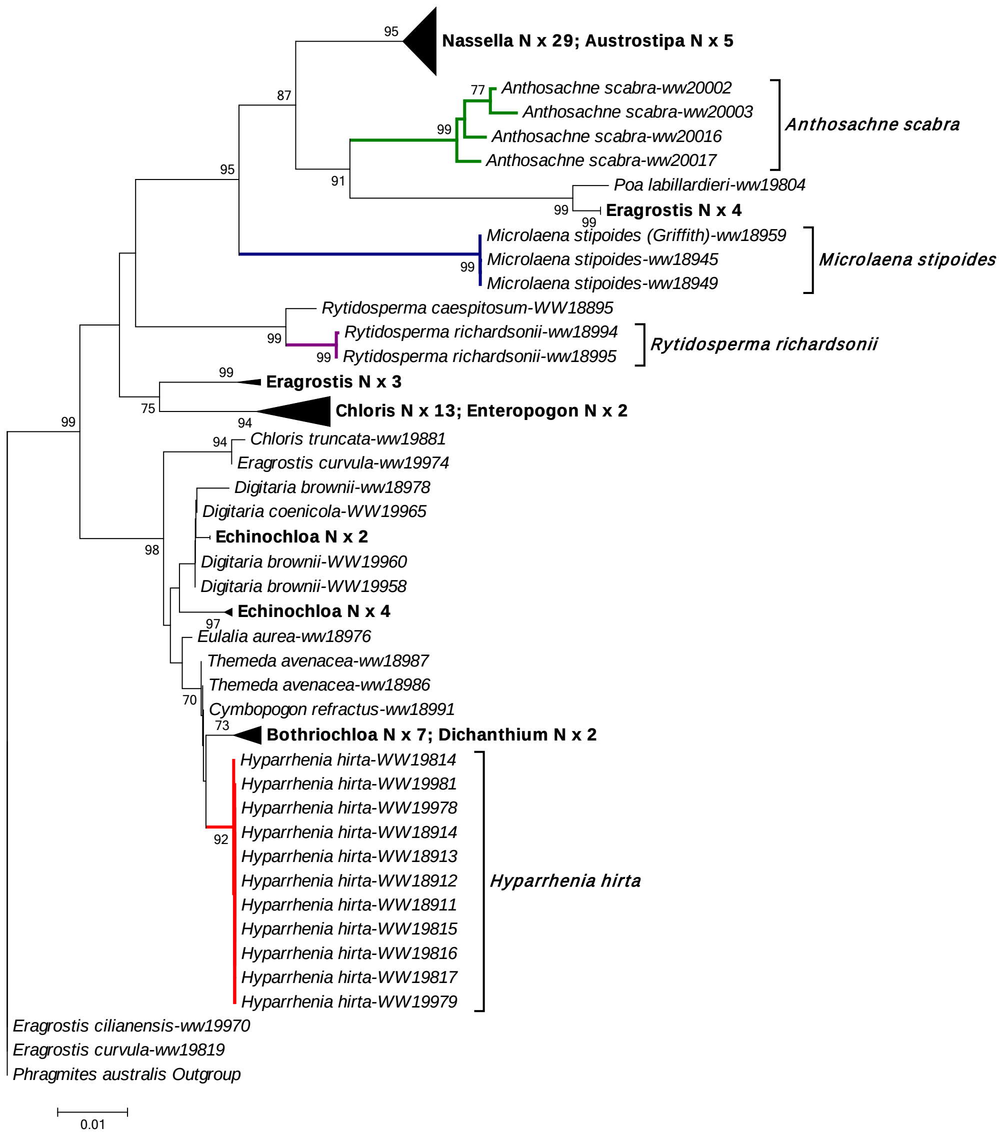


**Figure 2:** NJ trees constructed on the sequences of *atpF* across species of *Anthosachne, Austrodanthonia, Austrostipa, Bothriochloa, Chloris, Cymbopogon, Dichanthium, Digitaria, Enteropogon, Eragrostis, Eulalia, Hyparrhenia, Microlaena, Nassella, Poa, Rytidosperma* and *Themeda*.

### *ITS*

In recent years, the potential utility of the nuclear ribosomal internal transcribed spacer regions (ITS 1 & 2) as a core DNA barcode marker was recognized (Kress and Erickson, 2007; Zhang *et al.,* 2015). This is because ITS generally has higher nucleotide substitution rates than cpDNA genes. Our preliminary results (Table 2, Figure 3) indicates six of the seven species surveyed are monophyletic at this gene (*Chloris gayana* is paraphyletic with respect to *C. virgata*) and the minimum species difference among mophyletic sister species was > 5 %. The limited species representation examined here at this gene is however, an indication of the limited PCR success using an array of previously published ITS primer sets (data not shown). In addition fungal contaminants were detected in a proportion (about 75 %) of the failed specimen trials. This indicates we need to develop ITS primers which are specific to and universal for grass species, as a priority goal for our future work with this potentially useful DNA barcode region.

**Table 2: Preliminary PCR success rates of ITS gene regions at surveyed grasses. Evidence of species monophyly or paraphyly at each gene as indicated (* = native Australian grass, all other species are invasive to Australia)**

| Species | No of specimens | PCR success rate (%) | Results of Phylogenetic analysis |
|---|---|---|---|
| *Chloris gayana* | 25 | 80% | Paraphyletic |
| *Chloris truncata** | 15 | 60% | Monophyletic |
| *Chloris ventricosa* | 4 | 50% | Monophyletic |
| *Chloris virgata* | 4 | 50% | Monophyletic |
| *Enteropogon acicularis* | 5 | 50% | Monophyletic |
| *Eragrostis cilianensis* | 6 | 50% | Monophyletic |
| *Eragrostis curvula* | 79 | 55% | Monophyletic |

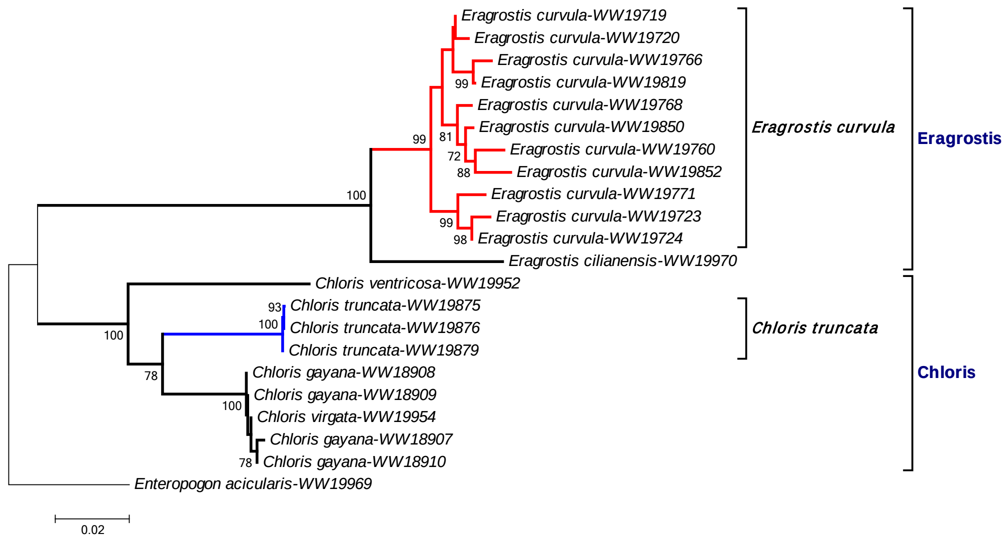


**Figure 3: NJ trees constructed on the sequences of ITS across samples of *Eragrostis, Chloris* and *Enteropogon.***

In summary, the preliminary results identified some promising DNA markers (*matK*, ITS, *atpF*, *ndhK* and *petL*) for separation of weeds grass species. We note that no single gene region could identify all of the studied taxa, which confirmed the complexity of weeds genetic composition and indicated the necessity of combining different markers for identification of particular weeds taxon. Our future work will increase our species coverage at the genes examined here, and explore the possibility of using specific sets of DNA barcode regions in concert for identification of particular species within focal genera.

## Acknowledgement

This study was funded by the NSW Weeds Action Program (WAP). The authors are grateful to Mr Peter Deane (WWAI), Mr Adam Shephard (WWAI) and a number of local council Weeds Officers across NSW and ACT for their assistance in field sampling. We also thank Dr Pina Milne and Mr Wayne Gebert from National Herbarium of Victoria (MEL) for providing Herbarium samples, Mr Ian Chivers from Native Seeds Nursery in Melbourne for providing seeds of native grasses, and Dr

Franco Chiarini from the Instituto Multidisciplinario de Biología Vegetal, for providing weeds DNA samples from Argentina.

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## Appendix

**Appendix table: Preliminary PCR success rates of three chloroplast gene regions at surveyed grasses. Evidence of species monophyly or paraphyly at each gene as indicated (* = native Australian grass, all other species are invasive to Australia)**

| Markers | Species | No of specimens | PCR success rate (%) | Results of Phylogenetic analysis |
|---|---|---|---|---|
| | *Anthosachne scabra** | 9 | 100% | Monophyletic |
| | *Austrodanthonia richardsonii** | 4 | 50% | Monophyletic |
| | *Austrostipa densiflora** | 6 | 67% | Paraphyletic |
| | *Austrostipa elegantissima** | 4 | 100% | Monophyletic |
| ***atpF*** | *Austrostipa variabilis** | 5 | 33% | Monophyletic |
| | *Bothriochloa bladhii** | 2 | 100% | Paraphyletic |
| | *Bothriochloa macra** | 4 | 100% | Monophyletic |
| | *Chloris gayana* | 25 | 58% | Paraphyletic |
| | *Chloris truncata** | 15 | 73% | Paraphyletic |

| Markers | Species | No of specimens | PCR success rate (%) | Results of Phylogenetic analysis |
|---|---|---|---|---|
| | *Chloris ventricosa* | 4 | 100% | Paraphyletic |
| | *Chloris virgata* | 4 | 88% | Monophyletic |
| | *Cymbopogon refractus** | 4 | 100% | Monophyletic |
| | *Dichanthium sericeum** | 4 | 100% | Paraphyletic |
| | *Digitaria brownii** | 8 | 83% | Paraphyletic |
| | *Digitaria coenicola* | 5 | 50% | Monophyletic |
| | *Enteropogon acicularis* | 5 | 88% | Paraphyletic |
| | *Eragrostis cilianensis* | 6 | 100% | Monophyletic |
| | *Eragrostis curvula* | 79 | 94% | Paraphyletic |
| | *Eulalia aurea** | 3 | 100% | Monophyletic |
| | *Hyparrhenia hirta* | 23 | 86% | Monophyletic |
| | *Microlaena stipoides** | 40 | 97% | Monophyletic |
| | *Nassella hyalina* | 20 | 78% | Paraphyletic |
| | *Nassella leucotricha* | 11 | 75% | Monophyletic |
| | *Nassella neesiana* | 92 | 88% | Paraphyletic |
| | *Nassella tenuissima* | 3 | 75% | Paraphyletic |
| | *Nassella trichotoma* | 85 | 84% | Paraphyletic |
| | *Poa labillardieri** | 10 | 83% | Paraphyletic |
| | *Rytidosperma caespitosum** | 5 | 100% | Monophyletic |
| | *Themeda avenacea** | 4 | 100% | Paraphyletic |
| ***ndhK*** | *Bothriochloa macra** | 4 | 100% | Paraphyletic |
| | *Chloris gayana* | 25 | 11% | Monophyletic |
| | *Chloris pectinata* | 3 | 50% | Monophyletic |
| | *Chloris truncata** | 15 | 78% | Paraphyletic |
| | *Chloris ventricosa* | 4 | 88% | Paraphyletic |
| | *Chloris virgata* | 4 | 88% | Paraphyletic |
| | *Digitaria brownii** | 8 | 100% | Paraphyletic |
| | *Digitaria coenicola* | 5 | 100% | Monophyletic |
| | *Enteropogon acicularis* | 5 | 88% | Paraphyletic |
| | *Eragrostis cilianensis* | 6 | 75% | Paraphyletic |
| | *Eragrostis curvula* | 79 | 60% | Paraphyletic |
| | *Hyparrhenia hirta* | 23 | 100% | Monophyletic |

| Markers | Species | No of specimens | PCR success rate (%) | Results of Phylogenetic analysis |
|---|---|---|---|---|
| | *Microlaena stipoides** | 40 | 90% | Monophyletic |
| | *Nassella hyalina* | 20 | 18% | Paraphyletic |
| | *Nassella leucotricha* | 11 | 60% | Paraphyletic |
| | *Nassella megapotamia* | 1 | 100% | Monophyletic |
| | *Nassella neesiana* | 92 | 66% | Paraphyletic |
| | *Nassella tenuissima* | 3 | 20% | Paraphyletic |
| | *Nassella trichotoma* | 85 | 61% | Paraphyletic |
| | *Poa labillardierei var. labillardierei ** | 4 | 50% | Monophyletic |
| | *Rytidosperma caespitosum** | 5 | 50% | Monophyletic |
| ***petL*** | *Anthosachne scabra** | 9 | 100% | Monophyletic |
| | *Bothriochloa macra** | 4 | 100% | Monophyletic |
| | *Chloris gayana* | 25 | 33% | Monophyletic |
| | *Chloris truncata** | 15 | 83% | Paraphyletic |
| | *Chloris ventricosa* | 4 | 88% | Monophyletic |
| | *Chloris virgata* | 4 | 88% | Monophyletic |
| | *Digitaria brownii** | 8 | 100% | Monophyletic |
| | *Digitaria coenicola* | 5 | 100% | Monophyletic |
| | *Enteropogon acicularis* | 5 | 88% | Monophyletic |
| | *Eragrostis curvula* | 79 | 56% | Monophyletic |
| | *Hyparrhenia hirta* | 23 | 92% | Monophyletic |
| | *Microlaena stipoides** | 40 | 85% | Monophyletic |
| | *Nassella hyalina* | 20 | 58% | Paraphyletic |
| | *Nassella leucotricha* | 11 | 67% | Paraphyletic |
| | *Nassella neesiana* | 92 | 72% | Paraphyletic |
| | *Nassella trichotoma* | 85 | 59% | Paraphyletic |
| | *Poa labillardieri** | 10 | 100% | Monophyletic |

**Pasture activities on the Central Tablelands highlight the importance of plant recognition.**

Edwards C[1], Cranney P[1] and Rose C[2].

1. Central Tablelands Local Land Services
2. NSW DPI, Tocal

**Abstract**

Plant recognition is important in any pasture management programme. Thirteen pasture plant recognition workshops held on the Central Tablelands of NSW revealed a need to persevere with extension programmes that help landholders recognise what plants they have on their farms. When quizzed about two of the main noxious weed threats in the region, many participants were unable to recognize the Nassellas (Chilean Needle grass and Serrated Tussock). This highlights the ongoing need for extension programmes to understand and minimise the impact of these weeds.

**Introduction**

Pasture identification is the basis of good pasture management, monitoring and measuring programme. Likewise, landholders' ability to be able to recognise pasture species is paramount when considering an integrated weed management plan. This paper reports on a pasture skills survey of 151 landholders in the Central Tablelands Local Land Services area which included two important noxious weeds.

In 2014, thirteen pasture plant recognition days were run with 207 landholders in the Central Tablelands of NSW. Most of these activities were Paddock Plant workshops (Edwards *et al.* 2006) a registered Profarm course developed by DPI and run in collaboration with Tocal College. Other activities were pasture recognition days. At the beginning of each of these activities, a pasture recognition audit was carried out. Around 75% of participants elected to be involved with this part of the day.

Ten pasture grasses species, were used in a quiz or pasture recognition skills audit. Two of these species were used as common weed standards for all groups. The standards were seed-heads of Chilean Needle grass (*Nassella neesiana*) and Serrated Tussock (*Nassella trichotoma).* The two Nassellas were laminated pressed seed heads, to minimise the biosecurity threat of spreading seeds. These samples had clear recognition features presented. This paper reflects on the two Nassellas and the importance of recognition on the Central Tablelands.

**Results**

Overall, recognition of the ten plants from the thirteen activities was 29%. The results from the two Nassellas species that were used as standards are shown in Figure 1.

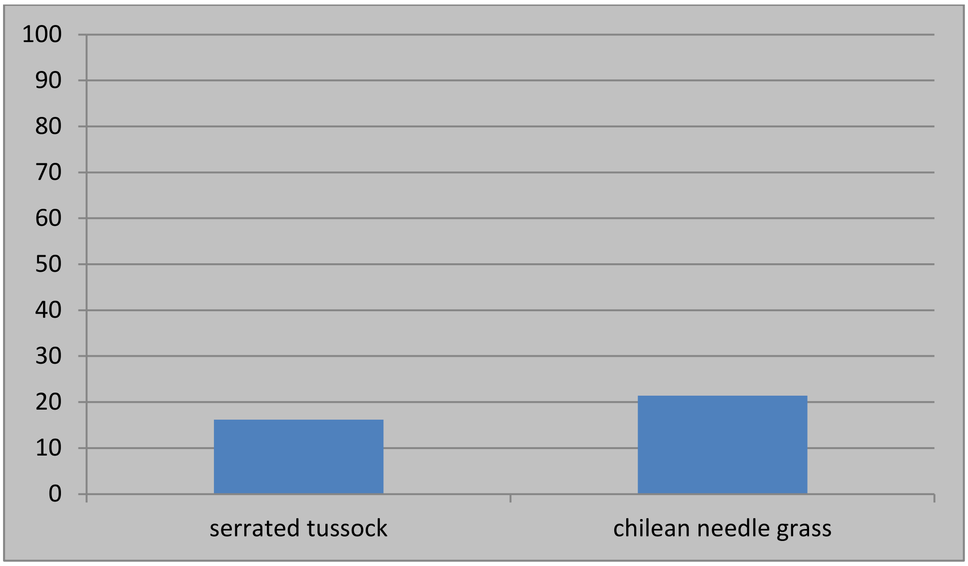


Figure 1 Correct identification of two Nassella species, Serrated Tussock and Chilean Needle grass as a percentage from 151 pasture pre course audits, carried out on the Central Tablelands LLS in 2014

There were some differences between the groups in identification of the weeds. For example, Chilean Needle grass was more likely to be identified correctly in the Oberon and Newbridge areas. There was less recognition in some areas where the weed is spreading and is a new or emerging issue eg in the Cumnock area.

**Discussion**

The laminated seed heads, are probably more difficult to recognise than live plants illustrating growth habit but was necessary for biosecurity. This is perhaps why a smaller number of landholders were able to recognise these species. Many attendees commented that they would have recognised the plant from its growth habit. Most knew of Serrated Tussock and many had heard of Chilean Needle grass and wanted to know more about it.

The laminated samples were the same used a Northern Tablelands survey of 52 participants carried out in 2010 (Edwards *et al.* 2011). Interestingly, similar results were found for Serrated Tussock recognition between the audits. However, while approximately 52% could identify Chilean Needle grass in the Northern Tablelands audit, only 21% could correctly identify it from the Central Tablelands survey. These activities were an opportunity to help producers develop skills to correctly identify the plant in the future. Many participants said that Serrated Tussock looked like the native Poa tussock (*Poa spp.*) and Chilean Needle grass was similar to the Stipa grass (*Austrostipa spp*.). There was even some reported confusion between some of the Brome species (*Bromus madritensis*) and Chilean Needle grass in the Cumnock area (Andrew Cosier Wellington Council per comms, 2014). The difficulty in differentiating Austrostipa species Chilean Needle Grass is well noted. This continues to be an issue across the region for landholders, advisors and weeds officers. The two weed species were examined at length and their recognition features illustrated. Time was spent on their potential and mechanisms for spread and recommended pasture management strategies to minimise risk of incursion.

This highlights an important role for pasture extension partnering with noxious weed authorities and county councils to improve recognition of this emerging weed.

While this is a small survey, it highlights the need to strive for improvement in plant recognition for pasture and weed management. The role of extension and advisory programmes is important in helping landholders with plant recognition as one element of integrated pasture and landscape management.

**Acknowledgments**

The authors wish to acknowledge and thank the producers and landholders that were happy to carry out a plant identification quiz. Funding for this project was under the Central Tablelands Local Land Services through the Australian Governments National Landcare Programme.

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# Soil management options for weed control

## The application of compost to control the noxious weed African Lovegrass in the Monaro region of NSW

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African Lovegrass *(Eragrostis curvula)* is a class 4 noxious weed in the Cooma-Monaro shire of NSW. Control is not an easy task and requires an integrated approach to be effective. The best option is to prevent establishment in the first place. For effective long-term control of larger areas of African lovegrass, an integrated program of spraying, sowing and pasture management can be used. Spraying alone is effective only where African lovegrass is selectively removed from a strong pasture.

The aim of management approaches is to maintain the vigour, persistence and competitiveness of desirable pasture species. The main control principle is to ensure the weed is replaced by better species. Consistent with this approach, Australian Soil Management (ASM) Pty Ltd is developing an additional option for weed control based on the improvement of soil quality to favour more productive pasture species. The premise is that the design and implementation of a soil management plan to permanently increase soil fertility will encourage ongoing competition from improved pasture species to reduce the establishment of Lovegrass.

The core strategy employed is the addition of compost supplied by Cooma-Monaro Shire Council. A permanent increase in soil quality from the addition of compost will require ongoing careful management for three to five years. The first year of the project, from 1 July 2014 to 30 June 2015, saw completion of site establishment and the beginning of monitoring and measurement of soil quality and changes in plant populations to more productive pasture species.

**Project site establishment**

There are two trial sites for the project:

1. The Billilingra trial site, seven kilometres south of Bredbo on the Monaro highway, is representative of an area covering about 80,000ha between Canberra and Cooma. The area is dominated by African Lovegrass on soils with granite as parent material.
2. The Macfield site is located adjacent to Numeralla Road on the outskirts of Cooma. African Lovegrass has not yet become established on basalt-based soils south of Cooma. However, landholders are already fighting a costly battle to prevent weed establishment.

The total area of each trial site is about 13,400m$^2$ or about 1.34ha. Both sites are fenced to manage grazing and maintain site integrity. Signage is located facing the Monaro Highway for the Billilinga site and Numeralla Road for the Macfield site. The sites are divided into six strips each approximately 1,440m$^2$ (8m x 180m) or 0.144 hectares. A ploughed 3m wide buffer separates each treatment and also surrounds each trial site. Treatments include the following:

1. Compost at 5 tonne per hectare

2. Compost at 3 tonne per hectare
3. No compost applied
4. Compost at 5 tonne per hectare plus ASM treatment
5. Compost at 3 tonne per hectare plus ASM treatment
6. No compost applied with ASM treatment

Both sites were sown with improved perennial pasture grass species on 20th October 2014. For Billilingra, all treatment strips were sown (direct drill) with an equal mixture of Australian and Holdfast Phalaris at a total of 5kg/ha. The Macfield site was sown (direct drill) with Cocksfoot at 7kg/ha. No chemical fertiliser was added. ASM treatments included compost pellets applied in row at 100kg/ha. No herbicides have been applied to the sites.

Soil samples were taken on 3rd July 2014 for independent laboratory analysis by Environmental Analysis Laboratories at Southern Cross University. At site establishment, ASM amendments have included a customised mix of lime and trace elements to address issues identified in baseline soil tests and an analysis of Cooma composts used in the trial. ASM lime and trace elements will not be added in Years Two and Three.

**Preliminary observations for Year One**

The Billilingra site is a light sandy loam over a clay subsoil whereas the Macfield site is a heavier clay loam with higher levels of organic matter. Soil pH is slightly acidic with high reserves of soil phosphorous and low levels of available phosphorous. Nutrient availability is much higher at the Macfield site possibly due to a higher clay and organic matter content. To assist with remediation of chemical deficiencies, a mixture of fine lime with nutrients was added to strips with ASM treatments at both sites on 28th October 2014.

On 3rd October 2014, agronomists from NSW DPI and local agricultural merchandise suppliers walked both sites to record the composition of plant types. African Love Grass poses a bigger problem at the Billilingra site with 39% of all plants and 29% bare ground. There is very little competition from other species apart from annual broadleaf weeds. The Macfield site has greater diversity in plant species providing competition from Phalaris, native grasses and legumes.

Compost from Cooma Council has been applied twice in Year One, on 16th October 2014 and again on 26th March 2015. In comparison to untreated strips, a visual growth response from all plant species is apparent where compost has been applied at both rates. This includes African Lovegrass where the positive response to compost is consistent with results from scientific trials and farmer experience. In these cases, an initial positive growth response to compost from African Lovegrass is followed by reduced growth and reduced seedling establishment in Spring. The unknown factor here is the quantity of compost needed to inhibit African Lovegrass. We have used rates of compost and management practices believed to be economically viable for farmers on a paddock scale in the Monaro region.

An important management strategy for the project has been mulching on 14th October 2014 and 20th January 2015 to simulate grazing. Mulching African Lovegrass allows light and rainfall to penetrate to ground level providing an opportunity for seedling establishment by other plant species. Mulch was raked onto buffers to slow weed establishment and prevent formation of a mulch air/water barrier forming on treated strips. The presence of surface rocks on the Macfield site prevented mulching to a low level (as used on Billilingra site).

**Preparations for Year Two**

The first year of the project is due for completion on 30th June 2015. However, data collection and observations in Spring 2015, especially late September to early October, are critical for assessment of progress. Plant counts will be repeated by a team of agronomists using methods employed for the original counts on 3rd October 2014 to assess any changes in populations of African Lovegrass. They will also be looking for any increase in numbers for more productive grass and legume species. In particular, the emergence of phalaris or cocksfoot sown on 20th October 2014. Soil sampling and analysis will be repeated for comparison of changes in soil quality from the original analysis made in July 2014.

Following data collection and analysis in Spring 2015, project methodologies will be assessed and changes made (if necessary) for Year Two of the project.

An article and radio segment on the project from ABC Rural can be found at:

http://www.abc.net.au/news/2014-08-15/compost-to-combat-lovegrass/5672376

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# IS THERE ANOTHER HERBICIDE TO REPLACE FLUPROPANATE? – THE REPERCUSSION OF RESISTANCE IN SERRATED TUSSOCK?

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## INTRODUCTION

Over the past 40 years the management of serrated tussock (*Nassella trichotoma*) has been mostly reliant on the application of flupropanate. This herbicide is relatively unique because it provides some selective control of many perennial weedy grass species whilst providing some a degree of safety to a range of native and introduced pasture grasses and legumes.

Historically, the industry had to cope with the temporary loss of the herbicide when it was withdrawn from the marketplace in the mid 1990's. At that time, there was little alternative other than to use glyphosate based products. Although effective at killing serrated tussock (Verbeek *et al.* 2004), the treatment caused unacceptable pasture damage if pastures species were actively growing and allowed more seedling tussock to emerge due to lack of competitive pasture species.

However, flupropanate resistant serrated tussock was first found in Victoria over a decade ago (Noble 2002). Since then there are increasing occurrences of flupropanate resistance (Ramasamy *et al*. 2008). For some in the industry that manage resistant serrated tussock, alternatives to flupropanate are needed. As stated previously, glyphosate may be used in some circumstances with off-target damage concerns, but another herbicide with selectivity is desperately required.

There are 21 modes-of-action herbicides classifications or groups available for various situations in Australia (Croplife Australia 2015). However, the list of potential candidates for serrated tussock control is narrowed down significantly due mainly to ineffectiveness on grasses. Furthermore, researchers from Victoria and NSW have found that some of the potentially useful grass herbicides were not suitable; however some were identified as having some potential use against serrated tussock (Melland and McLaren 1998; Campbell *et al*. 1999; Campbell and Nicol 2001).

Therefore the purpose of this paper is to thoroughly investigate alternative herbicides that may be used commercially to control flupropanate resistant serrated tussock.

The pros and cons of these new treatments will be discussed and if incorporated into an integrated management plan, the longevity of flupropanate and other herbicides should be prolonged.

## MATERIALS AND METHODS

All the experiments reported in this paper were located under field conditions in New South Wales. Application of herbicides was via a hand-held boom-spray or knapsack at spray water volumes of 100L and 1,000L/ha, respectively.

Application of adjuvants was in accordance to label directions for each specific product. All serrated tussock plants treated when actively growing to ensure treatment effects were not impacted by moisture stress interactions.

Assessments comprised of either plant counts per treated area or rated for the level of biomass necrosis using a scoring system with nil effect being a score of zero and full control a ten (where 6 or more is commercially acceptable). All experiments were finished after there were signs that the best treatments had passed their peak control levels. This was to ensure results presented within this paper reflect longer term performance of treatments not short-term brown-out effects.

The following experiments and treatment details are listed in the following table:

Table 1: Experiments undertaken on serrated tussock.

| Exp. No | Spray date(s) | Location | Investigating what? | Herbicides used (herbicide group) | No. of treatments |
|---|---|---|---|---|---|
| EXP1 | 18.10.12 | Armidale | Spot treating in spring – Group A herbicides (knockdown) ± imazamox (residual) | Glyphosate (M), flupropanate (J), 2,2-DPA (J), clethodim (A), butroxydim (A), propaquizafop (A), haloxyfop (A) and imazamox (B) | 15 |
| EXP2 | 13.5.13 | Armidale | Spot treating in spring – Group A herbicides (knockdown) ± imazamox (residual) | Glyphosate (M), fllupropanate (J), 2,2-DPA (J), asulam (R),clethodim (A), propaquizafop (A), haloxyfop (A) and imazamox (B) | 15 |
| EXP3 | 24.10.13 | Mount David | Spot treating haloxyfop – effect of dilution rate | Haloxyfop | 4 |
| EXP4 | 14.11.12 4.12.12 (paraquat) 27.3.13 (2,2-DPA) | Bredbo | Boom spraying Group A herbicide ± follow up spray with paraquat (double knocking). Plus other herbicide groups. | Glyphosate (M), flupropanate (J), 2,2-DPA (J), 4 group A herbicides ± paraquat (L), glufosinate (N), amitrole (Q) and paraquat + amitrole (L + Q) | 19 |
| EXP5 | 6.12.12 | Goulburn | Pre-emergence herbicide options – boom spray | 4 imidazolinone herbicides products (B), 3 sulfonyl ureas products (B), pendimethalin (D), terbuthylazine (C), triallate (J) and metoachlor (K) | 19 |
| EXP6 | 24.10.13 | Bredbo | Pre-emergence herbicide options – boom spray | 4 imidazolinone herbicides products (B), chlorsulfuron (B), pendimethalin (D), and metoachlor (K) | 15 |

## RESULTS

### *EXP 1: Spot treating in spring with combinations of Group A herbicides et al.*

This experiment was located on a patch of serrated tussock confirmed to have high levels of flupropanate resistance. This could be seen by the initial brownout of tussocks followed by fresh regrowth within a period of 6 months.

The data from this experiment is not presented in this paper, as results from most of the treatments were not commercially acceptable. However, there were some promising developments; these can be summarised as follows:

- The herbicide haloxyfop was the most promising Group A herbicide as it rated the highest control scores compared to butroxydim, clethodim and propaquizafop.
- Glyphosate was the best spot treatment with near 100% control of tussocks, however many seedlings emerged by the completion of this experiment.

- Both 2,2-DPA and flupropanate did not result in commercial control. This is due to the confirmation of resistance to flupropanate in this population and must have the same mechanism of resistance for 2,2-DPA as well (Group J).
- The additional of imazamox did not result in additional control of established plants nor did it prevent additional seedlings emerging around treated tussocks.

As a result of the treatment effects, a decision was made to increase the concentration rates of the Group A herbicides per volume of water in the subsequent experiment.

***EXP 2: Spot treating in autumn with combinations of Group A herbicides et al.***

Longer term assessments made 76 days after treatment (DAT) indicate that the two haloxyfop treatments resulted in the best control (Table 2). A control score of six or more is considered to be equivalent to commercially acceptable control. Therefore, haloxyfop at 80mL per 100L water achieved acceptable control; however a small proportion of these plants died (data not presented). Higher dilution rates are required to achieve greater mortalities (refer to EXP 3 for haloxyfop rate response data).

Both flupropanate and glyphosate treatments were carry-over treatments from the previous experiment (EXP 1) that were treated in spring (18.10.12). These treatments were actually assessed 7 and 9 months after treatment (MAT). Although these treatments had exceptional levels of control when initially assessed for this experiment, control dropped quickly by the last assessment. Primary causes for this were recovery due to herbicide resistance (flupropanate) and seedling emergence (glyphosate). Clethodim, propaquizafop and asulam did not reach the standards of a commercial treatment and were culled from further testing. 2,2-DPA was more effective than flupropanate but control was marginal.

Table 2: Effect of some Group A herbicides and standard treatments on serrated tussock control.

| Herbicide | Herbicide Group(s) | Rate of product per 100L water | Brownout (0-10) 31 DAT | Control (0-10) 76 DAT |
|---|---|---|---|---|
| Flupropanate 745g/L (spring) | J | 150mL | 8.0 | 2.0 |
| Flupropanate 745g/L (spring) | J | 300mL | 7.8 | 1.7 |
| 2,2 – DPA 740g/kg | J | 500g | 5.0 | 4.9 |
| 2,2 – DPA 740g/kg | J | 1.0 kg | 3.3 | 6.2 |
| Untreated | ----- | ----- | 1.0 | 1.5 |
| Glyphosate 450g/L (spring) | M | 1L | 9.0 | 1.0 |
| Glyphosate 450g/L + Imazamox 800g/kg (spring) | M | 1L + 5g | 9.7 | 1.0 |
| Haloxyfop 520g/L | A | 80mL | 5.0 | 7.3 |
| Haloxyfop 520g/L + Imazamox 800g/kg | A + B | 80mL + 5g | 5.7 | 6.2 |
| Clethodim 240g/L | A | 50mL | 7.2 | 3.2 |
| Clethodim 240g/L + Imazamox 800g/kg | A + B | 50mL | 7.2 | 3.3 |
| Propaquizafop 100g/L | A | 90mL | 7.3 | 2.5 |
| Propaquizafop 100g/L + Imazamox 800 g/kg | A + B | 90mL + 5g | 6.7 | 2.9 |
| Asulam 400g/L | R | 850mL | 7.5 | 2.5 |
| Asulam 400g/L + Imazamox 800g/kg | R + B | 850mL + 5g | 7.0 | 2.8 |

**Where DAT = days after treatment.**

***EXP 3: Spot treating with haloxyfop using a range of dilution rates.***

The rate response shown in Figure 1 demonstrates that haloxyfop 520g/L formulations need to be applied at 160mL/100L water. Reductions in dilution rate resulted in greater proportions of serrated tussock foliage showing photosynthetic potential, hence potential for plants to regrow. The inspection five months after treatment was considered a good yard stick for longer term control. Experience with this herbicide on serrated tussock has shown that obtaining peak control may require at least 2 to 4 months after treatment.

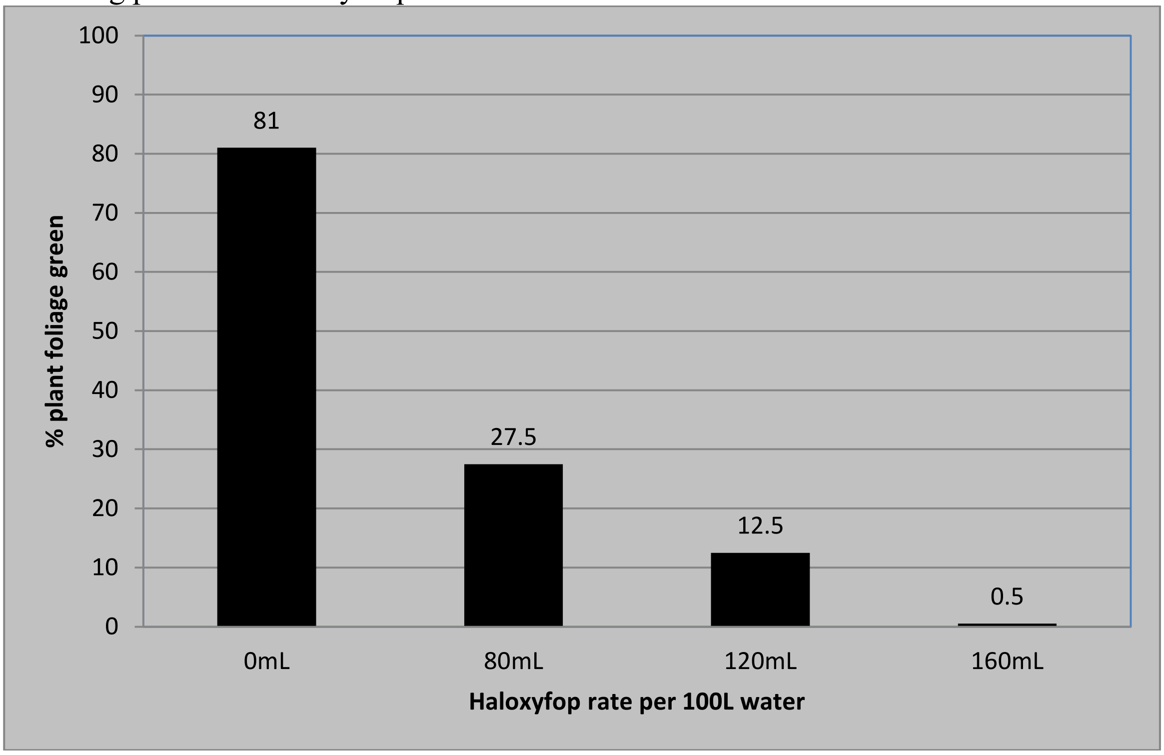


Figure 1: Effect of haloxyfop dilution on serrated tussock photosynthetic potential 5 MAT

An assessment made 11 months after treatment counted surviving plants per transect and measured the % of foliage that had green tissue (Table 3). These results have shown that some plants do recover from the top rate of haloxyfop but are still showing significant signs of herbicidal injury.

Table 3: Longer term assessments of haloxyfop treatments (11 MAT)

| Rate of haloxyfop per 100L water | Plants per transect | % foliage green |
|---|---|---|
| 0mL | 24 | 82 |
| 80mL | 17 | 79 |
| 120mL | 13 | 76 |
| 160mL | 7 | 34 |

***EXP 4: Boom spraying various Group A herbicides and follow-up treatment with paraquat (double knocking) and other standard treatments.***

The aim of this experiment was see if commercial control of serrated tussock could be obtained with the highest boom spray label rates of Group A herbicides. An additional application of paraquat was made to some of the Group A treatments to assist with desiccating the foliage. This practice is commonly used in cropping systems to effectively control grass weeds in fallows; a practice called double knocking.

Assessments made 4 MAT (Table 4) indicate that control scores for all Group A herbicide treatments were unsatisfactory. This was confirmed by the later assessment made 8 MAT that shows no long term effects from these treatments.

Alternative herbicides glufosinate, amitrole and Alliance®, were equally unimpressive and were culled from any further screening work.

The standard commercial boom spray treatments of glyphosate, and flupropanate produced excellent control. There appeared to be little rate response of either of these herbicides, thus using the lower rate would be adequate. Clearly, this population of serrated tussock is susceptible to flupropanate

2,2-DPA was applied in autumn approximately 4 months after the bulk of the treatments, to ensure it was applied at the most optimum season. This herbicide tends to work best in this season compared to flupropanate that needs to be applied in spring/summer. Despite, making the best efforts to get the best performance from this herbicide, control was just acceptable in terms of commercial acceptability.

Table 4: Effect of boom spraying Group A herbicides et al. on established serrated tussock.

| Treatment | Herbicide Group | Product rate per ha | Control score (0-10) 4 MAT | % biomass killed 8 MAT |
|---|---|---|---|---|
| Clethodim 240 g/L | A | 375 mL | 3.3 | 0.0 |
| Clethodim 240 g/L + paraquat 250g/L | A + L | 375 mL + 2.4 L | 0.7 | 0.0 |
| Propaquizafop 100 g/L | A | 900 mL | 0.5 | 0.0 |
| Propaquizafop 100 g/L + paraquat 250 g/L | A + L | 900 mL + 2.4 L | 1.7 | 0.0 |
| Haloxyfop 520 g/L | A | 400 mL | 0.3 | 0.0 |
| Haloxyfop 520 g/L + paraquat 250 g/L | A + L | 400 mL + 2.4 L | 2.3 | 0.0 |
| Butroxydim 250 g/kg | A | 180 g | 1.5 | 0.0 |
| Butroxydim 250 g/kg+ paraquat 250 g/L | A + L | 180 g + 2.4 L | 3.2 | 0.0 |
| Flupropanate 745 g/L | J | 1.5 L | 6.0 | 94.0 |
| Flupropanate 745 g/L | J | 3 L | 6.8 | 96.7 |
| Untreated | ----- | ----- | 0.3 | 0.0 |
| Glyphosate 450 g/L | M | 2.25 L | 9.3 | 95.3 |
| Glyphosate 450 g/L | M | 4 L | 9.7 | 98.0 |
| Paraquat 250 g/L | L | 2.4 L | 2.0 | 0.0 |
| Alliance® (paraquat 125 g/L + amitrole 250 g/L) | Q + L | 2.5 L | 2.2 | 0.0 |
| Amitrole 250 g/L | Q | 6 L | 0.8 | 0.0 |
| Glufosinate 200 g/L | N | 2 L | 0.7 | 0.0 |
| 2,2 DPA 740 g/kg | J | 5 kg | 0.0 | 58.3 |
| 2,2 DPA 740 g/kg | J | 10 kg | 0.0 | 75.0 |

### *EXP 5: Boom spraying pre-emergence (residual) herbicides – Goulburn.*

This experiment was the first of two pre-emergence experiments designed to find suitable chemistry to prevent serrated tussock from establishing after the control of established plants. The second experiment, located at Bredbo, was required to test the reliability of the successful treatments found in this experiment. Both experiments were initiated by applying suitable rates of glyphosate to control the established serrated tussock plants and allow ample bare soil to promote seedling tussock emergence.

Highest levels of control with pre-emergence herbicides are seen soon after application and control eventually declines as the herbicide is broken over time. Excellent pre-emergence treatments may provide control of weeds up to 3 to 6 months after treatment. For this reason this experiment was assessed up to 16 months after treatment (Table 5).

Table 5: Longevity and efficacy of residual chemistry on serrated tussock control - Goulburn.

| Herbicide | Product rate per ha | Herbicide Group | ST % Kill 8 MAT | Pasture % Kill 8 MAT | Control (0-10) 10 MAT | Control (0-10) 16 MAT |
|---|---|---|---|---|---|---|
| Imazapyr 250g/L | 1L | B | 98.3 | 23.3 | 8.7 | 6.0 |
| Imazapyr 250g/L | 0.5L | B | 98.0 | 40.0 | 8.0 | 6.3 |
| Imazapic 240g/L | 200mL | B | 70.0 | 25.0 | 5.7 | 5.7 |
| Imazapic 240g/L | 100mL | B | 81.7 | 30.0 | 7.0 | 4.3 |
| Imazamox 800g/kg | 50g | B | 73.3 | 13.3 | 7.7 | 4.3 |
| Imazethapyr 240g/L | 400mL | B | 99.0 | 30.0 | 8.7 | 4.3 |
| Imazethapyr 240g/L | 200mL | B | 95.0 | 0.0 | 9.0 | 5.7 |
| chlorsulfuron 750g/kg | 40g | B | 45.0 | 26.7 | 5.0 | 3.3 |
| chlorsulfuron 750g/kg | 20g | B | 51.7 | 3.3 | 6.0 | 4.7 |
| s-metolachlor 960g/L | 2L | K | 48.3 | 51.7 | 4.3 | 3.7 |
| s-metolachlor 960g/L | 1L | K | 81.7 | 41.7 | 6.0 | 4.0 |
| metsulfuron 600g/kg | 20g | B | 40.0 | 10.0 | 2.7 | 2.7 |
| metsulfuron 600g/kg | 10g | B | 23.3 | 6.7 | 5.0 | 2.0 |
| sulfometuron 750g/kg | 100g | B | 93.3 | 71.7 | 4.7 | 3.3 |
| sulfometuron 750g/kg | 50g | B | 60.0 | 43.3 | 8.7 | 7.7 |
| terbuthylazine 750g/kg | 1kg | C | 26.7 | 16.7 | 2.7 | 2.0 |
| pendimethalin 455g/L | 3.2L | D | 65.0 | 23.3 | 3.3 | 1.7 |
| triallate 500g/L | 2L | J | 13.3 | 23.3 | 6.0 | 3.3 |

First assessment of herbicide efficacy, made 8 MAT, revealed that the imidazolinone herbicide sub group of Group B was the most effective. These herbicide active ingredients start with the 'ima' prefix. Another important factor to consider is the effect of the active ingredient on desirable pasture species. Imazethapyr at 200mL/ha was the only treatment to cause no observable pasture damage and control serrated tussock soundly. The higher rate increased the level of control but at the expense of pasture damage. It appears the excellent levels of control were maintained up to 10 MAT but declined notably by the last assessment.

Other herbicides had potential as future serrated tussock treatments. For example, herbicides such as sulfometuron and imazapyr could not be used commercially over pastures due to their high levels of pasture damage and their use as industrial total vegetation control herbicides.

***EXP 6: Boom spraying pre-emergence (residual) herbicides – Bredbo.***

Results from this experiment are comparable with those obtained from Goulburn. The similarity was between the imidazolinone or 'imi' herbicides and their high level of efficacy. Levels of control in this experiment ranged between 88 and 100% (Table 6). At Goulburn the range was 70 to 99% (Table 5). Imazamox appeared to work better at this site and was on par with the imazthapyr treatments.

The flupropanate treatments were applied 11 months prior to the other treatments. Therefore the assessments for these treatments were 14 MAT. Despite the longer period between spraying and assessment, the flupropanate treatments had similar control of seedlings compared to the 'imi' herbicides. This emphasises the benefits of flupropanate; a treatment that can control established plants and give excellent long term control of seedlings.

Table 6: Efficacy of residual chemistry on serrated tussock control – Bredbo.

| Treatment | Herbicide Group | Product rate per ha | ST per m$^2$ 5 MAT | ST % control 5 MAT* |
|---|---|---|---|---|
| imazapyr 250g/L | B | 1L | 0.0 | 100 |
| imazapyr 250g/L | B | 0.5L | 0.0 | 100 |
| imazapic 240g/L | B | 200mL | 1.3 | 90 |
| imazapic 240g/L | B | 100mL | 1.3 | 90 |
| imazamox 800g/kg | B | 100g | 1.3 | 90 |
| imazamox 800g/kg | B | 50g | 1.0 | 93 |
| imazethapyr 240g/L | B | 400mL | 0.3 | 98 |
| imazethapyr 240g/L | B | 200mL | 1.7 | 88 |
| chlorsulfuron 750g/kg | B | 40g | 7.0 | 48 |
| chlorsulfuron 750g/kg | B | 20g | 8.0 | 40 |
| s-metolachlor 960g/L | K | 2L | 25.7 | -93 |
| s-metolachlor 960g/L | K | 1L | 18.7 | -40 |
| pendimethalin 455g/L | D | 3.2L | 16.7 | -25 |
| flupropanate 745g/L | J | 3L | 0.7 | 95 |
| flupropanate 745g/L | J | 1.5L | 1.7 | 88 |
| 2,2-DPA 740g/kg | J | 10kg | 12.7 | 5 |
| 2,2-DPA 740g/kg | J | 5kg | 9.7 | 28 |
| untreated | ------- | ------- | 13.3 | 0 |

*Note: negative numbers indicate an increase in serrated tussock numbers relative to the untreated control.

## DISCUSSION

Flupropanate is an excellent herbicide for various reasons. It can control established perennial serrated tussock plants, with good selectivity and can provide residual control for 6 to 12 months. Its importance within the grazing regions of south eastern Australia is paramount.

The chances of finding another herbicide as good as flupropanate are infinitesimally small. No new modes of action herbicides have been developed since the 1980's. The new molecules developed recently belong in pre-existing herbicide groups. In some cases within the broadacre grains industry the new herbicides developed have flaws as some weeds already have resistance to them due the evolution of various resistance mechanisms derived from overusing similar herbicides.

To lose flupropanate, due to resistance, is disastrous for the industry. The next registered option is glyphosate. It can control serrated tussock but usually with excessive damage to pasture species and would mainly have to be spot treated. If the industry was to be totally reliant on glyphosate for serrated tussock control, there would be enormous selection pressure in the future for selecting glyphosate resistant populations. Therefore we need as many alternative chemical options for control, allowing maximum diversity for farmers and weed officers. Having this diversity will limit the spread of resistant serrated tussock and lessen the risk of new populations developing resistance.

The results within this paper have shown that a small selection of herbicides to have some commercial relevance for control of serrated tussock. These treatments are best summarised in the Table 7.

An application to the national regulator, the Australian Pesticides and Veterinary Medicines Authority (APVMA), for a minor use permit, to use these new treatments, will be sought in late 2015. They will be added to the existing tussock grass permit number 9792.

All Group A herbicides at top label rates were not effective enough as boom spray treatments. In summary, only haloxyfop can only be applied as a spot spray treatment to allow enough active ingredient on the plant for effective results.

Table 7: Commercially viable chemical treatments for control of serrated tussock.

| Treatment | Product application rate | Situation | Herbicide Group | Comments |
|---|---|---|---|---|
| haloxyfop 520g/L | 160mL/100L water | Post-emergence spot treatment of seedling to mature tussocks | A | Not likely to replace the need to spot treat with glyphosate but could do if glyphosate resistance develops. Commonly sold as Verdict® 520. Need to Uptake Spray Oil at 500mL/100L water |
| imazamox 800g/kg | 50g/ha | For residual control of emerging seedlings, applied as a blanket spray after initial control of established plants | B | An excellent option to reduce re-infestation. May need re-application each year to extend control. Safe to legumes but likely to affect small pasture grasses. Sold as Raptor®. |
| imazethapyr 240g/L* | 200 to 400mL/ha | For residual control of emerging seedlings, applied as a blanket spray after initial control of established plants | B | An excellent option to reduce re-infestation. May need re-application each year to extend control. Safe to legumes but likely to affect small pasture grasses. Commonly sold as Spinnaker®. |

*Note: imazethapyr only sold as a 700g/kg formulation, therefore new proposed use rate for the current formulation is 70 to 140g/ha.

There is now some new weaponry in the fight against serrated tussock. Managers of the weed now have chemicals from two alternative herbicide groups, once APVMA approve a minor use permit. It may take some time for these treatments to be used widely in the community as people need confidence in the treatment before they commit to change. For this to occur, it is recommended these new treatments be demonstrated throughout serrated tussock infested regions, particularly in some flupropanate resistant hot spots.

In extreme cases of dense flupropanate resistant infestations these new herbicide options could play a vital role in the management of the weed. A suggested option could be to initially control the infestation with a blanket treatment of glyphosate. This may be done for again to control emerging seedlings six months thereafter to allow enough time for dead biomass to decompose. A legume based pasture should be sown then treated with imazethapyr once legumes are establishing to limit seedling tussock emergence. Lightly scattered seedling tussocks can thus be spot treated with haloxyfop. Once serrated tussock numbers are thinned to extremely low densities, a grass based pasture species can be introduced.

However the challenge is the control of flupropanate resistant populations in non-arable land that is not suitable for pasture improvement. Applying glyphosate in these areas is likely to result in excessive pasture damage. Pasture improvement would be difficult and is likely to be significantly less responsive than arable fertile soil. Accessing these areas to spot or blanket treat herbicides may be prevented by various obstacles.

Although herbicides comprise a large component of serrated tussock control programs, maintaining reliable control for longer periods can be improved by having well maintained competitive pastures. This too, along with these new herbicide options should be demonstrated to weed managers.

## ACKNOWLEDGEMENTS

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# Weed management for conservation
## (and primary industries, and for the community, and for cultural heritage, and for …)
## Where does it end?

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### Introduction

All weed management activities in New South Wales (NSW) can be placed on a generalised weed invasion curve, including weed management conducted for biodiversity conservation. This paper focuses on the latter part of the curve where Asset Protection (AP) is the primary motivation. These activities are generally reported to have lower benefit:cost ratios (BCRs) than those for other parts of the curve.

We contend that some weed management activities for AP have high BCRs, and are comparable to the BCRs for many eradication activities. Although it is difficult to properly account for all benefits and costs, especially with weeds that impact biodiversity conservation. Weed biological control programs often provide asset protection over long periods. Many such programs have reported BCRs exceeding 25:1, with some as high as 3726:1. In addition, weed biological control BCRs are often a 'snapshot' in time and as a result increase (become more cost effective) as the program progresses due to decreasing costs. Furthermore, high BCR ratios are also recorded for many weed management activities (i.e. localised quarantine strategies and eradication in areas outside the invaded zone which contains and reduces the weed to a specified geographic area) in the AP part of the curve.

The history behind the application of BCRs being applied to the weed management curve is examined in this paper. As a consequence, we suggest a more thorough explanation of such applications, when used. This analysis leads into a summary of the key principles learnt from managing widespread weeds as NSW government agencies. We compare and contrast weed management for biodiversity conservation at the AP end of the curve with weed management for AP in primary industries and for the community, including our cultural heritage. We suggest that respective managers of such assets can still learn many things from each other's approaches.

We would like this abstract/paper to be considered for the:

*Weed Management for Conservation symposium*

In particular in the topic area of

*Balancing effort across the Invasion Continuum: How to best invest for biodiversity?*

**Presenters name, organisation and details**:

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(biography to be provided upon paper submission)

Presentation length: 15 minutes.

**EFFECTIVE WEED MANAGEMENT FROM THEORY TO REALITY**

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## ABSTRACT

Weed management can seem overwhelming… "*Where do we start and why there? When should we do the work? What methods should we use? The people in the office telling me what to do don't know what they're talking about! Are we actually achieving anything? And when I finally do the work I find someone else has already sprayed it! Aaaaarrrgh!!!"*

It doesn't have to be this way. NPWS North Coast Region has developed some tools and processes to help empower staff and enable on-ground weed managers to easily access detailed planning information.

The methods being implemented ensure that the highest priority sites are selected; that staff involved in the work have an equal say in annual priorities and actions; that they have enough information to enable them to understand the problem and use best management techniques; that stakeholders are aware of what each other is doing, and that effective monitoring is in place. In combination, these methods help ensure that we are actually winning.

The presentation will discuss a number of issues affecting weed management such as establishing priorities; communication between staff, contractors and volunteers; weed and threatened species identification and management; local strategies; mapping; monitoring, and local case studies.

## INTRODUCTION

There are at least 1665 naturalized plant species present in NSW (RBG unpublished data) and 340 weed species with an ability to have a significant impact on biodiversity in the state (Downey *et. al*. 2010). The NSW North Coast is particularly threatened by establishment and growth of weed species due to its high rainfall, warm temperatures and generally fertile soils.

The reserve system in North Coast Region protects significant landscapes, including beaches, rocky shores and off-shore islands, coastal floodplains and estuaries, forested river gorges and valleys, spectacular sections of the Great Escarpment and plateau woodlands. There is a diversity of plant and animal communities in these reserves, including world heritage rainforests and old-growth eucalypt forest, as well as significant sites of Aboriginal and historic heritage. Land-use patterns, past and present, together with the diversity of natural environments have resulted in a range of weed species in these parks and reserves (OEH 2012).

The main objective of pest management within the NSW National Parks and Wildlife Service is to minimise the impacts of pest species on reserves and neighbouring lands and to work with other agencies and landholders to achieve these aims. However, given the complexity of species, environments and impacts and the limited resources available, it is critical to view these actions in a strategic context to focus limited resources on the most effective pest management (OEH 2012).

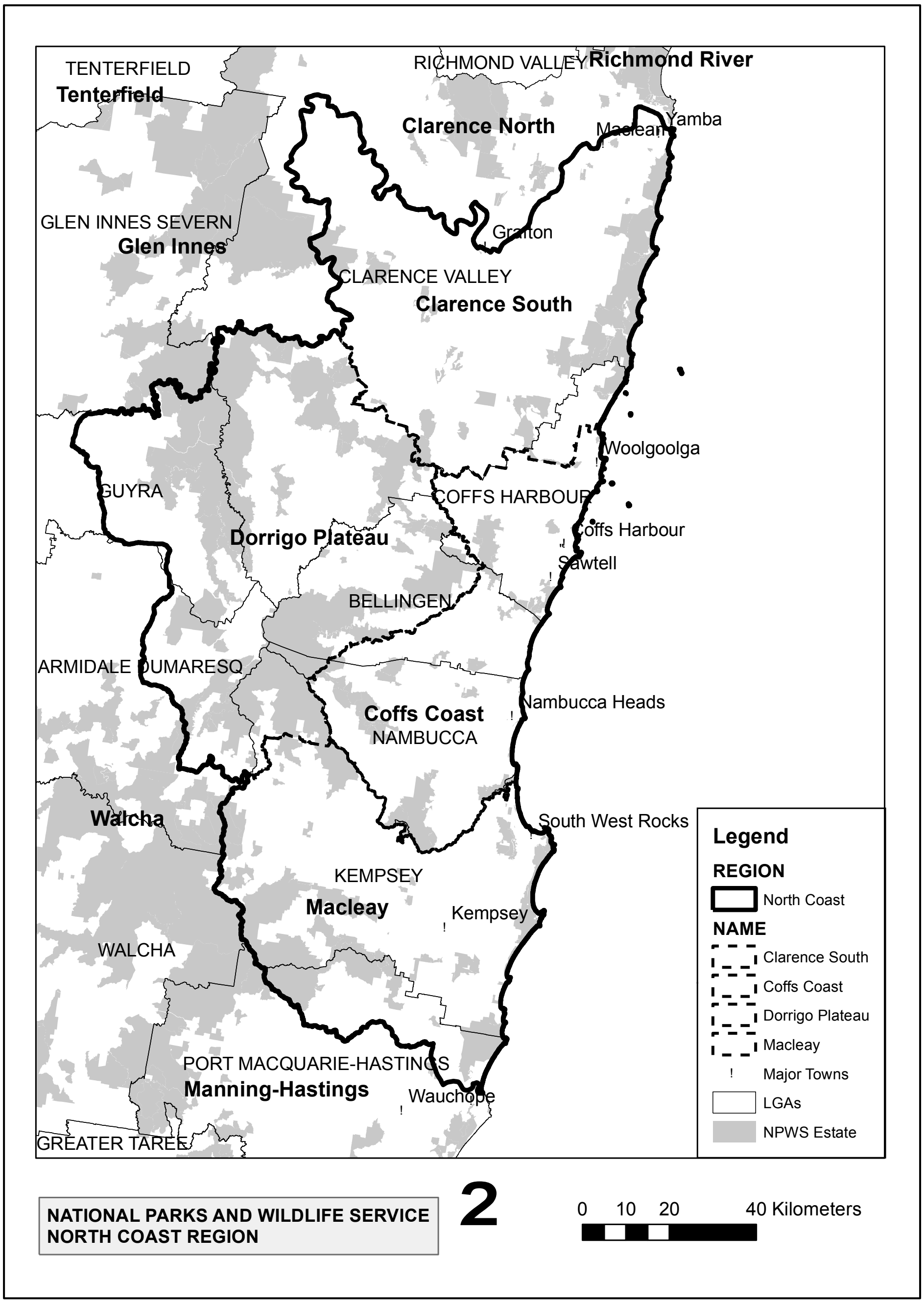
Pest management within the Office of Environment and Heritage (OEH) is guided by two core planning instruments:

- *NSW 2021 – A Plan to Make NSW Number One* sets out performance targets, including a specific priority action within *Goal 22 Protect Our Natural Environment* which is to *address core pest control in National Parks through the delivery of NPWS Regional Pest Management Strategies and improve educational programs and visitor access*.
- *NSW Invasive Species Plan* provides specific goals, objectives and actions in relation to invasive species management.

The NSW-based strategy, Managing Pests in NSW National Parks (DEC 2006), details the planning framework for the management of pests by NPWS. It documents the policy and organisational context and describes the logic used for identifying, prioritising and monitoring pest management programs. It also establishes state-wide pest management goals, objectives and actions. Regionally specific components including specific prioritised pest programs are detailed in Regional Pest Management Strategies such as the North Coast Region Pest Management Strategy (OEH 2012).

The National Parks and Wildlife Service (NPWS) North Coast Region includes 97 reserves covering an area of over 430,000 ha. Within the Region there are four Areas. This paper focuses on the work achieved in Coffs Coast and Dorrigo Plateau Areas; within the LGAs of Coffs Harbour, Bellingen, Nambucca and parts of Clarence Valley and Armidale-Dumaresq (see Figure 1), in implementing the above mentioned strategies and reducing impacts on the unique values of the region from weed species.

**Figure 1**: Map of NPWS North Coast Region



The two Areas employ 35 Field staff who undertake a variety of operational works including weed and pest management. In addition, the two Areas employ weed contractors and bush regenerators and work with 19 volunteer groups such as Landcare.

## PLANNING

### Priority location review

Weeds are a common component of the landscape on the NSW North Coast. Human nature means that staff will be most likely to control every weed near the park entrance but extremely rare plants, Endangered Ecological Communities and other assets away from the road may be missed. NPWS have a requirement to protect these important assets through the *National Parks and Wildlife Act (NPW Act) 1974* and the *Threatened Species Conservation Act* (TSC Act) *1995.* An overall assessment of important assets was required to ensure that important areas were being protected. This is particularly important due to the general reduction in resources for weed management in recent years.

Important assets within North Coast Region were listed on a spreadsheet and mapped on Arcmap® GIS for each Area. The respective priority of each work site was assessed using the following criteria:

<u>Endangered ecological communities</u> (as listed under the TSC Act)

- Number and condition of Endangered Ecological Communities occurring at the site

<u>Significance</u>

- Threatened flora recorded from the site and / or quality of habitat
- Threatened fauna recorded from the site and / or quality of habitat
- Presence of old growth forest
- Presence of “pristine” or weed free areas
- Aboriginal significance of the area
- Historic sites recorded in the area
- Presence of high scenic values
- Public profile of the site
- Visitation of the site
- Community support for work at the site (e.g weed issues in general area identified by Council Noxious Weeds Officers, presence of a nearby Landcare group or interested neighbours)

<u>Weeds present at the site</u>

- Threat posed by the weeds at the site based on their respective weed risk assessments

<u>Other weed issues at the site</u>

- Recent hazard reduction burns or wildfire occurring at the site
- Presence of new or emerging weeds
- Whether weed control at the site will provide strategic benefit to other areas (eg is treatment at the head of the catchment?)

<u>Weed control efforts – past, present and future</u>

- Assessment of the current impacts of weeds on the site
- Previous weed control investment at the site
- Future weed control investment that is required

The results of the above assessment now form part of the NPWS North Coast Region Pest Management Strategy (OEH, 2012). Due to the strong focus of the assessment on the ecological, social and economic significance of the locations, the outcomes of the assessment are that some of the highest priority sites in the Region do not actually have many weeds present. Regular inspections are undertaken at these sites and they are listed as an extremely high priority should threatening weeds invade these areas.

**Annual weed planning meeting**

The most important component of good weed planning for the Region is the annual Weed Planning meetings. These meetings are attended by all staff involved in weed management – Pest Management Officers, Rangers and Field Officers – with all staff having an equal say on priorities for each job. A Technical Officer is also present to assist with Arcmap® GIS mapping of all work sites.

The aims of the meetings are to establish priorities and confirm details for all completed and proposed weed programs in each Area; whether they be completed by NPWS staff, contractors (through either internal or externally sourced funding) or volunteers. At the meetings discussions confirm mapping of all works undertaken by NPWS staff, contractors and volunteers over the last year, reserve by reserve.

All proposed programs for the following year are discussed and the following details confirmed:

- Main weeds present
- Main techniques to be used
- Best month(s) for control
- Any issues re: chemical sensitivity of nearby residents
- Any specific site issues such as threatened species, erosion or recent fires
- Site location map
- Relevant priority of each job where 1 = Must be done; 2 = Should be done; 3 = Would be good to do; 4 = May be done if time permits, and; 5 = Probably won't get done.

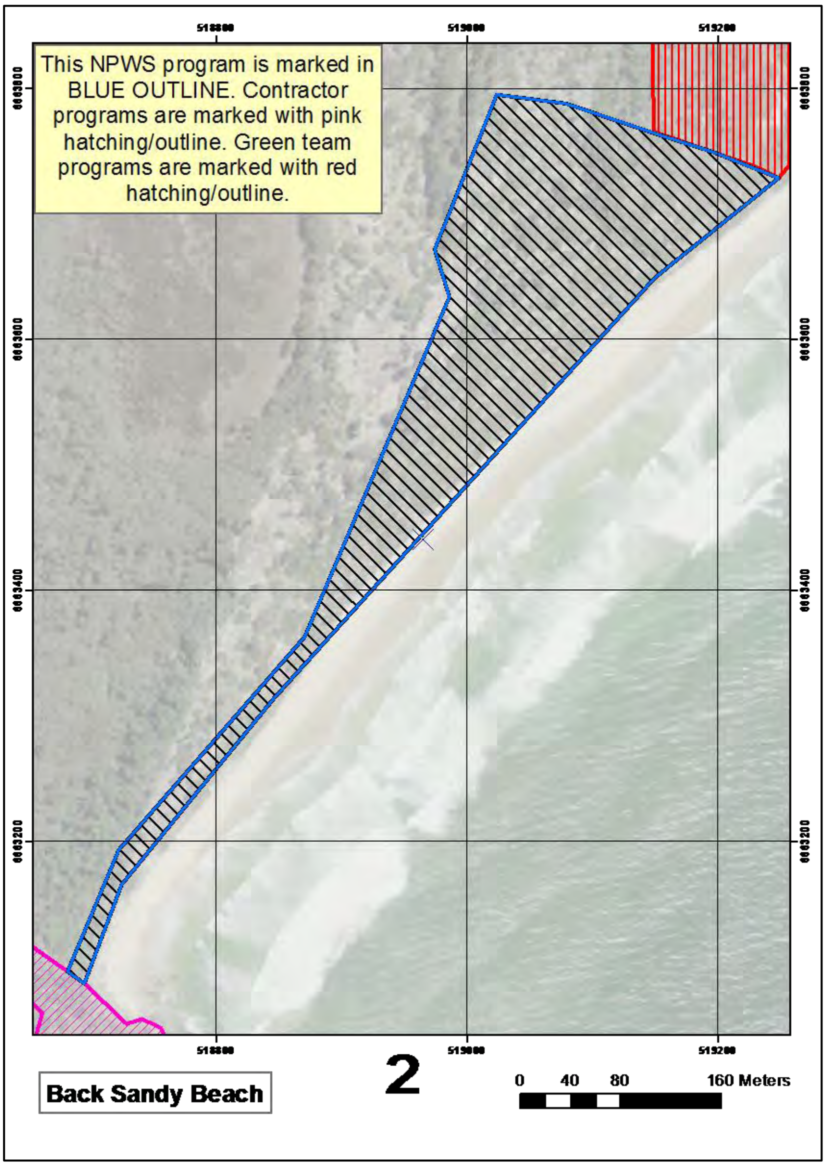
**Summary spreadsheet**

The outcome of the meeting is a plan (in the form of an Excel® spreadsheet) that lists all proposed staff, contractor and volunteer programs for the year, sorted by reserve. By clicking on the "Site name" a pdf map of the work site is produced (that includes other nearby staff, contractor and / or volunteer works)(Figure 2).

The summary spreadsheet and associated maps are sent to all relevant NPWS staff, contractors, Landcare and Local Council's Noxious Weeds Officers.

The spreadsheet and maps are updated during the year as required if additional funding is obtained.

**Figure 2**: Example of a work site map – Back Sandy Beach, Moonee Beach NR




**Local weed strategies and restoration plans**

Some sites are complex – they may support a number of different threatened species, have emerging weed species that may not be widely known, are managed by several stakeholders or have significant investment. Local site plans help summarise important information relevant to the site and outline the steps required to restore the site, in priority order.

Wherever possible, Local Site Plans should be one double sided A4 page in size – with relevant information on one side and a map on the reverse side.

**TRAINING**

NPWS staff have a variety of qualifications however most staff have not had previous weed management or bush regeneration training. A two day course in bush regeneration was conducted for Rangers and Field Officers in 2009. Staff completed three units of study as part of Conservation and Land Management qualifications; ‘Carry out natural area restoration’, ‘Work effectively in the industry (Core study)’ and ‘Treat weeds’. The training was relatively inexpensive and mostly completed “in the field” rather than in a classroom.

The course helped staff assess what techniques were best to use for different situations, improved their knowledge of various techniques such as cut and paint and tree frilling, and reduce impacts on non-target species when spraying herbicides.

**ON-GROUND TOOLS**

Best management practices
The Best Management Practices document lists the most appropriate control techniques including those listed in relevant off-label permits for all common weed species in the Region. The document is updated annually or as required as new Off-label Permits are issued, new control techniques developed or new herbicides released. The document helps standardise the techniques being used but includes a range of techniques to be used, depending on the specific situation.

Threatened species guides
Some work sites support as many as four threatened species and two endangered ecological communities. Not everyone can be expected to know what they look like. Threatened species guides were produced that include photographs and information on identification, general location and a specific readily accessible location (e.g a prominent track intersection) where staff can see the species in the bush and better learn how to identify it.

Weed control trials
Weed control trials are required from time-to-time to refine best management techniques. Glory lily trials were recently completed. A trial currently being conducted in-conjunction with Bellingen Shire Council is investigating the use of Bioweed™ and the addition of Fulvic acid to glyphosate and metsulfuron, methyl-based herbicides for control of riparian environmental weeds in one trial, and introduced grass and annual weeds in a “park / lawn” environment in another trial.

**IMPLEMENTATION**

A total of 204 weed control / bush regeneration / restoration programs were completed in 2014-15; 164 in Coffs Coast Area and 40 in Dorrigo Plateau Area.

The relative priority of the programs implemented are summarised in the table below. Although it is always hoped that 100% of Priority 1 projects will be completed, it is acknowledged that local logistical issues may arise during the year resulting in some jobs not being able to be completed whilst “windows of opportunity” may also arise for jobs initially considered to be of a lower priority.

**Table 1**: Summary of weed control programs in Coffs Coast and Dorrigo Plateau Areas, 2014-15

| Priority | Proposed | Completed | % |
|---|---|---|---|
| 1 | 125 | 119 | 95 |
| 2 | 62 | 47 | 76 |
| 3 | 36 | 25 | 69 |
| 4 | 22 | 11 | 50 |
| 5 | 7 | 2 | 29 |
| TOTAL | 252 | 204 | 81 |

Implementation of each program is tracked through the SAP® Asset Maintenance System, where work orders are created for each job, and when they are completed data such as work hours and budget expended are entered against that work order.

Each Depot has a folder with all relevant Work Orders and maps for each job assigned for that month. When staff are assigned to weed control for that day they generally open the folder and start implementation with the highest priority jobs, although of course some jobs require considerable planning, especially if they involve lengthy travel, initial site preparation (eg for tree planting) or use of heavy plant or helicopters.

Whilst in the field, staff carry:

- a Chemical record sheet which includes a map of the work site on the back. At the completion of the job they may need to adjust the mapped work area with a pen if it differed from what was actually undertaken
- the work order which summarises the work to be done at the site
- other requirements such as relevant Off-label permits.

All staff, contractors and volunteers have copies of maps highlighting their work area. If they work outside of these areas, or very close to other stakeholder's work areas, they need to contact that stakeholder and inform them so that the same area is not sprayed twice or important areas missed.

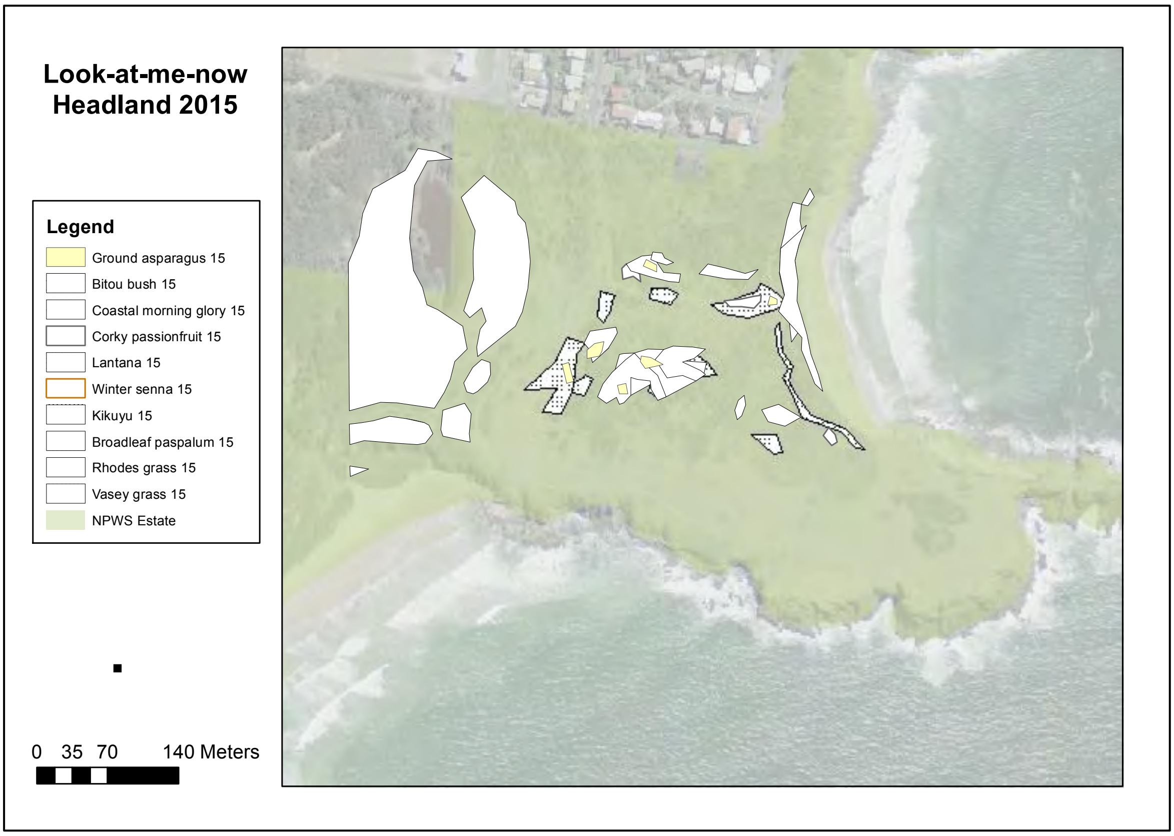
**MONITORING: INCLUDING A NEW APPROACH TO MEASURE VEGETATION CONDITION**

The success of each program is reviewed in the Annual Weed Planning Meeting in June. Throughout the year, Area Managers are able to assess progress by reviewing completion rates of proposed "Priority 1" programs for that month.

Arcmap® GIS maps of completed works are compiled on the NPWS "Pest and Weed Information System" (PWIS). The data for each year is able to be analysed using the PWIS dashboard.

For very high priority work sites and those where external funding has been obtained, restoration success is monitored using "Line intercept" site transects, photo points and, in some cases, quadrats (as per Hughes *et. al.* 2009) and weed / threatened species mapping (e.g Figure 3).

**Figure 3**: Comparison of weed distributions at Look-At-Me-Now Headland, Moonee Beach Nature Reserve in 2007 and 2015. The main changes are a dramatic reduction in woody weeds but continuing infestations of introduced grasses, particularly in areas heavily grazed by Eastern Grey Kangaroos.

Monitoring is an essential component of weed management and restoration programs, however each of the above tools have limitations. These are summarised below.

Assessment of the mapped areas is very time consuming, and to be truly effective needs to include mapping of different growth stages, otherwise the weed species will be highlighted as still being present even though all mature plants may have been controlled. This results in a very "busy" map. Assessment of the numbers of programs implemented, or implementation of Priority 1 programs does not provide qualitative feedback. It does not inform you if all issues have been addressed or whether native species are indeed replacing the weeds that have been controlled. Are they just being replaced by other weeds?

Site transects, photo points and quadrats are a very useful way to review the impact of the action on specific weeds and native species at the site, however their limitations include:

- they are very time consuming to establish
- multiple points / transects / quadrats are required at each site in order to be able to give a good picture for the overall site
- marker posts are often stolen, hence it can be hard to accurately locate them again
- human nature dictates that these locations are the ones where the most thorough work is undertaken whilst other areas may not receive as much work.

A rapid assessment of the "Vegetation Condition" of each site has been developed to better monitor the success of management. The assessment records the condition of the vegetation and not just the presence / absence of weeds.

Vegetation within the Condition Assessment is categorised as either:

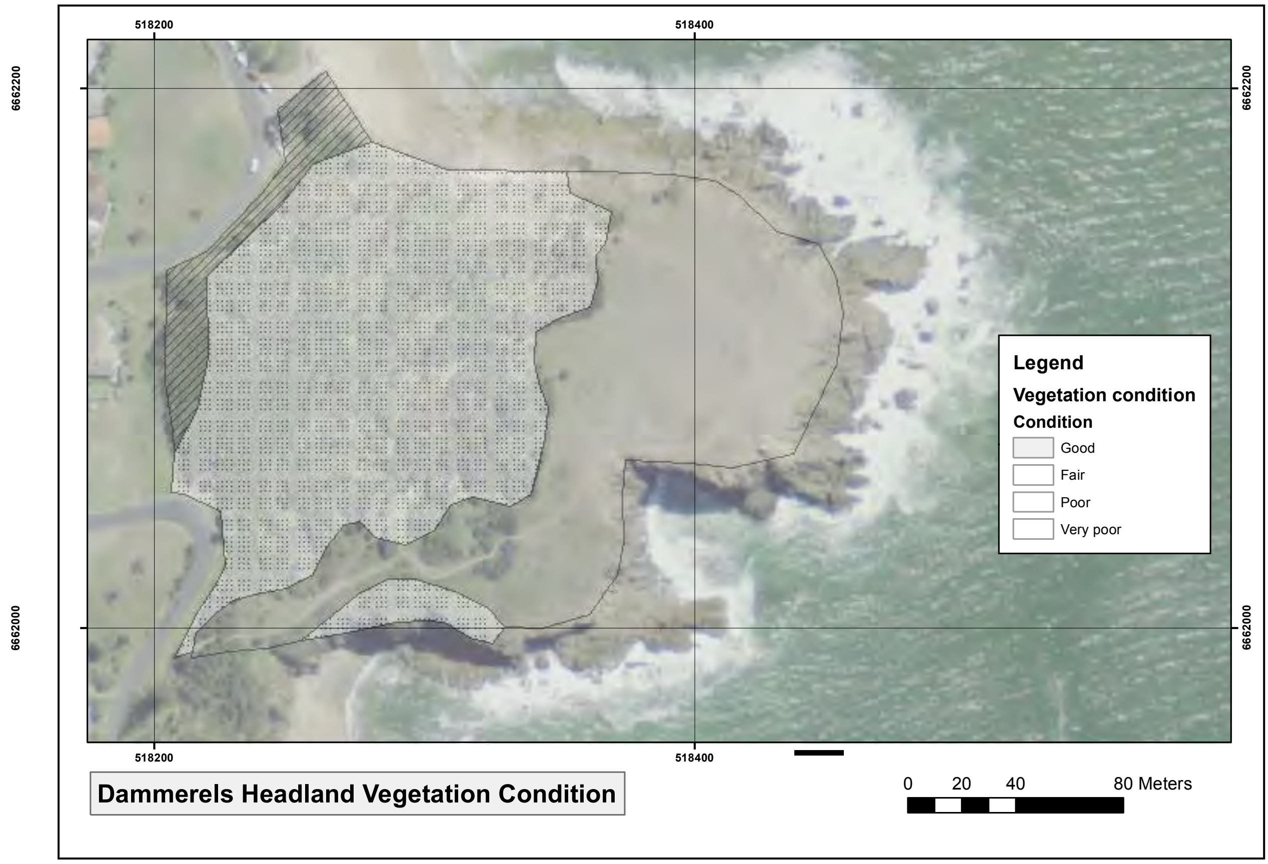
Good – Virtually weed free, structure / species composition and diversity typical for that community
Fair – Minor infestations of weed species, structure / composition mostly intact
Poor – Severe weed infestations, poor native regeneration and / or structure
Very poor – Virtually native-free! Missing most stratums, very limited regeneration

The negative of this approach is that weed management may have been undertaken and been 100% successful but the assessment only progresses from say "poor" to "fair" because there are still no mature native tree species at the site.

Despite these limitations, it is considered more important to look broadly at the condition because the focus must always be on protection and restoration of "the asset or value" (eg littoral rainforest, Themeda grassland), and not just about control of the weeds. Weed control can be a waste of time if there are no native species to take their place. Other management may be required such as tree planting.

Vegetation condition assessments have commenced with the highest priority locations. It is hoped to complete the assessment at each work site by June 2016. The assessment is being undertaken by the Pest Management Officer with as many staff as possible so that they become familiar with the technique and learn to use it when assessing their work sites prior to, and at the completion of, works.

**Figure 4**: Vegetation Condition Assessment for Dammerels Headland, Moonee Beach Nature Reserve




## DISCUSSION

NPWS North Coast Region Coffs Coast and Dorrigo Plateau Areas invest considerable resources into pest and weed management; including approximately 25% of Field Officer time. A number of tools have been developed to assist staff to implement best practice weed management. The outcomes of this are listed below, and how they relate to the seven key principles of the Australian Weeds Strategy (NRMMC 2007):

- The highest priority locations were selected through a clear scientific assessment. New and emerging weeds and assets most susceptible to impacts by weeds (such as threatened species populations and locations with few or no weeds present) are listed as "critical priorities" for management, This implements "*Principle 3. Good science underpins the effective development, monitoring and review of weed management strategies*", "*Principle 4 - Prioritisation of and investment in weed management must be informed by a risk management approach*", and "*Principle 5 - Prevention and early intervention are the most cost effective techniques for managing weeds*".
- Decisions on management and priorities are being developed in consultation with all relevant staff, and other stakeholders through field visits and regular meetings. This implements "*Principle 2 - Combating weed problems is a shared responsibility that requires all parties to have a clear understanding of their roles"*.
- Programs are being coordinated with other stakeholder programs through sharing of information regarding all proposed programs, and networking with relevant bodies such as the North Coast Weeds Advisory Committee. This implements "*Principle 6 - Weed management requires coordination among all levels of government in partnership with industry, land and water managers and the community, regardless of tenure*".

- Processes have been put into place to ensure that relevant legislation such as the *Pesticides Act 1999*, the TSC Act and the NPW Act are being adhered to such as guidelines that need to be followed "before leaving the depot", "whilst in the field" and "upon returning to the depot". This helps implement "*Principle 1 - Weed management is an essential and integral part of the sustainable management of natural resources for the benefit of the economy, the environment, human health and amenity*".
- Staff are supported through appropriate training and other assistance such as specialist plant identification, site-based restoration plans, threatened species identification guides and weed control trials and helps ensure that integrated best management techniques are utilised. This implements "*Principle 7 - Building capacity across government, industry, land and water managers and the community is fundamental to effective weed management*".
- Weed programs are being monitored through a variety of techniques that assess not just whether specific weeds have been controlled but the overall change in condition of the vegetation and ecological community. This also helps implement "*Principle 3*".

But the big question is "Are we winning?" in relation to the growth and impacts of weeds in the Region.

This will always be a difficult question to answer due to new weeds continually being introduced into the Region, regular disturbance in some areas and the many goals of weed management (and conflicting views of what those goals should be by different members of the community).

The overall distribution of weeds, including those classified as "new and emerging", are certainly being reduced at the highest priority work sites, however the overall impacts of that management on the vegetation and ecological communities occurring at the sites will not be known until follow up Vegetation Condition Assessments are conducted in three years' time.

**ACKNOWLEDGEMENTS**

I wish to thank Pete Turner, Denise Allen, Alan Jeffery and Hillary Cherry for comments on the Draft manuscript, and to NPWS North Coast Region staff for their dedication, hard work and commitment to effectively managing the Region's reserves on behalf of the wider community.

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# Cabomba control for the protection of the Ramsar listed Myall Lakes

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**Summary** This report summarises the results of a weed control project for the protection of the Ramsar listed Myall Lakes. Information is drawn from Caring for our Country (CFOC) annual reports, monitoring results and interviews with key stakeholders. During the project, significant gains were made towards achieving the key project goals of eradicating cabomba (*Cabomba caroliniana* A.Gray) to protect the Myall Lakes, increasing landholder and indigenous capacity to manage cabomba, and contributing to national best practice initiatives for controlling cabomba with herbicides.

This report details the first broad scale use in Australia of the recently registered Shark™ herbicide (240 g $L^{-1}$ carfentrazone-ethyl) against the Weed of National Significance (WoNS) cabomba. Significant inroads into reducing the extent of cabomba infestations were made, however further efforts are still required. For a more detailed account of the project, download the comprehensive 'Cabomba Control Case Study 2011–2013 for the protection of the Ramsar listed Myall Lakes' at Councils website http://www.greatlakes.nsw.gov.au/Environment/Plants_Trees_and_Weeds/Weeds.

**Keywords** *Cabomba caroliniana*, herbicide control, SharkTM, carfentrazone-ethyl, Ramsar, Myall Lakes.

## INTRODUCTION

**The project partners** This project was a joint initiative between the Mid North Coast Weeds Cocoordinating Committee (MNCWCC), Great Lakes Council (GLC), New South Wales Department of Primary Industries (NSW DPI) and the National Aquatic Weeds Management Group (NAWMG).

**About cabomba** Cabomba is an aquatic plant native to South America. It is fully submerged except for occasional floating leaves and emergent flowers. It is identified by: its characteristic fan shaped leaves that are arranged oppositely on the stem; white flowers that emerge from the water; and a seasonally purple stem during the warmer months, especially when growing in full sun.

Cabomba was introduced to Australia through the aquarium industry as an ornamental and oxygenating plant for aquariums. It was first found naturalised in Australia in 1967 and has since spread to over 100 sites across eastern Australia. Its sale is now banned in all Australian states and territories.

Cabomba has the potential to cause significant impacts to water bodies. It can form dense underwater monocultures that affect the biodiversity and function of wetland and riparian ecosystems. It decreases water quality, interferes with water storage, distribution and infrastructure, and negatively impacts on the recreation and amenity values of water bodies.

**Local infestations** Cabomba was first discovered growing in the Great Lakes Council Local Government Area *c.* 1995 in a wetland at a retirement home in Forster. Between *c.* 1995 and 2011 an additional nine infestations totalling approximately 16 hectares were found in the Great Lakes Council Local Government Area and the southern reaches of the Greater Taree City Council Local Government Area, as a result of local council property inspections or self-reporting by the land owners.

**Necessity** A do nothing approach with cabomba management in the region, would potentially result in the further spread to key waterways, including the freshwater sections of the Ramsar listed Myall Lakes National Park and the 2200 million litre Bootawa Dam which is the main potable water supply for the Manning Valley of New South Wales.

Limited effective management options were available for the treatment of cabomba in Australia, especially in the high rainfall environment of the mid north coast of NSW. Up until 2011 a control program for cabomba was not feasible due to the lack of suitable control strategies for infestations in this region.

## PROJECT CONCEPT

**Management options** Management options for the control of cabomba were considered to be limited. Drawdown (draining of water bodies) was considered unsuitable due to the high rainfall climate of the Great Lakes region. Mechanical removal of the cabomba utilising aquatic weed harvesters, or control of the weed using shade provided by floating and benthic blankets was tedious and time consuming and unlikely to provide a long term management option.

**Herbicide availability** Since the suspension of the registration of AF Rubber vine Spray™ (800 g $L^{-1}$ 2,4- D n-butyl ester) in 2004, no registered herbicides were available for the treatment of cabomba in Australia. Between January 2008 and June 2010 New South Wales Department of Primary Industries in partnership with Great Lakes Council and other stakeholders undertook a national project to find a suitable herbicide for the effective control of cabomba and to seek its registration nationally.

**Registration** Shark™ herbicide (240 g $L^{-1}$ carfentrazone-ethyl) proved to be very effective (Officer *et al.* 2009) and in 2011 was subsequently registered for use on cabomba. The registration of Shark provided weeds managers with a much needed tool to control this weed. Shark is a contact herbicide with no systemic properties. It works by attacking the fats and proteins of the plant cell membranes. It does not translocate through the plant and requires a good level of contact with the plant biomass to achieve control.

**Funding** In 2011 with the impending availability of Shark, Great Lakes Council partnered with the Mid North Coast Weeds Coordinating Committee successfully applied for $191,760 from the Australian Government's 'Caring for our Country' program to implement a two year project to control cabomba and prevent its spread to high value water bodies, build landholder and indigenous capacity to manage cabomba, and refine herbicide management techniques for cabomba.

**Steering committee** A project team consisting of representatives from Great Lakes Council, Mid North Coast Weeds Coordinating Committee, Macspred Australia, New South Wales Department of Primary Industries and the National Aquatic Weeds Management Group was established to oversee the implementation of the project and the roll-out of the Shark herbicide. This project commenced in late 2011 and concluded in June 2013.

## PROJECT SCOPE

**Planning** The project aimed to target the ten known cabomba sites that were located within a 50 km radius of Myall Lakes National Park. These infestations had the potential to spread to the parks wetlands and other high value water bodies in the region through floodwaters, as a contaminant on eel traps, or via the backyard trading of ornamental aquatic plants collected from infested sites.

Herbicide control was selected as the primary treatment method for cabomba by the project Steering Committee, as it was the most cost effective. Given the climatic conditions of the region and environmental conditions of the individual sites, the use of Shark provided a greater likelihood of eradicating infestations than any of the other control methods.

On ground control programs aimed to reduce the biomass of cabomba infestations to less than 1% of their original size within the two year time frame with a longer term goal of eradication.

One landholder, however, had concerns over the use of herbicides killing exotic water lilies on their dam, and subsequently withdrew from the offer of assistance within the scope of the project. The project team, in conjunction with National Parks and Wildlife Service, will be pursuing adequate control of cabomba in this water body over the coming years through negotiations with the landholder and, if necessary utilising the functions of the New South Wales *Noxious Weeds Act 1993*.

**Data collection** Prior to the commencement of the control program, baseline data on the size and density of the infestations was collected. Baseline data on cabomba density (percentage cover) was collected through visual estimates and samples. Sampling entailed the use of two separate devices for gathering cabomba from strategic locations on the floor of individual water bodies. These samples were washed, dried and weighed so later comparisons could be made to measure the effectiveness of subsequent treatments.

In addition to sampling, photo points were established at each site to provide visual records of the changes to cabomba density pre- and post-treatment.

Accurate measurement of water body volumes was essential to ensure that compliance with chemical label requirements was met, and to maximise the effects of the herbicide.

Water body volumes were assessed by mapping dam depths, and combining these profiles with the surface areas of each dam. Both infested and non-infested sections of each dam were mapped concurrently. All gathered data was used to calculate the amount of chemical needed to conduct an individual treatment.

**Implementation** Larger water bodies were broken into management units to assist with the precise delivery of herbicide mixtures to the respectively mapped areas.

Some ponds required pre-treatment of non-target vegetation (e.g. *Eleocharis sphacelata*, *Eleocharis acutus*, *Philydrum lanuginosum*, *Nymphaea* species, *Ludwigia peploides* ssp. *montevidensis*, etc.) with aquatic registered glyphosate formulations of up to 1.3% concentration. This was done to either provide improved access to cabomba, manage low dissolved oxygen issues, reduce herbicide costs or increase the efficacy of Shark by limiting wastage on non-target vegetation.

Shark herbicide was applied only where cabomba was present, at a rate of 2 ppm (active ingredient) to a maximum of 50% of each water body, as per label directions.

Due of the broad geographic and micro-climatic variations between the individual areas, each site posed its own unique challenges for the management team. Consequently, every treatment was a learning experience as site specific delivery techniques had to be developed, often on the fl , to overcome each sites challenges.

**MERI (Monitoring Evaluation Reporting and Improvement)** Following the herbicide treatments, each site was monitored by the landholders for any adverse effects. All sites were inspected post-treatment by members of the project team at strategic intervals.

Information gathered during monitoring was used in the production of reports, and to identify areas were improvement was necessary.

A comprehensive assessment of each pond was conducted at the completion of the project during September and October 2013 and again in January 2014.

## CAPACITY BUILDING

**Education** Stakeholder capacity building and engagement activities included several community information sessions, field days and media releases, plus the erection of interpretive signage, training of indigenous workers and involvement of landholders in on-ground works and monitoring.

**Community engagement** The project had a strong emphasis on working with landholders, who provided the project team with in-kind support where requested. These contributions included the provision of on ground assistance during treatments, visual monitoring of waterways post herbicide treatment, before and after photography, and storage and maintenance of plant and equipment.

## RESULTS

**Treatments and monitoring** All sites were originally scheduled to be treated in Summer 2011/12. However adverse weather conditions postponed treatment of smaller ponds until late March 2012. Treatment of the larger water bodies was further postponed until January 2013, in an attempt to mitigate wastage of the herbicide and to comply with label requirements.

The herbicide control program has resulted in effective control of cabomba at all of the targeted sites, with each reduced to less than 1% of their original density by January 2014.

**Table 1.** Percentage of cabomba cover within infestations of the project area.

| Site Name | Size (ha) | Cabomba cover (pre-treatment) |
|---|---|---|
| Charlotte Bay | 0.3 | 66% |
| Golden Ponds (4 ponds) | 2.0 | 80% |
| Mayers Flat | 5.0 | 66% |
| Nabiac 1 (East) | 2.0 | 50% |
| Nabiac 2 (West) | 3.8 | 80% |
| Tea Gardens 1 | 0.5 | 100% |
| Tea Gardens 2 | 0.5 | 100% |
| Topi Topi | 0.5 | 33% |
| Wootton 1 | 0.5 | 50% |
| Wootton 2 | 1.5 | 50% |

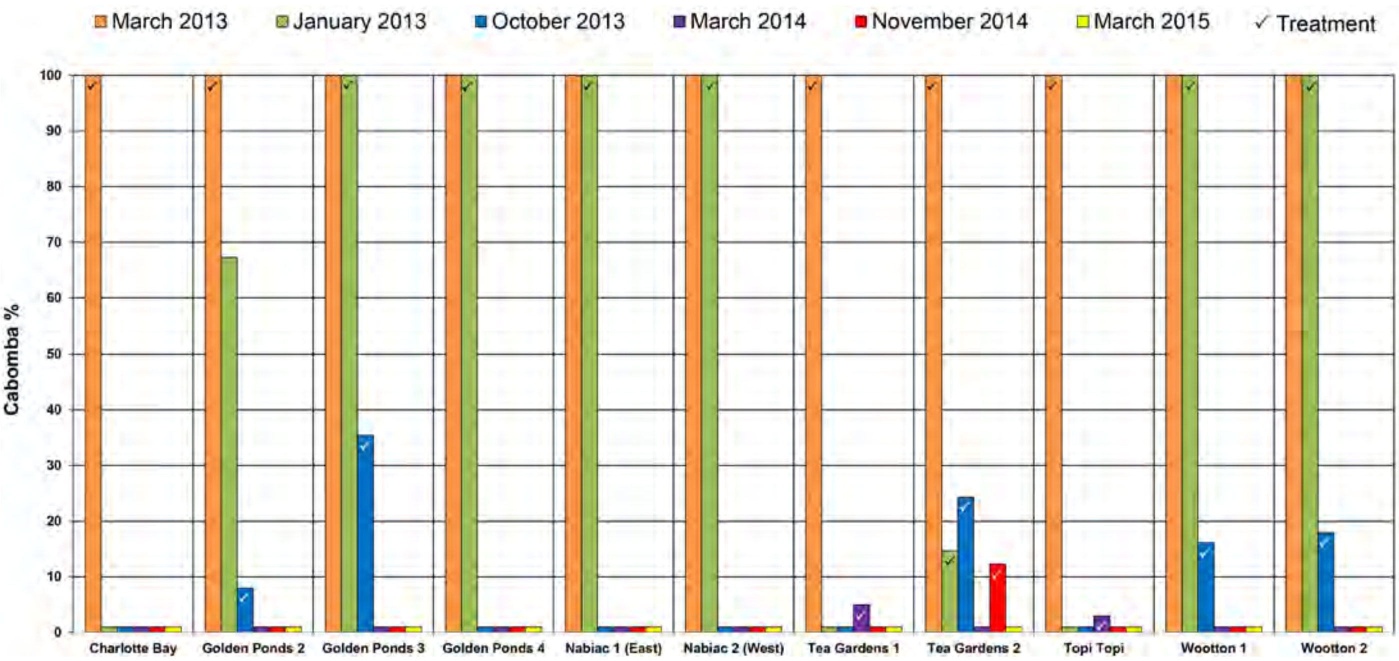


**Figure 1**. Effect of respective herbicide treatments on cabomba density at monitoring intervals.

## BEST PRACTICE MANAGEMENT

This project was the first opportunity for broad scale use of the herbicide Shark following its registration in late 2011.

As such the project pioneered some innovative herbicide application techniques and learned some key lessons about this herbicides effectiveness against cabomba.

**Mixing technique** The project team identified that a 'water penetration' and 'mechanical mixing technique' provided a far more effective means of treating cabomba than herbicide broadcasting.

This technique helps improve the deep distribution of the herbicide throughout the water column, which is important for cabomba control.

Broadcasting of chemical onto the water surface fails to provide adequate mixing throughout the water body and results in a poor kill of cabomba.

Injecting the herbicide into the water at high pressure (15–20 bar with a 3 mm nozzle) helped the herbicide break through the surface tension of the water being treated.

Different methods were used to ensure the chemical mixed rapidly within the water column. Applying the herbicide close to the motors propeller, enabled it to mix through the water column more efficientl . Traversing the boat through the treatment area immediately after application also assisted with mixing.

**Physical obstacles to control** Treatment sites were often plagued with old tree stumps, branches and palm fronds, many of which were not visible from the surface. Fallen branches sometimes impeded the use of motors for propulsion, which caused problems for fluent navigation

Branches in the water often meant the need to use ropes to move the spray platform around and also made sampling a challenge.

The use of propellers through cabomba leads to fragments in the water. These fragments can foul the intakes on water-cooled motors leading to overheating problems. This was overcome by the use of an electric motor, which enabled improved access to even the densest infestations.

Non-target vegetation, when it was co-inhabited with cabomba, was pre-treated with aquatic registered glyphosate mixes four to six weeks prior to the cabomba treatments. Pre-treatment provided better access for watercraft, helped prevent low dissolved oxygen issues, and reduced the amount of non-target vegetation that would otherwise absorb the Shark herbicide, ensuring more Shark was available for uptake by the cabomba plants.

**The treatment window** For effective control, the cabomba needs to be actively growing. This means treating in late spring and summer is the optimum treatment window.

In most cases Shark treated cabomba was still declining three months after treatment (late summer or autumn). Because the cabomba was not showing signs of recovery we found only one treatment per year was possible at the treated sites.

It was common practice during this project to use tank mixes of around seven to eight litres of Shark in 100 L of water to treat a surface area of approximately 800 $m^2$. If physical challenges were present in a particular area, the water volume was increased to 150 or 200 L to ensure adequate coverage of the chemical throughout the section of the water body being treated.

**Water quality and daylight hours** As Shark is light dependent, ideally at treatment time the water will have low turbidity. This means there are low levels of inorganic or organic solids suspended in the water column allowing maximum penetration of light. The higher the turbidity the less effect the chemical may have on its target. Avoid treating cabomba when you cannot see a Secchi disk at a depth of 45 cm.

It is also important not to begin treatment too late into the day. The more daylight hours available immediately after application of the chemical, the better the results will be.

Sections of a water body which are shaded throughout the day should be treated prior to treating areas that receive full sun.

**Adverse weather conditions** Rescheduling programmed treatments when rainfall events have been predicted is a difficult call, especially when taking into account inaccuracy of both long and short range weather forecasts, and the potential of missing windows of opportunity in regards to optimum treatment times within a growing season.

Delaying treatments in a growing season could lead to missed opportunities for up to a twelve month period. On the other hand, careless applications could lead to increased treatments adding further cost to an already expensive program.

Where there is potential for significant rainfall to flush the herbicide from water bodies, careful consideration needs to be given to delaying control, especially when treating large areas where a lot of chemical is required to achieve the desired 2 ppm concentration.

## CONCLUSION

Sound planning and thorough monitoring is imperative for a successful project.

Approach each water body knowing that the control program may need to be tailored to address unique or site specific challenges

Herbicide treatment of exotic water lilies (*Nymphaea* spp.) can lead to rafts of decaying root matter floating to the surface, which can result in aesthetic impacts at the site. It is recommended that allowances be made in projects to remove these rafts.

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# Using pathogens to biologically control environmental weeds – updates

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**Summary** Fungal plant pathogens offer exciting opportunities for the classical biological control (biocontrol) of environmental weeds in Australia. Three recent cases of successful or highly promising fungal pathogen biocontrol agents are discussed: the white-smut fungus *Entyloma ageratinae* on mistflower (*Ageratina riparia*); the rust fungus *Baeodromus eupatorii* on Crofton weed (*Ageratina adenophora*) and the leaf-smut fungus *Kordyana brasiliensis* on wandering trad (*Tradescantia fluminensis*). The mistflower white-smut fungus is now established across the range of the weed in eastern Australia and has been highly damaging on mistflower in many areas of NSW. Following extensive host-specificity testing, the Crofton weed rust fungus (ex. Mexico) was approved for release in Australia in May 2014. The fungus established readily in the field on the NSW South Coast and extensive defoliation of Crofton weed has been observed 6-12 months after release. A large-scale release program for this fungus, in partnership with the community, is currently underway across NSW. Host-specificity testing of the wandering trad leaf-smut fungus (ex. Brazil) is on-going in the CSIRO Canberra quarantine facility. Initial results are highly promising and it is hoped that this fungus will eventually get permission to be released in Australia.

**Keywords:** Mistflower, Crofton weed, wandering trad, biocontrol, fungi

## INTRODUCTION

Fungal plant pathogens offer exciting opportunities for the classical biological control (biocontrol) of environmental weeds. This approach involves the deliberate introduction of a host-specific pathogen of the target weed from its native range into the region where it has become a problem. One of the advantages of fungi over insect biocontrol agents is the high number of generations that can occur and large quantities of inoculum that can be produced during a single growing season of the target weed (Morin *et al.* 2006). Fungal pathogens of a range of weeds have proved to be very effective biocontrol agents in Australia, e.g. *Puccinia chondrillina* on skeleton weed (Cullen 2012), *Puccinia myrsiphylli* on bridal creeper (Morin and Scott 2012) and *Maravalia cryptostegiae* on rubber vine (Palmer and Vogler 2012).

Biocontrol is often considered the most viable option for effectively managing weeds in natural ecosystems (van Driesche *et al.* 2010). Manual removal is suitable for control of small infestations of some environmental weeds, but can be very labour-intensive. Great care however, must often be taken to remove all material since for some species new plants can successfully establish from very small stem, rhizome or root fragments. Chemical control is considered more practical for the management of large weed infestations, although there is potential for non-target negative effects on native flora and cost can be prohibitive.

In this paper, I will present the latest research and findings on fungal pathogens that are either successful or highly promising for the biocontrol of three environmental weeds in eastern Australia – mistflower (*Ageratina riparia* (Regel) K. & R.; Asteraceae), Crofton weed (*Ageratina adenophora* (Spreng.) King & Robinson); Asteraceae) and wandering trad (*Tradescantia fluminensis* Vell.; Commelinaceae).

**Mistflower white-smut fungus**

Mistflower is a perennial herbaceous alien plant originating from Central America that invades wet habitats, particularly riparian areas and moist cliff faces, in eastern Australia (Parsons and Cuthbertson 2001). It is primarily a problem in mid to high elevation rainforest areas where it creates a canopy over headwater streams and displaces native riparian plant species, including many threatened and endangered species (Coutts-Smith and Downey 2006). It also reduces forage quality for livestock in wet meadows. The gall fly *Procecidochares alani* Steyskal was introduced in Australia in 1986 for the biocontrol of mistflower (Schooler *et al.* 2012). It spread and established widely, but it is heavily parasitised by native parasitoids and has not been effective in reducing the abundance of mistflower.

The white-smut fungus, *Entyloma ageratinae* R.W. Barreto & H.C. Evans (ex. Jamaica) (Fig. 1A, B), has been a highly successful biocontrol agent of mistflower in Hawaii, South Africa and New Zealand (Morris 1991, Morin *et al.* 1997, Trujillo 2005, Barton *et al.* 2007). It has significantly reduced mistflower abundance, which has facilitated re-colonisation by desirable pasture or native species (Trujillo 2005, Barton *et al.* 2007). The white-smut fungus infects leaves of mistflower if moisture is present. Within 7 to 10 days at 20° C, small lesions appear on the under surface of leaves and the fungus begin to produce large amounts of small, needle-like, windborne spores (conidia), making lesions appear woolly white (Fig. 1B). Angular, reddish-brown lesions later appear on the upper surface of leaves (Fig. 1A). Lesions coalesce and leaves eventually die and fall off from plants.

The white-smut fungus was found for the first time in Australia in October 2010 in Lamington National Park, south-east Queensland (QLD), following an unauthorised introduction. The pathway of introduction is unknown. Soon after this initial discovery, the fungus was found at all mistflower infestations surveyed in south-east QLD and North Coast and Mid-North Coast of New South Wales (NSW) (Morin *et al.* 2012). It was not found further north in QLD and south in NSW. Results from host-specificity tests subsequently performed revealed that Australian native *Adenostemma* spp., which belong to the same tribe as mistflower (Eupatorieae), as well as other closely-related species that had not been tested before as part of biocontrol programs overseas, were all immune to the fungus. Only Crofton weed, a congener of mistflower, developed disease symptoms, albeit to a much lesser extent than mistflower (Morin *et al.* 2012). In light of these results, the fungus was transferred in May 2011 to mistflower populations free of the disease on the Central Coast and South Coast of NSW and the Blue Mountains. Within six months, extensive defoliation of mistflower was observed at all sites and the fungus had naturally spread across the entire region (Morin *et al.* 2012).

The initial impact of the fungus was measured in 2012 in permanent plots at eight sites in NSW and three in QLD where baseline vegetation data had been collected 12–18 months earlier. Percentage cover and biomass of mistflower were each reduced by more than 50% across all sites, with a corresponding increase by more than 60% of the percentage cover of other plant species. The fungus has continued to be highly damaging on mistflower, especially in NSW where conditions have been most conducive for disease development in recent years. At some sites, mistflower has basically disappeared and been replaced by native plant communities.


**Figure 1.** Disease symptoms caused by the mistflower white-smut fungus, *Entyloma ageratinae*, on the upper (**A**) and lower (**B**) surface of leaves; Crofton weed rust fungus, *Baeodromus eupatorii* (**C**) and wandering trad leaf-smut fungus, *Kordyana brasiliensis* (**D**).

**Crofton weed rust fungus**

Crofton weed, a plant native of Mexico, is an erect and multi-stemmed perennial herb that grows 1–2 m high (Parsons and Cuthbertson 2001). It reproduces by seed (10 000 and 100 000 seeds per plant per year) or vegetatively from its rootstock. Seeds are windborne over long distances, which allow the weed to invade previously non-infested areas. It is widespread in eastern Australia, and most prevalent in the Sydney-Wollongong region, the NSW North Coast and south-east QLD. It is present at high density in many areas of Lord Howe Island, an island off the NSW coast declared a World Heritage Area. Crofton weed readily invades cleared land that is not grazed, such as public reserves. It is unpalatable to cattle and poisonous to horses, but can be eaten by goats and sheep without apparent ill effects providing other pasture species are present. It is reported to negatively affect native flora, possibly through the release of allelopathic compounds (Zheng and Feng 2005). With its wind-dispersed seed, it readily colonises large-scale natural disturbances on Lord Howe Island, preventing native fern, herb and tree species regeneration and succession (Auld and Hutton 2004).

Two biocontrol agents for Crofton weed were introduced in Australia in the 1950s: the fly – *Procecidochares utilis* Stone that causes galls on stems and the leaf-spot fungus – *Passalora ageratinae* Crous & A.R. Wood (previously known as *Phaeoramularia eupatorii-odorati* (J.M. Yen) X.J. Liu & Y.L. Guo) that causes necrotic lesions on old leaves (Cruttwell McFadyen 2012). These agents cause some damage on Crofton weed, but their overall impacts on populations of the weed have been negligible. A similar situation occurs in South Africa, and for this reason a search for additional candidate biocontrol agents for Crofton weed was initiated with a series of surveys in Mexico between 2007 and 2009 (Heystek *et al.* 2011). The rust fungus *Baeodromus eupatorii* (Arthur) Arthur (Fig. 1C) was collected during one of these surveys and imported in quarantine in South Africa, but a culture could not be maintained and it was not further investigated.

The Crofton weed rust fungus infects young leaves and stems. It is a microcyclic and autoecious rust (no alternate hosts) with only pycnia (spermogonia) and telia reported to be produced on *Eupatorium* or *Ageratina* species (Buriticá and Hennen 1980). Pycnia are mostly produced on the upper surface of leaves (Fig. 1C), and telia on the under surface. Petioles and stems with pycnia and telia are often swollen and contorted. Cross-fertilisation between pycnia is necessary for telia to develop. This typically occurs under natural conditions by insects transferring pycniospores produced in sweet, attractive mucus between pycnia. Telia are made up of strongly attached teliospores, which germinate immediately upon formation and produce four windborne basidiospores. Basidiospores germinate readily and directly penetrate plant tissue, providing some moisture is present and ambient temperature is in the vicinity of 20° C. First visible signs of infection are observed 8 to 9 days later. Within 15 days, pycnia with visible mucus containing pycniospores are observed. Providing cross-fertilisation occurred, telia begin to develop within the next few days.

The rust fungus was re-collected in Mexico by South African colleagues in December 2011 and imported into the CSIRO Canberra quarantine facility. Host-specificity tests on 60 non-target plant species, selected on the basis of a recent molecular phylogeny of tribes in the family Asteraceae (Funk *et al.* 2009), demonstrated its high specificity. The fungus successfully developed only on Crofton weed and two other *Ageratina* species: *A. riparia* (mistflower) and *Ageratina altissima* (L.) R.M.King & H.Rob. (syn. *Eupatorium rugosum* Houtt.) (Morin 2013). The latter is an introduced garden plant, not yet recorded as a weed in Australia, but known as an agricultural weed in other countries (Randall 2007). Disease symptoms on *A. altissima* were similar to those on Crofton weed. In contrast, pycnia were infrequently produced on mistflower and when telia developed they were often associated with necrosis. The fungus was approved for release in Australia in May 2014 by the relevant authorities on the basis of results provided, which showed that it would not pose a threat to economic and native plant species.

During winter-spring 2014, the fungus was released at five sites within national parks and conservation areas on the NSW South Coast and north of Sydney. It established readily providing that infected potted plants were used for release and that conditions were conducive for infection in the following 2-3 weeks. Within 6-12 months of these releases, the rust fungus has caused extensive defoliation of Crofton weed and spread to nearby Crofton weed infestations (in some cases a few kilometres away from the release site). A large-scale release program across NSW, in partnership with the community, began in autumn 2015 and will continue until the end of 2016. Rust-infected potted plants, grown either in pasteurised soil or in rock wool, are distributed to managers of private or public land at field events or via the post. Managers are provided with simple guidelines on how to make the release and monitor establishment and spread, and are expected to provide feedback. The fungus has also been released in autumn-winter 2015 at 11 sites in national parks in south-east QLD.

**Wandering trad leaf-smut fungus**

Wandering trad is a long-lived perennial, prostrate herb. It is primarily spread via stem sections by water, soil movement and in garden waste (Blood 2001). It is most common and invasive in the coastal regions of NSW, Victoria and south-east QLD. It forms dense mats up to 60 m deep (Blood 2001) that smoothers vegetation and kills seedlings, leading to a major decrease in species richness and abundance of native plants (Standish *et al.* 2001). In addition, it can also increase the rate of decomposition, thus altering nutrient availability (e.g. higher available nitrogen) (Standish *et al.* 2004). No biocontrol agents have been released in Australia for wandering trad.

Surveys of natural enemies of wandering trad in Brazil, the region of origin of this weed, were performed by Brazilian colleagues in 2005-09, as part of a new biocontrol program undertaken by Landcare Research in New Zealand (Fowler *et al*. 2013). Three beetle species (now released in New Zealand; Fowler *et al*. 2013) and an undescribed *Kordyana* sp. leaf-smut fungus (Pereira *et al.* 2008) were discovered during these surveys. Based on morphological and molecular characteristics, the fungus has recently been described as a new species – *Kordyana brasiliensis* D.M. Macedo, O.L. Pereira & R.W. Barreto sp. nov. (Macedo *et al.* in press) (Fig. 1D).

The leaf-smut fungus produces basidiospores that germinate and penetrate leaves via stomata if moisture is present. Seven to eight days later, small flecks are observed on the under surface of leaves. A few days later, lesions appear on the upper surface of leaves as diffuse chlorotic spots, which become more prominent as chlorosis spreads. Within 15 days, if exposed to high humidity, the fungus begins to sporulate on lesions on the under surface of leaves, giving lesions a whitish appearance (Fig. 1D). The central area of lesions on the upper leaf surface turns reddish brown as they mature, eventually becoming necrotic. Coalescing lesions lead to complete necrosis and death of leaves.

*Kordyana brasiliensis* has not been found on any other species in Brazil (R.W. Barreto, personal communication 2014). In a series of host-specificity tests performed in Brazil, the fungus was found to be highly specific towards wandering trad (Barreto and Macedo 2011, Barreto 2012, Fowler *et al.* 2013). On the basis of these results it was approved in 2013 for release in New Zealand (EPA 2013), but has not yet been introduced. These initial host-specificity tests however, did not include native and horticultural species in the family Commelinaceae that are present in Australia (there are no crop plants in this family).

The wandering trad leaf-smut fungus is of interest to Australia, especially considering the extensive research on it that has already been conducted and the extent of damage that it can cause on the weed. The fungus was imported into the CSIRO Canberra quarantine facility in June 2014 and a series of additional host-specificity tests was initiated to assess risks that it may pose to closely-related non-target species present in Australia. So far it has been tested on 26 of the 28 non-target species/cultivars selected within the Commelinaceae family, as well as on 14 accessions of wandering trad from QLD, NSW, Victoria and South Australia. The fungus successfully developed and produced normal lesions on all wandering trad accessions. Only five non-target species developed a limited number of small flecks, either water-soaked in appearance or necrotic, following inoculation with the fungus and were rated as resistant. All other 21 non-target plant species tested did not develop any visible symptoms and were either rated as immune or highly resistant to the fungus. Testing, including microscopic examinations of samples, will need to be completed before an application to release the fungus in Australia can be submitted.

**Conclusion**

Fungal pathogens can provide targeted, sustained, high level of biocontrol of dominant weeds in natural ecosystems at the landscape scale. Successful fungal pathogen biocontrol agents, such as the mistflower white-smut fungus, generally possess the following characteristics: 1) have high level of specificity, 2) produce wind-dispersed spores, 3) build-up to epidemic levels and 4) cause severe damage that reduces photosynthetic ability and impose an energy drain on the weed.

All indications so far point to the Crofton weed rust fungus also having these characteristics, although it is still too early to know how successful it will be in reducing populations of Crofton weed. It is expected that the Crofton weed rust fungus will work in tandem with *P. ageratina*, the other pathogen that causes damage on old leaves of Crofton weed, and cause increased stress on plants.

Although the wandering trad leaf-smut fungus is still at the testing stage, it nonetheless shows great promise for biocontrol, especially considering that it is very similar to the mistflower white-smut fungus – both fungi belong to the same Class (Exobasidiomycetidae) and have similar life cycles. Biocontrol of wandering trad may also benefit from combining the leaf-smut fungus with one or more of the beetle agents that have been released in New Zealand (Fowler *et al.* 2013). A suite of biocontrol agents that attack different parts of wandering trad and collectively colonise all habitats and region where infestations occur, could provide a long-lasting solution to this weed problem.

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## Afternoon Sessions

| | Agronomy – Marquee | Conservation Symposium Auditorium |
|---|---|---|
| CHAIR | Craig Mitchell | Pete Turner |
| 3:30pm | The tale of two Lovegrass Invasions – Jennifer Firn – Queensland University of Technology and Lachlan Ingram – University of Sydney | Conserving Biodiversity in Grass-lands – Geoff Robertson - Friends of Grasslands |
| 3:50pm | The use of unmanned aerial vehicles in regional weed inspection & surveillance programs – Josh Biddle - New England Weeds Authority | Initial identification and prioriti-sation of invasive weeds in the Kosciuszko to Coast Partnership Corridor (K2C) – Bob Godfree and Jacqui Stol, CSIRO |
| 4:10pm | Supporting communities to collectively manage widespread weeds in South-East NSW – Bronwen Wicks - NSW DPI | A collaborative approach to the impacts of a changing climate – Early detection of emerging weeds in the Australian Alps – Mel Schroder, OEH and NPWS |
| 4:30pm | How are we positioned for effective weed control today? Never better and this is not surprising – Peter Scott - Liverpool Plains Shire Council | Using robotic aircraft & intelligent surveillance systems for Orange Hawkweed detection - Calvin Hung and Salah Sukkarieh - University of Sydney |

**5:00pm NSW Weeds Officers Association AGM**

**6:30pm Social Networking Soiree - Ex Services Club - Vale Street Cooma**

**A Tale of Two Lovegrass Invasions: the efficacy of different control strategies compared between Bega NSW and Darling Downs, QLD.**

Jennifer Firn

jennifer.firn@qut.edu.au, mobile: 0403802525

Duration 20 minutes

For almost 100 years, *Eragrostis curvula* (African or weeping lovegrass), a $C_4$ perennial grass native to southern Africa, has been sown throughout Australia for pasture improvement and soil conservation. In some localities it has proven more valuable for pasture improvement than in others. In places where it is considered a weed control efforts have proven challenging. In this seminar I will compare the efficacy of common control efforts, e.g. spot spraying and slashing, at field sites in two regions characterised by very different management histories, soil types and climates, Bega NSW and Darling Downs, QLD. The data comparison I will discuss will highlight the complexity of the management of African lovegrass and I will recommend a generic approach as opposed to one 'silver bullet' solution.

Biography: Jennifer Firn is a theoretical and applied ecologist who specializes in linking ecological theory to the sustainable management of degraded grasslands and forests. She is a senior lecturer in Ecology at the Queensland University of Technology. Jennifer has been researching the biology and ecology of African lovegrass for the past nine years.

# The use of unmanned aerial vehicles in regional weed inspection and surveillance programs

Josh Biddle
District Weeds Officer
New England Weeds Authority
Armidale

## SUMMARY

This paper presents the results of the Northern Inland Weeds Advisory Committee's (NIWAC) NSW DPI Innovative Project 2013-15 investigating the potential impact of unmanned aerial vehicles (UAVs) and mapping as part of a Local Control Authorities regional inspection program.

Field work was conducted by The University of Sydney's Australian Centre for Field Robotics. Low altitude aerial Images were collected on Tropical Soda Apple, Alligator Weed, Serrated Tussock and Water Hyacinth using a hexacopter UAV to calculate the optimum altitude to achieve the highest classification accuracy for the four weeds.

The extracted data was then used to train and evaluate the weed classification algorithms. It was demonstrated that image classification algorithms are able to correctly classify the four weeds from remote sensing data collected from a small UAV.

Following on from the field work, a cost benefit analysis was then conducted by RM Consulting Group, comparing the use of unmanned aerial surveillance, maintenance and operational costs against the conventional methods of utilising on-ground surveillance and aerial inspections by manned helicopter.

In addition, a further project (NSW DPI Innovative Project 2) will be completing the "pipeline", where images obtained from the UAV quadcopter are processed, loaded into the Weedtr@cer regional mapping system, with the capacity to be imported in to the NSW Biosecurity Information System (BIS).

## INTRODUCTION

It has been recognised for some time that to progress weed management and control techniques that we must look to continually improve our methods of weed surveillance in an innovative and cost effective manner.

The NIWAC innovative pilot project looks at taking the regional inspection program to the next level by way of integrating new technology through the adaptation of UAVs, and a proven existing mapping system for the detection and surveillance of high risk invasive weed species.

The project comprised two major components;

a) A **feasibility study** outlining recommendations on the integration of unmanned aerial vehicles, multi spectral imaging and mapping in the NIWAC region.

b) A **cost-benefit analysis** of the implementation of the recommendations of the feasibility study within the NIWAC region.

Central to the success of this project has been the engagement of the Australian Centre for Field Robotics (AFCR) faculty of the University of Sydney (USYD) in the study of the four different weed species detection using low altitude unmanned aerial vehicles and aerial imaging.

Consultants RM Consulting Group were engaged to carry out a Cost-Benefit Analysis (CBA) comparing the costs and benefits of incorporating the technology into a regional inspection program.

**Tropical Soda Apple Weed**

**Serrated Tussock**

**Water Hyacinth**

**Alligator**

**Photo 1: Nominated weeds for this study.**

# Methodology

## Stage One - Field Trials

Field Trials collected images of four different weed species using a UAV hexacopter, at different altitude settings of 10, 20 and 30 metres to determine optimal settings for future data collection operations.

The optimum altitude for each weed is summarised in the table below.

| Weed Type | Survey Altitude (m) | Pixel Size (mm) | Classification Accuracy (%) |
|---|---|---|---|
| Water hyacinth | 30 | 7.8 | 90.0 |
| Serrated tussock | 20 | 5.2 | 90.7 |
| Tropical soda apple | 10 | 2.6 | 72.2 |
| Alligator weed* | 20 | 5.2 | 86.8 |

**Table 1: Optimal Altitude Settings**

## Stage Two: Weed Classification

The USYD Research team achieved acceptable classification results for the four subject weed species, with Tropical Soda Apple the most difficult to classify.

Results showed that classification accuracy was highly dependent on how distinguishable the weed was from the surrounding plants. The ideal time to survey the weeds would be when they are most distinguishable from neighbouring plants ie during flowering season.

It was demonstrated that image classification algorithms are able to correctly classify weeds of interest from remote sensing data collected from small UAVs.

**Data Analysis and Import to WeedTr@cer Mapping System**

In addition to collecting data with a UAV, the data must then be be analysed, stored and disseminated.

After the classification process was completed data is then extracted in either paper, xml or Microsoft Excel ® format or directly to software on a computer or tablet.

This information can then be made readily available for reporting and data integration (compliant with NSW DPI Weeds Metadata Standard 1.0) into the NSW DPI Biosecurity Information System (BIS).

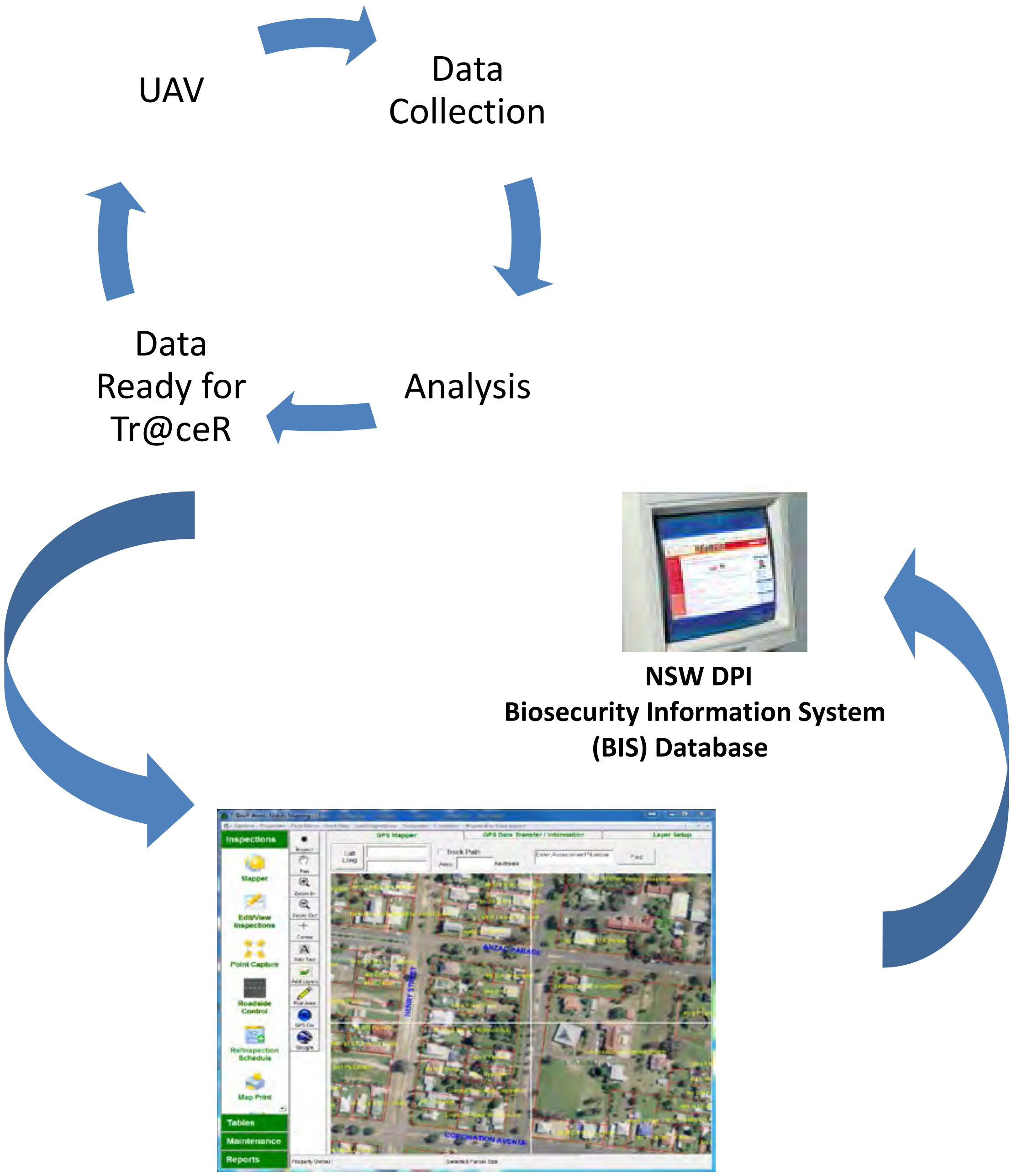


**Figure 1: Integration of UAV data into Weedtr@ceR mapping system.**

## Stage Three: Cost Benefit Analysis:

RM Consulting Group was commissioned by NIWAC to undertake an economic assessment of the use of UAVs and weed classification analysis as part of their trial of the technology.

### Approach

RM Consulting Group developed costing scenarios for four weed inspection activities undertaken by NIWAC. The four scenarios explored were:

1. 20 hectare block inspections, which are visually inspected whilst driving around the property.
2. 250 hectare block inspections, which are also visually inspected by driving around the property.
3. Riparian waterway inspections, which are currently undertaken by vehicle and on foot and are labour intensive activities.
4. High risk pathway inspections, which are undertaken by two officers in a vehicle, where one drives and the other inspects either side of the pathway.

Two alternative scenarios were developed for UAV use:

1. Hand-held UAV use by NIWAC staff, which involves the ownership and operation of a fleet of UAVs by NIWAC, and bringing them on-site to assist with inspection activities. Data was then sent to the University of Sydney for analysis and returned to NIWAC. Where weeds are identified, staff returned to the site for confirmation.
2. 
3. A fly-over approach to UAV data collection, in which a service provider is commissioned to fly the region in advance of inspections, the data sent to the University of Sydney for analysis and returned for use in the inspection. Sites with identified weeds are inspected manually for confirmation.

## Results

Results from the analysis are summarised in the charts below which compare the cost-effectiveness of UAVs for each scenario.

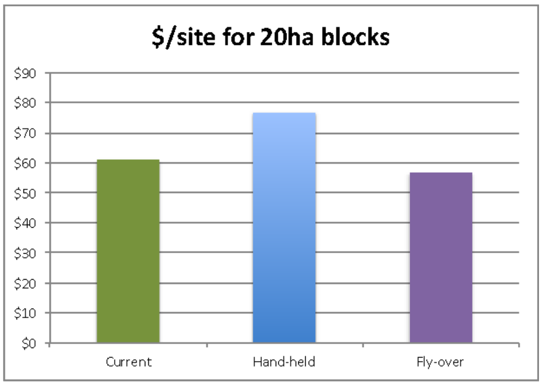


Figure 2 shows the current costs of a 20 hectare site inspection (in green) compared with the estimated costs of the inspection using hand held (blue) and fly-over (purple) UAVs. As can be seen, hand held costs are slightly more expensive and fly-over costs slightly lower.

**Figure 2: Cost-effectiveness assessment for 20 hectare sites**

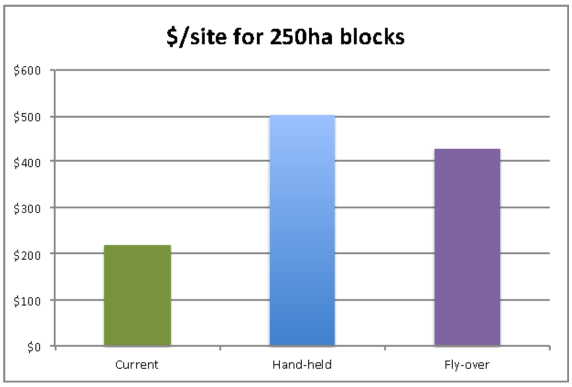


Figure 3 provides the same comparison for 250 hectare blocks. In contrast to 20 hectare blocks, the labour and vehicle cost savings for larger blocks are more than offset by the additional cost in data collection and weed identification analysis.

**Figure 3: Cost-effectiveness assessment for 250 hectare sites**

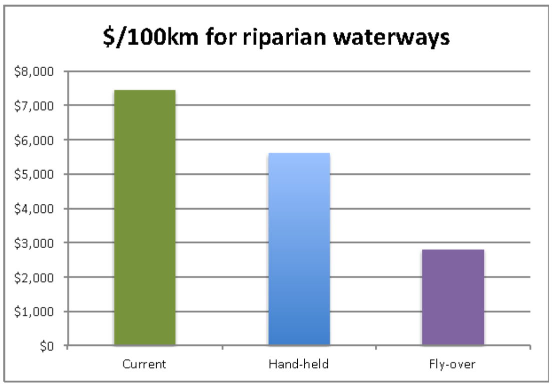


Figure 4 summarises the results of riparian waterway inspections, which suggest that the incorporation of UAV technology would be highly cost-effective. This is especially so for a fly-over approach, which in addition to significant labour cost savings from reduced manual inspection, has the added benefit of delimiting the inspection area by identifying which tributaries are affected and where the source of the infestation begins. This approach is estimated at less than 50 per cent of current inspection costs.

**Figure 4: Cost-effectiveness assessment for riparian waterways**

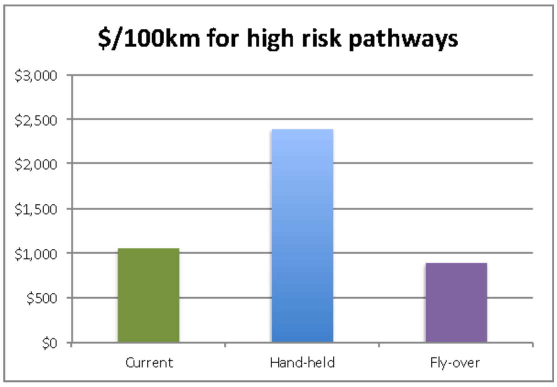


Figure 5 summarises the cost-effectiveness of different methods of high risk pathway assessment, using the example of a fire trail.[1] This scenario may not lend itself as well to hand held UAV use, as it does not reduce labour costs and has added data collection and weed identification costs. A fly-over approach is cost-comparable with current inspection methods.

**Figure 5: Cost-effectiveness assessment for high risk pathways**

## Conclusion

This analysis showed that under specific scenarios UAV technology and weed classification analysis can be used by weed managers in a cost-effective way. This was demonstrated in the following scenarios of the study:

- Small block assessments can be undertaken using UAV technology at a similar order of magnitude cost to current practice.

- Large block assessments (250 hectares) using hand held UAVs appear to be more expensive than current practice largely due to the larger scale of the area producing higher data collection and weed classification analysis costs.

- Riparian water assessments using UAVs appear to be significantly more cost effective than current practice, due to the labour-intensity of current manual inspection and the ability to use a fly-over approach to help delimit the area requiring manual visits.

- High risk pathways have somewhat limited use for UAVs, as highways are no-fly zones and the use of hand held UAVs for other pathways do not appear to produce significant time savings. However, the use of manned fly-overs and potentially regional UAVs appears to be similarly cost effective compared to current practice.

The cost-effectiveness of UAVs in weed management is, unsurprisingly, affected by the cost of using the technology, which will reduce over time, and the technology will also find a number of other practical uses for Government and private business, thus making it commercially more viable, and valuable for day-to-day operations.

This is a very important point, not only because technological advancement may reduce the cost of data collection and analysis over time, but also because there may prove to be a number of different uses for the data by both Government and private business.

For example, if landholders could use the data for crop management or business planning, they may be willing to co-fund data collection with weed management agencies. Similarly, there may be many uses of aerial photography data across agencies and tiers of Government, leading to opportunities for cost-sharing among Government departments and other entities in the future.

Furthermore, technological advancement in camera resolution may result in cost-effective state-wide data collection for multiple purposes.

If so, it is conceivable that annual data collection and weed identification analysis across a region or even the state could become standard practice over time. In such a scenario, where weed officers are collecting data using UAVs in a cost effective manner and uploading the data to the ACFR server, the identification and control of weeds could become far more coordinated and effective than is currently possible. The benefits to Government, landholders and the community of such an outcome are likely to be significant.

With further development to operationalise the technology, the study suggests that UAVs could play an important role in early detection of outbreaks of high-risk new and emerging invasive weed species, to complement existing field inspection methods.

Where a rapid response is required for a new incursion, the hand held UAV has potential to reduce the time required to locate the spread of the incursion and subsequent treatment of the area.

In looking to the future, there may be opportunity to build on these findings to explore the merits of applying the technology at multiple scales:

a) A Local Land Services regional fly over capturing data for multiple uses by a number of organisations – eg farm management, feral animals and weed management.

b) A fly over on a sub-regional scale, similar to (a) but on a smaller scale.

c) A fly over of riparian areas in a Local Land Services region.

In the interim these results suggest that further work on the technical effectiveness of the technology can be approached by placing into operation low-cost UAVs for weed officers and testing out the data passing to the ACFR and automated classification.

## ACKNOWLEDGEMENTS

This project was funded by the NSW DPI Innovative Grants Program.
Partners in the project include The Sydney University Australian Centre for Field Robotics, (ACFR) and RM Consulting Group (RMCG).
Special thanks to Professor Salah Sukkarieh and Research Associate Calvin Hung (AFCR) Kym Whiteoak and Simon McGuiness (RMCG) together with NIWAC Project Officer Heather Apps and Program Manager – Wayne Deer

# "SUPPORTING COMMUNITIES TO COLLECTIVELY MANAGE WIDESPREAD WEEDS IN SOUTH-EAST NSW."

Widespread weeds and their long-term management are one of our great agricultural, environmental and social challenges. Often the importance and social well-being of the local community of people, who are the on-ground managers of these weeds and in there for the long haul, has been overlooked. While often anecdotally acknowledged, the impact of managing widespread weeds on individuals and their community has rarely been formally included in assessing the feasibility and effectiveness of long-term weed management.

The affect on human relationships, such as the quality of land managers' relationships with other land managers (including neighbours), extension and government staff, and within their own communities, has implications for sustaining the long-term effort required to manage widespread weeds.

A partnership project between the South East Local Land Services and NSW DPI Weeds Action Program (WAP) has trialed a novel approach to managing widespread weeds. The project deliberately focused on the local community of people in a given district, with the intent of enabling the community to collectively set their own weed direction and objectives at the local level, and to identify relevant capacity and skill development needs to support this. One of the formal planned outputs was the development of an agreed community widespread weed plan.

Three pilot areas were chosen in south-east NSW – Bungendore, Numeralla and Tilba Tilba. These areas were chosen based on a number of social capital criteria, supported with information from local weed officers, community members and social demographic information. An initial community focus group was held in each area to ascertain community support for the project, and to identify key local weed-related and other important issues. The opinion and priorities of local weed officers was also included in the information gathering phase of the project. This information was used to tailor and refine local delivery of the project in the three areas to include local issues, specific weed species and identified topics of interest.

Project delivery was based on a series of workshops developed specifically for each area, with an on-going theme of managing local widespread weeds. The workshops were roughly based around a 50/50 split between a topic of interest to the local community and further developing the understanding and collective planning for widespread weeds. A workshop evaluation form was handed out at each workshop. This information together with other sources of feedback was used to refine the next workshop and the broader project.

Relevant and suitable social indicators for the project were identified at the project outset. These were used as the basis for a baseline survey for the project. All participants at workshops were asked to complete the survey, with the understanding it would be sent out again at the end of the project/series of workshops in the area.

Insights gained from running the project in south-east NSW will be discussed, together with the findings from a research study of existing successful collective action community weed groups. Suggestions or principles for a methodology for managing widespread weeds at a landscape scale will be proposed. It is hoped the these principles and insights can inform Local Land Services in developing and supporting future widespread weed initiatives.

# 18th NSW Weeds Conference Paper

Cooma - Monaro Shire Council - 13th October to 15th October 2015

**Peter Scott:** Author/Presenter - Diploma of Management (BSB51107)

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## "Weeds – the future, innovations and adaption"

The technology in use to-day [seventeen (17) month after LLS launch] was once in the realms of science fiction and just wishful thinking but now, integrated into everyday use; it shapes the view and future outcomes of Noxious Weed control. This must continue to be embraced, evaluated and expanded or we will be left behind. Consider the evolution of our industry's vast range of weed control resources. A remote controlled retractable hose spray system (Quick spray) is a quantum leap forward from a fire stick**,** chipping hoe or a knapsack.

### How are we positioned for effective weed control today?

Never better and this is not surprising. We have accumulated an impressive, diverse, and growing technology base that is well supported and overseen on-ground, by professional practitioners. There are now a plethora of broad spectrum or selective, residual, non-residual and environmentally friendly herbicides available that can be delivered from aircraft or sophisticated boom spray equipment with calibrated selective electronic eye "Weedseeker" technology. The ever-expanding range of technology and its applications offers many options, with elements and adaptions, for a holistic "Integrated Weed Control" approach. Used now in conjunction with live GPS remote mapping, tracking and plotting systems that with hindsight, all seems so obvious.

Consolidating current developments to maximise efficacy will involve technology with the potential to further integrate existing capabilities to reassess, analyse and fine-tune aggregated reports or Big Data. (Google "Big Data!") Automated remote detection already contributes significantly, through a diverse ability and observation capacity by identifying target species from not only satellites but all manner of aircraft including unmanned drones. Pragmatic advantages, generated by drones or satellites with eyes in the sky, and their instantaneous connectivity, should not be diminished, limited or headed off by Drones on the ground. A great deal of published supporting information as commentary on the beneficial advances is readily available for assessment and this continues to expand at a significant rate.

Some technology, initially developed for a specific or single purpose, is now being adapted and interfaced for use in a wide range of beneficial applications. Automated, remotely gathered Data or Imagery is widely and strategically communicated. This includes: weather data analysis for forecasting, directing firefighting efforts, gathering military intelligence, GPS guidance control, detecting mineral deposits, asset deployment and to identify or quantify vegetation mass or to assess fruit tree yields. It is also extensively used in broad acre farming operations for irrigation and livestock performances monitoring. These are just a few situations. Now in addition, contemplate an expanded horizon of diverse applications, potentially to be powered by the new generation of Lithium Ion batteries with a markedly increased capacity to more efficiently store harnessed power generated by renewable energy sources. Or, coming soon, the uses and potential Biosecurity "inspection applications" for a manned, "drone like", flying platform, about the size of a freight pallet fitted with sophisticated cameras and interfaced with GPS locating capabilities.

Many operations are now running commercially with some still in the development stage and showing enormous potential to make major contributions well into the future. Meanwhile and justifiably, efforts will continue to develop and refine new technology. Many new applications have rapidly progressed from "concept to practical use." Consider the growing number of Mobile phone "Apps" now available and that collectively the IT industry in Australia now boasts a workforce equal to that of our mining industry.

Having been involved in initiating, coordinating, observing and evaluating a remote controlled unmanned helicopter assignment that effectively delivered herbicide onto specifically targeted Noxious Weeds, within a generally inaccessible but environmentally sensitive area, further potential applications are possibly as extensive as imagination itself. Some examples to consider:

- The "Smart Farm Innovation Centre" facility @ Armidale in northern NSW is a stand out example. They are currently engaged remotely in an impressive interstate property management assignment, with an expanding list of capabilities and applications.
- Effective management tools to remotely monitor the environmental health and status of small or isolated areas of threatened species, with a High Conservation Priority (HCP) or the vast areas of remote Crown Land lease assets. We just need to know where to look!
- Strategic surveillance and monitoring of high risk pathways, for early detection of new invasive species incursions. Potentially this may deliver the greatest cost saving benefits.
- Strategically and objectively measure, monitor and report on widespread weeds to help develop realistic control plans to support effective containment strategies.

Of great interest to weed control professionals are potential applications, utilising the NBN (or similar technology) to evaluate and integrate with complementary new or emerging technology that will help resolve or monitor to mitigate Biosecurity Risks of unwanted arrivals or incursions within Natural Resource Management situations. Ref NW Review Recommendation (Rec) No 7.

A note of caution though! The unbridled pursuit of technology (ideology) per se will not provide a solution for all "Weed problems." Alone and unsupported, it may be distracting or cause disruption to on-ground efforts and real endeavor. It is the integration of cohesive strategies and realistic plans supported by technology with effective on ground actions that achieves cold, hard but desirable "Results." (Something these days affectionately called "Outcomes.") For some, this includes an unpalatable reality and the unspeakable commentary, "Compliance." But, without satisfying the inherent obligation, delivered as effective control, we fail, as previously we have failed and will continue to fail. While progressively success, utilising supportive technological advantage will be measured as outcomes.

An impasse challenging weed professionals is resolution, hopefully of some remaining bureaucratic elephants in the room, (old chestnuts) that without objective justification, continue to hinder the efficacy of leading edge technology. In reality, it is these old chestnuts and not technology that actually stifles our ability to deliver further advantageous adaptations for a suite of our best intentions. We must continue to communicate more convincing arguments to replace shallow, outdated, subjective reasoning that continues "against change," despite well-founded argument, with supporting technology offered but overlooked in past Noxious Weed Reviews.

**Adaption:** -To be fair, some old chestnuts have been acknowledged and addressed, or at least, nominated as "Supported" or are to be, but time will tell. For example:

- Noxious weed control expectations and standards are to be applied "Tenure Neutral," Ref Rec 1 (b) and is "Supported," irrespectively, for all individuals and managers controlling various land parcels. For example, Statuary Authorities including Crown land, roadsides, National Parks and Forestry, *etc*. - Finally, this has acknowledged an unfortunate and inappropriate cost shifting exercise that had its genesis in the late 1990's. Locally, expectations are equal, for both private and public land to eliminate the perception of "corrupt control standards." Installing control equality as the expected standard, Tenure Neutral, will also be seen as an example for the public. (Who is to administer and how this is to be funded, is yet to be determined?)
- Transparency: A say with local input into Local and Regional Weed Control Orders and Classifications applicable to specific weeds, reportedly is pending! Ref Rec No 2 c. (i) is "Supported" and should or could start happening tomorrow, (Unfortunately, just like removing weeds from the declared list) but it remains to be seen. Regrettably the Weed Risk Assessment Process is not infallible and by loading a variable control biases, into the equation it can be and is manipulated to secure a nominated academic outcome.

- An absurd injustice or antinomy highlights a contradiction in law that exists. Unchecked septic tank (or toxic waste) overflows, discharging uncontained onto neighboring property, are illegal, certainly not tolerated and carry proportional consequences to match. But, uncontrolled Noxious Weeds next door comparatively are as endearing (not really) to the community as a disqualified, unlicensed, alcohol or drug impaired driver, on the roads with us, in an uninsured vehicle, placing our families (livelihood) "at risk."
- Lacking in the past and now is delivery of the reasonable expectation from existing mandatory obligations. *ie.* "Consistent effective weed management outcomes." A more transparent, realistic and even-handed outcome for offences, dealt with by the Judiciary through LCA's, is required. Community members are entitled to expect a measured, encouraging, authoritative oversight with substantial and proportional consequences, through and as incentives, for offenders. This committed assurance is to be offered through the accountability of LLS's operations and the pending overarching Biosecurity Act. (Ref: LLS Performance Audits to commence in 2017 and as per Rec 2(c) (iii) & 6(b)

**However**, several old chestnuts (issues) continue to be identified as, "In need of adaption and resolution" but regrettably they remain "Not Supported," again without convincing or objective advice offered, despite creditable endorsement from Independent Noxious Weed Reviews.

- Section 64 Certificate. The inadequacies, inequities and shortfalls of the system must be addressed objectively. A cooperative, inclusive and conciliatory based review will result in a far more beneficial outcome. New or prospective land owners must have better access than is currently available, to reliable information, explicitly and more generally about possible noxious weed implications regarding property they are inspecting to buy. It is agreed "information empowers," and that many may be genuinely inexperienced and unaware of potential, undisclosed obligations. It is simply unreasonable to ambush and disenfranchise the unsuspecting without prospect of a comeback, for a positive outcome in and for the big picture.
- For a weed where Best Management Practice (BMP) does not provide reasonable and effective control measures, generally or specifically, it must be further subjected to ongoing research and not just rejected for listing as Noxious. Control requirements should not be conveniently downgraded without due process and objective assessment of supporting data, with criteria also tested against the triple bottom line. Certainly not just taken off the Noxious Weeds list for unquantifiable reasons. Rec 7
- The adaption to a state wide, (dare I say nationally embraced) compatible system based on practical technology is essential to accumulate spatial data from standardised Noxious Weed Inspection Reports, for ongoing evaluation. An analysis of data that has been accumulated generally lacks integrity (accuracy) to be truly indicative and cannot be regarded as convincing. There are too many gaps and variations Rec 6(i) & (ii)
- Decisions to remove weeds from the "Declared list" remain a call of convenience, a symptom of the shortcomings of our weed control approach, a dismissive, offhanded easy

way out and the one that has failed to deliver more, acceptable and achievable outcomes. Inappropriately, they are an epiphany, a perception without foundation, a shortcut that demonstrates contempt for the system. Shamefully, these decisions are taken from a privileged position, fueled by a self-serving logic. Political egoism has initiated the conclusion: "There are too many Noxious Weeds now and we can't do anything about the existing problems. Knock some off, so we, (those in authority) can be seen and considered as proactive by shuffling the deck chairs to include other weeds onto the list!"

- The removals are an arrogant distraction without objective support, taken in self-defense to deny, disguise and excuse, while unconvincingly oblivious to all else, including the inevitable insidious, long-term consequences. Instead it just serves to highlight the failings of past inactions. The unsupported assumption is that the weeds removed are no longer a problem. Once weeds reach a level or extent that is now recognised as the "white flag," a trigger, if you like, for all those irresponsible to duck for cover and without due process, yell out, saying and admitting, "Take them off the list, we have failed."
- Alternatively, do we need to consider or confirm the sobering and questionable scenario? *Ie.* "It's ok now, the weeds are wide spread and will continue to foul the landscape, we have taken them off the list! The past and real problems they created were imaginary. They don't present difficulties now, nor will they be in the future!" Denying their existence or just turning our backs realistically is not the way to effectively manage or contain threatening natural disasters, bushfires or other Biosecurity risk situations!
- Historically, some private landowners along with successive governments (of either persuasion) and their leadership team advisors have, as managers or custodians, "progressively ignored the obvious." By not promoting or supporting the pursuit of effective control as a pre-emptive priority, they have facilitated the proliferation of weeds widely, to further invade neighbors and the environment generally. Try now with hindsight to calculate and justify the resultant compounding opportunity cost blow out, due to past inaction and ineffective control measures! Lost productivity collectively in $ terms, is enormous. While the lost opportunity, cost burden on the wider community, as a remaining debt continues to grow, it may never be extinguished but only written off.
- Relatively and regrettably, it takes two minutes to remove a weed, without transparency, rigor or consistency of "due process" that is supported by objective justification, from the declared list as Noxious. But, conversely it may take anywhere from a standing start, (but rarely) for an emergency declaration and up to 10- 12 years, (if then) to have one included as Noxious! This does not include comment about an LCA's audacity to apply for, (heaven forbid) "A Change, locally" to an imposed Weed Control Category. Is "Local input and consideration" to help determine Regional and Local weed control categories, really on its way for Local Delivery? Ref NW Rec 3(a) (d) &(f)
- Recognising and acknowledging a weed spread problem is one thing, but not acting is to accept the status-quo. The lost opportunity is counter-productive because weeds that do cost the most are those present now, both treated and untreated. Ignoring inherent

responsibility compounds the ongoing impasse and achieves nothing. Problems we (those in authority) see or standards we aspire to but ignore sidestep and fail to alleviate, are the ones others overlook. This breeds apathy, installs a public standard by perception that, objectively, is totally unacceptable. It further damages the environment, disenfranchises individuals, negatively impacts productivities bottom line and the wider community's resilience.

- The ability and ease to transport fodder and livestock is, regrettably and undeniably acknowledged as a High Risk Pathway, for the effective distribution of Noxious Weed material. Mandatory "Statutory Declaration Certificates," (or similar) to cover fodder distribution and establish "Point of Origin with a Destination," to facilitate connectivity via Property Identification Number (PINs) was "Not Supported." Again without objective or convincing reason offered, this was simply overlooked highlighting a lack of understanding, support or commitment from the administration for early detection and prevention. The initiative is a potent "checks and balances" platform for general Biosecurity Obligations and Objectives, by providing vital elements for short and long term positive management prospects with built-in measured starting points. By utilising new technology practically, there must be potential for adaption of a compatible system!
- Weeds listed and known as Invasive Species should be declared as Noxious Weeds so that, supported by regulation and statute under Section 12, we can expect and insist on effective control. Failure to do so questions their integrity and highlights a lack of credibility as invasive problems per-se. The question remains: Why do and how is it that Invasive Plants or Pest Species not declared as noxious, command and are given, a higher priority than some Noxious Weeds?

COMPLIANCE: - "in keeping or accordance with mandatory requirements" (of land ownership)

Bridging the gap between historical behavioral expectations and how we get there, will need to involve: a relevant, specifically targeted strategy, a comprehensive and convincing explanation of the reasons it is needed and contain language about "intent," that details plans involved.

As WO amongst the community we are principally here to:

- **Help** and encourage a mutually beneficial commitment to be forthcoming by providing relevant information to explain "Why!"
- **Not to hinder,** manage or run their operations for them and certainly not just to resolve neighborhood disputes.
- **Showcase** the successful and positive outcomes that clearly demonstrate and prove, "it can be achieved" with relevance to their personal space and situation.
- The rest of whatever we think or assert is, unquestionably, supportive endeavor but only aspirational and therefore open to a variety of interpretations, all of which are objectively unsupported and at best, warm and fuzzy, without measurable or quantifiable outcomes based on, or supported by existing regulation or statute.

This is not intended to be negative but maintains the strategic big picture point of view that is not complicated. But sometimes it can be, when land owners /occupiers fail to accept, recognise or fulfill their mandatory obligations of land ownership. Under these circumstances, as WO, we must not lose sight of or be confused about our obligations. The fact is that Noxious Weed control responsibilities rest with the land owners /occupiers, **not us**. Identifying effective control "Tenure Neutral" is a positive explanation designed to encourage participation and provides an example with good reasons for land owner commitment. We must maintain a reasonable and objectively strategic position by following procedures to fulfill relevant Policy.

LCA Policy must:

- (1) Be binding, to reflect and support the expectation that Weeds Officers (WO) will be proactive and effective.
- (2) Provide all reasonable capacity, including relevant education and training for WO's, with appropriate resources allocated to ensure that control obligations are met as an everyday, Tenure Natural, expectation. In fact, effective control is then expected as the norm, clearly demonstrating that the benefits installed are the foundation base line point, going forward.

When we accept the job and become an authorised WO /inspector, the primary objective of our employment package is clearly polarised and recognisable. We are required with all reasonable intent to ensure so far as practicable, that owners/ occupiers fulfill their obligations to effectively control noxious weeds to satisfy the Objects of the Act. (Section 3) This, both strategically and locally, involves an overarching, oversight of the intended "Outcomes." This expectation is expressed concisely and without ambiguity in Section 12 of the Act.

As weed professionals, our obligation and contribution is to strategically inspect land and report on the presence, or otherwise, of Noxious Weeds. In pursuit of effective control, we must remain alert at all times but not alarmed. We are a conduit for the distribution of current educational advice and material that is essentially capacity building information, to promote and support strategies focused on sound technology that demonstrates clearly the benefits derived from Best Management Practice (BMP) activities.

<u>QUESTION</u> How do we achieve and apply a more consistent outcome expectation**?** Look around now and decide who and where the cap fits**?** Is it because, enough of us (collectively) have been under-performing by failing to deliver the intended outcomes of effective control by land holders? Historically, this has contributed to the perception that the war on Noxious Weeds has been lost under apparently ineffectual Local Control Authorities, (LCA's) through successive NSW Governments and Local Government (LG) administrations. Undoubtedly, this perception has been installed and fueled by the many complaints about us. Not all complaints or questions were baseless and should not have been successively ignored by incumbent administrations that must have been appeased or convinced otherwise, by advisors, both from behind their desks.

What have we failed to do and not achieved? This question may be obliviously or conveniently lost, on selectively deaf ears. However, it is directed to the LCA administrations, dominated by lethargy or those with restrained, hesitant or inactive WO's, who have chosen to avoid or deny the fundamental obligation. Or those, partnered by an inept bureaucratic leadership that has provided oversight and advice, that more than occasionally, has been well wide of the mark and lacking on other Biosecurity issues too.

The fact is, we are and have been perceived as under performers and reformers, falling short on delivering many tangible and measureable results. These are all bad but compelling reasons that explains historically "Why the general malaise," has driven the necessity for the many past enquiries into the Noxious Weeds Act Outcomes. As a last resort of desperation, the principle of "the lowest common denominator" was applied. Hence the solution for the Government of the day was to Legislate. "Change the makeup of the team and system. Transfer Noxious Weed Control Responsibility to LLS". Some will continue to ask, why? Realistically, many of us need to seriously reconsider our position. Collectively, there is no one else to apportion or divert the blame to but ourselves, possibly including some of us at conference.

Ok, yes, as Weeds Officers we are but a few and insignificant in the eyes of some; nevertheless we should not compound or contribute to the shortcomings of underachievers. The challenge is to adopt and maintain a positive mind set. How many Senior Weeds Officers are required to and do (or /don't, because they are not specifically asked to do so!) report their operational activities against their WAP, to encourage and facilitate informed discussion or scrutiny at Council Meetings?

Many are quick to nominate and blame uncooperative, noncompliant land owner /occupiers "with attitude." They play the game with us, because we, whether you agree or not, facilitate and contribute to the result of ineffective control outcomes. It is not the active and effective controllers amongst them that we have an issue with so, guess what the problem is? It is the inept, unconvincing and avoided pursuit of those who are ineffective and noncompliant.

- Some advice offered to and heeded by this old thistle! - It is ok for others to doubt your considered opinion, (ask Peter Andrews) make allowances for that doubt, encourage and allow them their best shot. But, given the first line of defence is often (a verbal) attack; remain receptive, considerate and objectively honest. Be a heard quitter. Continue to search for and analyse points of view outside the (norm) square. Do not be intimidated into accepting hollow defensive or the dismissive assumptions of an alternate, unsupported opinion. Challenge their rhetoric and evaluate the facts.
- Undeniably there is an enormous capacity to move forward with further benefits available by embracing technology, to reclaim lost initiatives and definitely, this has my support.

18th NSW WEEDS CONFERENCE COOMA, NSW
12th - 15th October 2015
"Weeds - The Future, Innovation & Adaptation"

'Conserving biodiversity in grasslands and grassy woodlands and weeding: theory and case studies' by Margaret Ning and Geoff Robertson

**Introduction**

At this conference we shall hear presentations on weeds from a number of perspectives and so we wish to begin my explaining a little of our background. In July 1993, Margaret and Geoff decided to buy a bush block near Nimmitabel. By then we had developed a love of Australian landscapes, plants and birds. We wanted something that was largish, with river frontage and relatively weed free. We were about to live overseas as Geoff had been offered a job that would finance our dream of having such a property. We called the property Garuwanga, Ngarigo for dreaming.

We did not spend any meaningful time there until late 1996. Then we began to collect and record the 340 native plant species we have since discovered. Later we went on to record many birds, reptiles, frogs, some insects and other species. We joined Friends of Grasslands as we considered we could learn much of what we needed to know from the group. We soon found ourselves very involved in its organisation. We were already members of native plant and bird groups and eventually joined many more similar groups. Through these we became very involved in the Monaro Regional Weeds Committee, the Conservation Council for the Canberra Region, Kosciuszko 2 Coast, the ACT Herpetological Association, and the Cooma Rural Lands Protection Board (later the Livestock Health and Protection Authority South-east Region) to mention just some. We have been consulted by many agencies, organisations and land owners and managers who consider we have something to contribute.

The case studies discussed below are dominated by natural temperate grasslands, snow gum grassy woodlands, and yellow box red gum grassy woodlands - acknowledged threatened ecological communities. Grasslands are naturally treeless areas dominated by a diversity of grasses and other herbaceous plants such as wild flowers. Grassy woodlands have a similar grassy storey to grasslands, with higher layers of scattered trees and shrubs. Because grasslands and grassy woodlands have attracted intensive farming and grazing, only small remnants of what existed in 1788 remain. Some grazed areas have retained much of their pre-settlement vegetation due to sympathetic management. Nevertheless, even quality remnant grasslands and woodlands have been highly modified and are prone to weed attack.

This presentation focuses on managing for conservation without the use of stock grazing. This is only one of a number of scenarios that could be considered. Some scenarios could involve 'conservation grazing', where grazing is used to control biomass and weeds, or management for both conservation and production.

**Garuwanga**

Garuwanga is a 270ha property with large areas of natural grassland and grassy woodlands, as well as heath, shrubby woodland, riverine and occasional wet areas, such as water courses, drainage lines and ephemeral springs. It also has some spectacular rocky outcrops and amazing landscape, including many types of riverine landscapes. While most of the property remains relatively weed-free, by early 1997 we discovered we had several small patches of serrated tussock, some large patches of verbascum, and a large hill side ex sheep camp totally weed covered. The worst areas were former sheep camps including an area that had been pasture improved.

Margaret took the initiative, researching various weeds and the best methods of control. She also consulted many practitioners. One friend in particular devoted many hours assisting us. We equipped ourselves with backpacks, over time graduating to two 4WD bikes equipped with spray tanks and long hoses. We acquired bags for collecting weed/ seeds, dauber-doovers for daubing, and hand tools, especially to tackle scattered isolated plants and patches. Additionally, we purchased a large trailer to transport the bikes and a smaller trailer attachable to the quad bikes for moving weeds. We also purchased a slasher to slash heavy infestation of weeds to avoid leaving bare ground. This doubled as a grass cutter. We obtained and maintained our weed certification. We read intensively about individual weed identification and ecology, and methods of weeding and native vegetation restoration. We participated in many presentations, workshops, field days and working bees on weeding and vegetation restoration sometimes as participants, but also as organisers and presenters.

At Garuwanga, we divide weeds (for us any exotic plant) into three categories. First, well established weeds that are noxious or generally regarded as undesirable and which we attempt to eradicate (e.g. serrated tussock; slender, spear, Scotch, nodding and variegated thistle; verbascum; Madagascan fireweed; salsify; and woody weeds such as briar rose, blackberry and hawthorn). Second, isolated noxious and undesirable weeds which have not become established and which we have removed (e.g. St John's wort, vipers bugloss, African love grass, and yarrow). Third, other undesirable weeds which we have not seriously attempted to control (e.g. Yorkshire fog grass, some annual exotic grasses, flat weed and the like, and clover). We conscientiously seek out weeds in the first two categories. For some weeds in the third category we have been contemplating what approaches might work to control them. However, these have remain somewhat beyond our skills and resources.

Weeding is only a component of grassland and grassy ecosystem vegetation management which needs to address biodiversity, biomass, feral animals, fire, fencing and equipment, safety and financial management. One tool which may meet weeding and other objectives is the use of traditional Aboriginal landscape management techniques, especially the use of fire which has much promise. About 10 years ago we entered into an Aboriginal Heritage Agreement with the then Murrumbidgee Catchment Authority to protect Garuwanga for its biodiversity and traditional cultural values, and as part of that we conducted five workshops, sponsored by Friends of Grasslands and the Murrumbidgee CMA, on traditional land management led by Rodney Mason, a traditional land management practitioner. This gave us new insights into land management and we have experimented with the use of fire.

We estimate that annually we devote 350 hours to weeding and spend around $4000 on herbicide and equipment, although the later figure is trending down.

**Friends of Grasslands**

Friends of Grasslands (or FOG) proved useful to us in providing knowledge of and experience in weeding, as well as access to experienced practitioners, as from its earliest days, FOG organised various working bees to assist rural and other landowners and managers. It continued to play this role for a number of years.

In this presentation we will focus on FOG projects associated with Old Cooma Common Grassland Reserve, the National Capital Authority sites, and Hall Cemetery to provide examples of case studies.

**Old Cooma Common Grassland Reserve**

About 1998, David Eddy, then working for the World Wide Fund for Nature as the Monaro Grassland Officer established the Monaro Grasslands Conservation Management Network (CMN). He persuaded FOG to apply for a grant to establish a grassland reserve at the Cooma site then known as Radio Hill which contained a high quality natural temperate grassland, and the best known population of the Monaro golden daisy. The Cooma

**Friends of Grasslands Working Bees to Dec 2014**

| | No of activities | No of volunteers | Total hours | Value* |
|---|---|---|---|---|
| **Old Cooma Common Grassland Reserve** | 36 | 306 | 1876 | $51,590 |
| **Hall Cemetery** | 22 | 158 | 700 | $19,250 |
| **National Capital Authority lands** | 65 | 994 | 4509 | $123,998 |
| **Total** | 123 | 1458 | 7085 | $194,838 |

* Valued at $27.50 an hour.

Monaro Shire Council is responsible for this site which it manages as a Crown Land Reserve. FOG applied for and received the grant and thus began a more than 15 year partnership between Council and FOG. Margaret played a key role in organising FOG working bees at the site which later became known as Old Cooma Common Grassland Reserve.

The initial grant paid for fencing of the site, signage, a brochure, herbicide and a genetic study on the Monaro golden daisy. Cooma Council organised for African love grass spraying and FOG arranged fencing and organised many working bees which removed the woody weeds. Weeds such as great mullein, vipers bugloss, cinquefoil and many more are also prevalent. However, these have not been a priority.

FOG's objectives at the time were to assist the launch of the Monaro Grassland CMN and to assist it to promote grassland conservation and management, to undertake many working bees in the first year and thereafter occasional working bees to remove woody weeds, to find funding to tackle other weed issues, and to encourage local people to take on the long-term roll of care-taker for the reserve. FOG met these objective except the last. Although local Cooma people have been involved, FOG was unsuccessful finding local people to take on the longer term management responsibility.

FOG's working bees comprised a mix of people with varying skills. Tasks undertaken were chain-sawing, cutting and daubing, and weed spraying from back packs, quad bikes, 4WD motor vehicles, or Council's high intensity weeding equipment. The relationship with Cooma Council has been a strong one, and it and FOG have organised a number of grants to have African love grass professionally controlled from time to time. FOG organised its last working bee at Old Cooma Common in 2012.

An invasive weed to emerge was St John wort. In response, FOG organised a series of working bees to spot and boom spray the wort using a few highly skilled volunteers in a series of multi-day working bees in which the volunteers once even camped overnight at the reserve. On other occasions funds have been found, including use of Council resources, to employ professional sprayers to control the wort.

FOG's involvement at the Common had a number of external benefits. FOG learn important lessons about project management and sourcing finance; FOG's knowledge of weed management was enhanced; volunteers received training and their skills were greatly improved; FOG education and advocacy programs were better informed and carried greater authority; FOG received suitable media coverage; and all the proceeding benefits enhanced the profiles of FOG and grasslands.

Earlier this year FOG applied for a grant to obtain funds to spray African love grass and St John's wort at Old Cooma Common and two other nearby reserves, particularly focused on the protection of the Monaro Golden Daisy. If successful, FOG will undertake monitoring of these sites and conduct annual field days to explain the importance of the sites and methods to control weed issues.

**Hall Cemetery**

FOG members have visited Hall Cemetery in the Australian Capital Territory over many years. A key attraction is the Hall or Tarengo leek orchid. This once widely spread grassland orchid is now only known from a few sites. Oddly the orchid found a home in the main section of the Hall Cemetery, a secondary grassland (that is, the original scattered trees and scrubs have been removed leaving a treeless area). It was recognised that the orchid population faced a new threat when eucalypts started to regenerate. At the request of the ACT government, FOG took on a project in conjunction with the Government and ACT Cemeteries Trust to hand remove the regenerating trees and their roots. Once achieved FOG then focussed its attention on the removal of woody and herbaceous weeds from the adjoining woodland and verge areas. While this task is ongoing, FOG has since turned its attention to removing phalaris which is being replaced by colonising microleana. Andy Russell became the first coordinator of this project and John Fitz Gerald took over this role when Andy stood down.

**National Capital Authority Land**

The National Capital Authority (NCA) is the Commonwealth agency responsible for certain aspects of ACT planning and for managing certain lands in Canberra. Like many government agencies, funds for weed and biodiversity management are limited. FOG member Jamie Pittock, who has had a long association with grassland conservation, put forward a proposal to FOG. His proposal led to FOG approaching the NCA with the suggestion that NCA and FOG should form a restoration/weeding partnership. When approached, the NCA readily agreed as it saw this as a practical way forward to manage its biodiversity and weeding responsibilities.

For its part the NCA devised a management plan for several of its sites, particularly Stirling Ridge, a large woodland area that has been set aside for a future Prime Minister's residence, and Yarramundi Reach, a large grassland remnant adjacent to Lake Burley Griffin. Both were deteriorating from lack of adequate management. The NCA agreed to finance larger weeding and biodiversity management tasks dictated by the plan, while FOG organised regular working bees to remove woody and herbaceous weeds using volunteers. FOG targeted tertiary students, appealing to their sense of community responsibility, and offering skills training and an experience in working in a diverse threatened grassy ecosystem. The NCA agreed to supply funds to FOG for equipment, herbicides, training and catering. Jamie Pittock has since coordinated this work and recruited some very able assistants to share the workload. For example John Fitz Gerald, Peter McGhie, Sarah Sharp and Margaret, between them, spend numerous hours organising working bees, planning on-ground work, organising surveys and monitoring, providing technical expertise, and transporting equipment. Many local residents near Stirling Ridge (or Stirling Park as FOG likes to call it) now play a major role in organising and participating in working bees.

FOG does not engage in on-ground work unless the project meets FOG's goals of protecting and managing important grassland and woodland areas, educating target groups and the community more broadly on the importance of grasslands/woodlands and their management, and imparting training and skills to volunteers. These objectives are being achieved at all of FOG's project sites. Other FOG goals were to stop and reverse further deterioration of these sites and, by creating a sense of community ownership, prevent their being converted to a non-conservation use.

**Gundharwar**

I would like to mention briefly another case study that brings out a very useful lesson. Gundharwar is a 100 acre property on the Murrumbidgee River near Michelago owned by Tony and Gill Robinson. This might be described as a life-style block with grasslands and a scattering of other vegetation communities. There is no grazing. Tony is active in landcare and Kosciuszko to Coast and conscientious about his weeds. He has been using a backpack and measuring the number of litres of herbicide he has used each year. His very precise records and graphs show a clear trending down in his use of herbicide as he has brought various weeds, particularly African love grass and St John's wort, under control.[1]

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[1] The main weeds are St John's wort, viper's bugloss, great mullein and African love grass, while minor weeds include sweet briar, horehound, serrated tussock, saffron thistle and fleabane. Tony divided the property into zones and added a new zone into his weed plan each year. He has estimated that he spends

**What we have learnt**
Through attending numerous conferences, workshops and the like, and through our on-ground experience and research, we have learnt a number of valuable lessons.

First, natural temperate grasslands and grassy woodlands are less than 5% of their 1788 area. Nevertheless remnants are important for their biodiversity, ecosystem services and as a source of valuable plant material for farming and landscape management. Unfortunately many remnants no longer function as they once did and are weed prone.

Second, weeds out compete and shade out native vegetation and are usually not suitable as a food source for native insects and larger animals, and hence if unchecked they create a break in the food chain and are poor habitat for native vegetation and fauna.

Third, grasslands and woodlands require active intervention to manage biomass and weeds and if left unattended they simply deteriorate and become weedy. At Garuwanga we are reminded of this every time we look over our neighbour's fence.

Fourth, good weed management requires clearly identifying objectives, developing a weeding strategy, knowing the ecology of wanted and unwanted plants, training in and experience of herbicides and equipment, and, most importantly, having the appropriate resources, including financial, to carry out the task. There is a lot to be said for trial and error and adaptive management but, as projects get larger, formal planning and monitoring are essential. Integrated weed management is a useful concept in this context.

Fifth, important elements of a weed strategy are knowing weed life cycles, stopping seed dispersal, and focusing on larges patches of weeds as well as isolated and scattered plants.

Sixth, examining our attitudes to landscape management. Since becoming involved in grassland conservation, we have probably completely changed our attitudes on every aspect of grassland management. In particular we can possibly learn from traditional (Aboriginal) landscape management. The first lesson is that our grasslands and woodlands are cultural landscapes and hence have always been managed since Aboriginals settled this region. Rediscovering and reintroducing traditional practices, or suitable alternatives, is likely to assist in land management and weed management in particular.

Seventh, FOG's projects on public lands have worked well because of FOG's close partnership with the institutional owner, clearly and mutually defined objectives underpinned by a management plan, the iconic nature of the sites chosen, and the opportunities provided to FOG and community volunteers to contribute to a worthwhile social and environmental objective and to learn skills.

Eight, we need to become strong advocates for better land management. However, a prerequisite is to identify clearly what the objectives of this advocacy are, given the huge dimension and complexity of weeding issues, and the very limited resources available to

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almost $10,000 a year, including herbicide, dye, and equipment when he factors in his own labour cost at $30 an hour.

combat weeds. Those objectives might differ according to who owns the land and the purpose for which it is managed. We also need to change attitudes to weeding and we might focus on the following messages:

1. Good land management practices lead to better production and or conservation outcomes.
2. A good neighbour ensures that his or her property is not a weed source.
3. Prevention is better than cure, and eventually cheaper.
4. Weeding raises the aesthetic and economic value.
5. Landowners and managers need to plan properly and to resource weed management.
6. Weed management is equally the responsibility of urban land owners.
7. There is a need to strengthen legislation and enforcement and to have, say, a three-yearly weed audit which must be drawn to the attention of property purchasers.
8. It is essential that weed management training is set within the context of holistic farming management and or bush regeneration (which takes an integrated approach to conservation management and restoration). Such training should address all methods of weed control and illustrate the use of traditional land management practices, especially the use of fire.
9. There needs to be increased extension services and provision of training to assist landowners to understand their responsibilities and acquire the necessary skills and resources. Current training and its delivery should be reviewed.
10. More emphasis should be placed on the creation of bush regeneration teams to manage public lands - note such teams take integrated land management approaches rather than a focus on just high priority weeds.
11. There needs to be more funding for research into weeds, their impacts, methods of control and integration into broader management practices. Cuts to research is a scandal.
12. Attention should be paid to the development of strategies that integrate chemical and non-chemical weed control methods and that address threats to weed management. These should address the concerns raised by the anti-chemical brigade and possibly the overuse, or inappropriate use, of herbicides.

**Acknowledgements**

Finally, we would like to acknowledge the many people that have contributed to assisting us to gain the knowledge and experience. We would also like to thank David Eddy, John Fitz Gerald, Jamie Pittock and Sarah Sharp who have provided information on FOG's experience and to Tony Robinson for his contribution; FOG's institutional partners with whom we have established a deep rapport; Brett Jones for his enthusiasm and friendships over many years; and the Weeds Conference Committee in accepting our presentation.

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**Initial identification and prioritisation of invasive weeds in the Kosciuszko to Coast Partnership (K2C) corridor**

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**Summary**

Weed management remains a central problem for landscape-scale conservation projects both in Australia and globally. However, relatively little is known about the invasive species that tend to be favoured by increasing landscape connectivity, and whether these have the greatest impact on broad-scale conservation goals. In this paper we provide an initial identification and prioritization of the weed species that have the greatest impact on biodiversity conservation projects undertaken in the southern and central Kosciusko to Coast (K2C) Partnership corridor area of south-eastern NSW. We show that the control of invasive weeds remains a significant problem for virtually all landowners and land managers in the region, and that consistent with expectation, there was strong evidence that *Hypericum perforatum* (St. John's wort), *Rubus fruticosus* (blackberry) and several annual or biennial species tend to increase under management regimes designed to benefit native biodiversity. However, the most serious invaders were invasive grasses species like *Eragrostis curvula* (African lovegrass), *Nassella neesiana* (Chilean needle grass) and *Nassella* trichotoma (serrated tussock), which degrade both agricultural and conservation land use types and drive reorganisation of infested socio-ecological systems. Local successes in controlling these species were *E. curvula* and *N.neesiana* were not replicated at regional scales, and the intractability of managing *E. curvula* infestations indicates that this species must now be considered a critical threat to the viability of biodiversity conservation and agricultural production across the K2C region. There is a strong need for further research into the impacts of invasive weeds on functional landscape connectivity and the development of integrated weed management strategies for the most damaging species.

**Introduction**

Increasingly, conservation initiatives both in Australia and globally are adopting landscape-level planning to encourage the conservation of native biodiversity alongside other human land uses (Doerr *et al.* 2011). At this scale, management of the composition and proportion of different land use types and their level of connectivity is aimed at facilitating animal and plant dispersal (Hilty *et al.* 2006), thus allowing viable metapopulations to persist on otherwise fragmented habitat. Landscape-level conservation initiatives often involve protection of high conservation value areas, rebalancing human and conservation needs in agricultural areas, and enhancing structural connectivity among remnant patches by revegetating and restoring degraded areas. In this way, the long-term sustainability of the entire socio-ecological system is potentially improved.

Weed control is often a central focus of management in conservation initiatives, since they often hinder the establishment of newly planted tubestock (Cole & Lunt 2005), compete with native plant communities (Snell *at al.* 2007), or harbor feral animals (White *et al.* 2006)**.** However, very little is known about the characteristics of weed species that are most detrimental to these projects, or about species-level responses to management strategies put in place to preserve native vegetation (e.g., restriction or removal of livestock grazing) or establish new connectivity (e.g., tree plantings). While we might expect animal-dispersed weeds to benefit from such changes, other species capable of invading both agricultural and conservation areas, like some invasive grasses (e.g., Osmond *et al.* 2008), may pose an even greater threat to landscape conservation.

In this paper we report the results of a study aimed at providing an initial identification and prioritization of the weed species that have the greatest impact on biodiversity conservation projects undertaken in the southern and central Kosciusko to Coast (K2C) Partnership corridor area of south-eastern NSW. The objective of the K2C Partnership is to conserve and restore native flora and fauna in the region, and to increase connectivity between forested areas of the Snowy Mountains and the coastal escarpment, the latter as part of the broader objective of the Great Eastern Ranges corridor initiative (Pulsford *et al.* 2013).

**Materials and Methods**

Data on weed prevalence, impact and control were collected during a series of in-person interviews of fifteen landowners and several regional land managers from southern and central parts of the K2C Partnership area. The landowners were concentrated in the Monaro region of the Southern Tablelands (12), with a further two in the eastern Australian Capital Territory (ACT) and one in the Shoalhaven Region of the north-eastern K2C (Fig. 1). These covered a total of 15,316 hectares of private land. One survey participant provided two surveys; one for the Murrumbidgee River corridor and the other for the whole property, including dry sclerophyll forest. An additional seven regional surveys were conducted (Fig. 1), two covering the whole of the Cooma Shire (518,000 ha), one centred on the Bredbo region of the northern Monaro, one covering the entire K2C region, and three in the ACT. The latter three surveys covered wet sclerophyll forest, riparian and box gum grassy woodland (BGGW) communities, urban lowland grassland, and BGGW of the north-east ACT, but only provided information related to biodiversity/corridor areas. Potential survey candidates were identified by contacting local public land management bodies (e.g., shire or territory) and K2C Partnership Facilitators.

Surveys were conducted using in-person interviews that usually lasted between 30 mins and one hour in duration. Questions covered basic property information (size, property type, farming methods and types of farm management actions undertaken for a biodiversity benefit) and the nature of invasive weeds at both the whole-farm or regional scale and within areas managed specifically for biodiversity and/or landscape connectivity. Key questions included: 1) which invasive weeds were considered the worst at the whole property/region (i.e. those that have greatest potential to seriously impact property/management operations); 2) which weeds were considered worst in areas managed for biodiversity/connectivity; 3) which species became worse over the duration of the biodiversity/connectivity project; and 4) which species required management and how successful this management was. For question two, survey participants listed the top five species, which were given scores indicating their severity between 6 and 2 in descending order, and any other significant species, which were each given a score of 1. For the last question, survey participants were asked to rank control success according to the following scale: 0 = completely unsuccessful, 1 = mostly unsuccessful, 2 = moderately successful, 3 = very successful, and 4 = complete success.

For each weed we calculated the frequency of occurrence (number of records) and the mean severity score at the general property or regional scale and also within biodiversity/connectivity projects. We also calculated, for the most significant species, the mean success score of control measures.

**Results**

Private properties ranged in area from <50 ha to 5000 ha, and were mainly managed either as commercial grazing enterprises or as a mix of lifestyle, conservation and commercial land use types. Some properties undertook cropping on limited areas. Ten of 15 properties contained biodiverse plantings, with a significant majority also undertaking grazing management (11), fencing (12), pest animal control (9) and weed control (13) to improve farm-scale biodiversity outcomes. A minority of properties used management techniques such as fire, shelterbelts, soil stabilisation and soil manipulation to control weed species. Work conducted in eight of 15 properties was formally included in a regional corridor (K2C) or connectivity initiative. Across all properties, key vegetation types included box gum grassy woodland, dry sclerophyll forest, native and derived grassland and alluvial or riverine systems.

A total of 36 problematic weed species were recorded by property owners and regional managers, four of which were native (Table 1). The most frequently recorded species at the whole property scale ('overall weeds') were *Eragrostis curvula* (African lovegrass; 93% of properties), *Hypericum perforatum* (St. John's wort; 80%), *Nassella trichotoma* (serrated tussock; 73%), *Rosa rubiginosa* (sweet briar; 60%), and *Verbascum* spp. (mainly *V. thapsus*; 53%). Thistles were recorded in 14 properties (93%), the most important being *Carthamus lanatus* (6 properties) and *Onopordum acanthium* (5). Regional managers recorded a further three overall weed species (Table 1), but collectively their species list was similar to that provided by landowners.

Both landowners and regional managers rated *E. curvula* as the most serious overall weed (mean severity score ($Sev_{mean}$ = 5.14 and 5.75 respectively; Table 1), although *N. trichotoma* was almost as severe ($Sev_{mean}$ = 5.09 and 5.33). Other severe and more widespread general weeds include *H. perforatum*, *Rubus fruticosus* (blackberry), *Rosa rubiginosa* and various thistles. Other species, such as willows and garden escapes (Grevillea hybrid 'annual gem') were very significant in specific locations. Regional managers also rated *Nassella neesiana* (Chilean needle grass) as being of high overall severity ($Sev_{mean}$ = 3.5), but by chance this species did not occur on any of the specific properties surveyed.

Within biodiversity and connectivity projects ('conservation area weeds'; Table 1), where 30 weed species were recorded, regional managers consistently ranked *E. curvula* as the most serious ($Sev_{mean}$ = 5.57), significantly ahead of *N. neesiana* (4.25), *N. trichotoma* (4.00), *H. perforatum* (3.43) and *R. fruticosus* (2.4). Data from landowners were similar, although they rated *N. trichotoma* as being slightly more severe than *E. curvula* ($Sev_{mean}$ = 5.18 vs 4.75), and considered thistles to be a major problem ($Sev_{mean}$ = 3.5). Virtually all species were recorded less frequently in biodiversity/connectivity projects than on farms in general, although willows were an important exception.

Of the most widespread species, the most difficult to manage at the property scale (Table 2), by a significant margin, was *E. curvula* (mean success score, SSmean = 2.29), followed by *H. perforatum* (2.63), thistles (2.67), *N. trichotoma* (2.73) and *R. rubiginosa* (3.2). Interestingly, however, control of all of these species except *R. rubiginosa* proved challenging under certain circumstances (SSmin = 2, equating to moderately successful), with *E. curvula* often being intractable (SSmin = 1; mostly unsuccessful). This view was confirmed by regional managers, who rated control of *E. curvula* (and also *N. neesiana*) as mostly unsuccessful to moderately successful (SSmean > 1 to < 2). Interestingly, regional managers rated the success of control measures for virtually all species much lower than did property owners (Table 1), indicating that regional control is generally more challenging than it is at the individual farm scale. Indeed, these managers indicated that *E. curvula* and *N. neesiana* appear to be still spreading across the K2C region.

*Eragrostis curvula* was mentioned by 11 survey participants as becoming an observably worse weed over the duration of conservation projects, more than twice as many as *N. trichotoma* (5) and *H. perforatum* (4). Furthermore, only 5 respondents (31%) indicated that *E. curvula* was under control, a lower proportion than for *N. trichotoma* (6 respondents; 54%) and *H. perforatum* (3 respondents, 43%). Other species such as *R. futicosus, N. neesiana, Onopordum acanthium* were recorded as becoming worse by two or fewer respondents, although it was clear that under some circumstances their control was difficult. The most successfully controlled significant weed species appeared to be *R.*

*rubiginosa*, with no respondents indicating an increase in abundance and three indicating successful control.

**Discussion**

Our data support the view that the control and management of weeds remains a central problem at property to regional scales within the Kosciuszko to Coast Partnership area. While this is unsurprising, several important features of the weed assemblage appear to have important implications for the viability of conservation-related projects at both on-farm and broader spatial scales in the future.

First, it is clear that despite the fact that the invasive flora the K2C region is both floristically diverse and ecologically heterogeneous, only a restricted number are pervasive at the landscape scale, and even fewer appear to pose major problems for effective control and management. The most important species in the study area, according to both landowners and regional managers, are *E. curvula, N. trichotoma, H. perforatum, R. fruticosus, R. rubiginosa*, and a group of annual or biennial species that includes thistles, *Verbascum* spp., and *Echium* spp.. Among these species, however, *E. curvula* clearly emerges as the most serious weed threat to regional conservation in the K2C Partnership area.

This low-palatability species, which tends to form extensive areas of relatively unproductive grassland (Robinson & Whalley 1991) with a greatly impoverished native flora, clearly has the capacity to invade on-farm conservation project sites while at the same time threatening the viability of grazing enterprises (Firn 2009). By generating a large standing body of above-ground biomass, *E. curvula* also has the capacity to alter the intensity and behaviour of fire in infested areas, which may be an example of the grass/fire feedback dynamic associated with other invasive grasses (e.g., Brooks *et al.* 2010). Most landowners and land managers (69%) in the study region report increasing abundance of *E. curvula* over time, with control efforts being mostly unsuccessful to only moderately successful. Success is clearly higher when infestations are identified and targeted in early stages of the invasion process. Landowners note that the difficulty in controlling *E. curvula* is greatly increased by invasion from adjacent properties where control is lacking, property subdivision into smaller lifestyle blocks, lack of species recognition by new landowners, and spread by native animals, especially kangaroos. The fact that at least one survey participant reported that kangaroo culling was a key strategy for controlling the spread of *E. curvula* illustrates the way that interactions between non-native and native species, especially across trophic levels, can greatly complicate weed control in biodiversity conservation initiatives.

The general intractability of *E. curvula*, especially at the regional scale, differs in some important ways from that of *N. trichotoma*, which, as a Weed of National Significance (WONS; Osmond *et al.* 2008) has been the target of broad-scale efforts for several decades. Indeed, a significantly higher proportion of landowners report successful control of *N. trichotoma* than *E. curvula*, a difference which was even more notable at the regional scale (mean success score 2.4 vs. 1.5 for *E. curvula*). While control of *N. trichotoma* certainly depends on sustained effort at high economic cost, most landowners appear to consider it to be at least a tractable problem. In contrast, many noted the lack of any realistic, economically viable options for controlling *E. curvula*, and several even regretted not selling their properties when *E. curvula* was first noticed. *Nassella neesiana* is another exotic perennial grass species which has proved extremely difficult to manage, and given its severe impacts on both agricultural profitability and biodiversity conservation (Snell *et al.* 2007) is likely to be an increasing problem in the K2C area in the future. Collectively, all three species appear capable of significantly transforming the social and ecological attributes of entire landscapes, including high conservation value areas. There is an urgent need for new integrated management strategies to improve control of these species at the regional scale.

As expected, several species appear to directly benefit from management practises conducted in biodiversity conservation projects. Perhaps the most important of these is *H. perforatum*, which often increases in abundance following livestock removal (Campbell *et al.* 1995). As a consequence, it is a growing problem in “lifestyle” properties which often have little or no grazing, and can dominate native grassland, woodland and restored native vegetation (Buckley *et al*. 2003), particularly due to the potential impact of herbicides on non-target species. In contrast, *R. fruticosus* appears to directly benefit from increased movement of animals through revegetated parts of the landscape. Indeed, foxes, birds, and wombats often move along fencelines or through tree plantings, rapidly spreading seed into conservation areas from adjoining infested areas (often public land). Populations build up rapidly, and once established chemical control is virtually impossible without very significantly damaging revegetation tubestock.

Interestingly, while *R. fruticosus* has long been abundant in moister sclerophyll forests across the western ACT and along the Murrumbidgee River corridor, it has, until recently, been less common in the Monaro. However, a recent trend towards higher summer rainfall is reported by some respondents to be significantly increasing the invasiveness of *R. fruticosus* in this region, and observation which deserved further study. While control of *R. fruticosus* is often successful, its tendency to grow in rocky, steep and inaccessible terrain causes significant logistical problems for those using heavy equipment to apply herbicides to infestations. Finally, annual grasses and forbs frequently increase following grazing exclusion, and so management of infestations using livestock can be attractive even in areas targeted for conservation.

Another interesting result was that regional managers tended to give weed control success scores that were considerably lower than those provided by landowners. These data indicate that while many landowners experience moderate to high levels of success in their weed control efforts, at broader spatial scales most species, and especially *E. curvula, N. neesiana* and *H. perforatum*, continue to expand, resulting in an ever-increasing regional propagule pressure (Simberloff 2009). The pattern that emerges is one of a landscape gradually becoming dominated by these species, with only specific, targeted areas remaining at lower densities. Over time, it appears likely that such areas will become the exception, rather than the rule. The decision taken by many landowners to simply live with species like *E. curvula*, combined with subdivision of large agricultural properties and an increase in absentee or “lifestyle” property owners, will likely hasten this perhaps inevitable process.

While it is clear that many of the weed species identified in this paper can adversely affect native plant communities and broader biodiversity conservation goals, surprisingly little is known about the impact of most on functional landscape connectivity for native flora and fauna. Invasive species can, for instance, have disastrous transformational effects on entire ecosystems (e.g., D’Antonio & Vitousek 1992), and weeds that dominate the ground layer are likely to adversely affect native plant species with short dispersal distances. Yet many, including grasses, can also provide habitat or resources for endangered species (e.g., Richter *et al*. 2013), and even play a role in reducing erosion and other drivers of landscape degradation. The degree to which weeds reduce functional connectivity for native assemblages requires further targeted studies if the benefits of future landscape-scale conservation work are to be maximised.

**Conclusions**

The results of our survey indicate that the control of invasive weeds remains a significant problem for virtually all landowners and land managers undertaking projects to enhance biodiversity conservation and landscape connectivity within the Kosciuszko to Coast corridor Partnership. Consistent with expectation, there was strong evidence that *Hypericum perforatum* and a range of annual species increase in abundance following livestock removal, and that *Rubus fruticosus* benefits from increased movement of birds, foxes and wombats along fencelines and through revegetation areas. Future projects will clearly need to anticipate these weed responses to land use change. However, the most serious invaders were species like *Eragrostis curvula*, *Nassella neesiana* and *Nassella trichotoma* that degrade both agricultural and conservation land use types and drive broad-scale landscape transformation and socio-ecological reorganisation. Control of all of these species has been particularly challenging at the regional scale, and *Eragrostis curvula* must now be considered a critical threat to the viability of biodiversity conservation and agricultural production across the K2C region. There is a strong need for further research into the impacts of invasive weeds on functional landscape connectivity and the development of integrated weed management strategies for the most damaging species.

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Table 1. Weed species identified by landowners and land managers at property and regional scales in the K2C Partnership corridor area. Species lists are provided for both conservation areas and overall, including agricultural areas. Numbers in brackets refer to the number of relevant surveys conducted, while 'records' indicated the number of surveys in which a species was recorded. Mean severity is the average severity score across all surveys in which the species was recorded. * = native species.

| | **Overall weeds** | | | | **Conservation area weeds** | | | |
|---|---|---|---|---|---|---|---|---|
| | Properties (n = 15) | | Regional ( n = 4) | | Properties (n = 16) | | Regional ( n = 7) | |
| Species | Records | Mean severity | Records | Mean severity | Records | Mean severity | Records | Mean severity |
| *Eragrostis curvula* (African lovegrass) | **14** | 5.14 | **4** | 5.75 | 12 | 4.75 | 7 | 5.57 |
| Thistles | **14** | 2.43 | 1 | 3.00 | 10 | 3.50 | 2 | 2.00 |
| *Carduus nutans* (nodding thistle) | 3 | 3.67 | 1 | 2.00 | 2 | 1.50 | 1 | 1.00 |
| *Carthamus lanatus* (saffron thistle) | 6 | 1.50 | 1 | 2.00 | 3 | 1.67 | - | - |
| *Cirsium vulgare* (black thistle) | 1 | 2.00 | - | - | 1 | 2.00 | - | - |
| *Onopordum acanthium* (Scotch thistle) | 5 | 2.40 | 1 | 3.00 | 3 | 5.33 | - | - |
| *Hypericum perforatum* (St. John's wort) | **12** | 3.67 | **4** | 3.50 | 9 | 3.44 | 7 | 3.43 |
| *Nassella trichotoma* (serrated tussock) | **11** | 5.09 | **3** | 5.33 | 11 | 5.18 | 5 | 4.00 |
| *Rosa rubiginosa* (sweet briar) | **9** | 2.67 | **3** | 2.67 | 6 | 3.00 | 3 | 1.33 |
| *Verbascum* spp. (*thapsus*) (Aaron's rod) | 8 | 2.13 | 1 | 2.00 | 6 | 2.83 | 3 | 1.00 |
| *Echium vulgare* (Viper's bugloss) | 7 | 1.43 | 1 | 1.00 | 3 | 1.00 | - | - |
| *Rubus fruticosus* spp. agg | 5 | 3.80 | **3** | 2.33 | 8 | 3.75 | 5 | 2.40 |
| *Echium plantagineum* (Paterson's curse) | 5 | 2.40 | 1 | 1.00 | 4 | 1.75 | 2 | 1.00 |
| *Conyza* spp. (fleabane) | 4 | 1.00 | 1 | 2.00 | 4 | 1.00 | - | - |
| *Marrubium vulgare* (horehound) | 3 | 2.33 | 1 | 3.00 | 3 | 3.00 | - | - |
| Exotic annual grasses | 3 | 1.00 | - | - | 2 | 3.50 | 1 | 1.00 |
| *Avena barbata/fatua* (oat) | 1 | 1.00 | - | - | 1 | 5.00 | 1 | 1.00 |
| *Hordeum* spp. (barley grass) | 1 | 1.00 | - | - | - | - | - | - |
| *Senecio madagascariensis* (Madagascan fireweed) | 2 | 3.00 | 1 | 3.00 | 2 | 3.00 | 1 | 3.00 |
| *Salix* spp. | 2 | 1.00 | 1 | 5.00 | 4 | 3.00 | 1 | 4.00 |
| *Grevillea* hybrid 'Canberra Gem'* | 1 | 5.00 | - | - | 1 | 5.00 | - | - |
| *Ulex europaeus* (gorse) | 1 | 2.00 | - | - | - | - | - | - |
| *Holcus lanatus* (Yorkshire fog) | 1 | 2.00 | - | - | 1 | 3.00 | - | - |
| *Kunzea* spp.* | 1 | 2.00 | - | - | 1 | 2.00 | - | - |
| *Chondrilla juncea* (skeleton weed) | 1 | 1.00 | - | - | - | - | - | - |
| *Cytisus* spp. (broom) | 1 | 1.00 | 2 | 1.00 | 1 | 1.00 | 2 | 2.00 |
| *Hypochoeris glabra/radicata* (flatweed) | 1 | 1.00 | - | - | - | - | - | - |
| *Amaranthus* spp. | 1 | 1.00 | - | - | - | - | - | - |
| *Pteridium esculentum* (bracken)* | 1 | 1.00 | - | - | 1 | 1.00 | - | - |
| *Nassella neesiana* (Chilean needle grass) | - | - | 2 | 3.50 | - | - | 4 | 4.25 |
| *Salvia reflexa (mintweed)* | - | - | 1 | 2.00 | - | - | - | - |
| *Conium maculatum (hemlock)* | - | - | 1 | 1.00 | - | - | - | - |
| *Phalaris aquatica* (Phalaris) | - | - | - | - | 2 | 3.50 | 1 | 1.00 |
| *Hieracium aurantiacum* (hawkweed) | - | - | - | - | - | - | 1 | 1.00 |
| *Crataegus monogyna* (hawthorn) | - | - | - | - | - | - | 2 | 1.00 |
| *Cotoneaster glaucophyllus* (cotoneaster) | - | - | - | - | - | - | 2 | 1.00 |
| *Pyracantha angustifolia* (firethorn) | - | - | - | - | - | - | 1 | 1.00 |
| *Acacia baileyana* (Cootamundra wattle)* | - | - | - | - | - | - | 1 | 1.00 |

Table 2. Mean control success scores for weeds in conservation areas provided by landowners (properties) and regional land managers in the K2C Partnership corridor area. Control success was scored as 0 = completely unsuccessful, 1 = mostly unsuccessful, 2 = moderately successful, 3 = very successful, and 4 = complete success.

| | Properties | | | | Regional | | | |
|---|---|---|---|---|---|---|---|---|
| Species | Records | Mean | Max | Min | Records | Mean | Max | Min |
| *Eragrostis curvula* (African lovegrass) | 12 | 2.29 | 3 | 1 | 6 | 1.5 | 2.5 | 1 |
| *Nassella trichotoma* (serrated tussock) | 11 | 2.73 | 3 | 2 | 4 | 2.38 | 3 | 2 |
| *Hypericum perforatum* (St. John's Wort) | 8 | 2.63 | 3 | 2 | 3 | 2 | 2.5 | 1.5 |
| Thistles | 6 | 2.67 | 3 | 2 | | | | |
| *Carduus nutans* (nodding thistle) | 2 | 2 | 2 | 2 | | | | |
| *Onopordum acanthium* (Scotch thistle) | 1 | 3 | | | | | | |
| *Rosa rubiginosa* (sweet briar) | 5 | 3.20 | 4 | 3 | | | | |
| *Rubus fruticosus* spp. agg | 3 | 2.67 | 3 | 2 | 2 | 2.5 | 2.5 | 2.5 |
| *Echium plantagineum* (Paterson's curse) | 2 | 2.25 | 2.5 | 2 | | | | |
| *Salix* spp. | 2 | 3 | 3 | 3 | 1 | 2.5 | | |
| *Verbascum* spp. (*thapsus*) (Aaron's rod) | 2 | 3 | 3 | 3 | | | | |
| *Marrubium vulgare* (horehound) | 1 | 3 | | | | | | |
| *Ulex europaeus* (gorse) | 1 | 3 | | | | | | |
| *Senecio madagascariensis* (Madagascan fireweed) | 1 | 4 | | | | | | |
| Exotic annual grasses | 1 | 1 | | | | | | |
| *Avena barbata/fatua* (oat) | 1 | 1 | | | | | | |
| *Nassella neesiana* (Chilean needle grass) | | | | | 3 | 1.67 | 2 | 1 |
| *Cytisus* spp. (broom) | | | | | 1 | 2 | | |

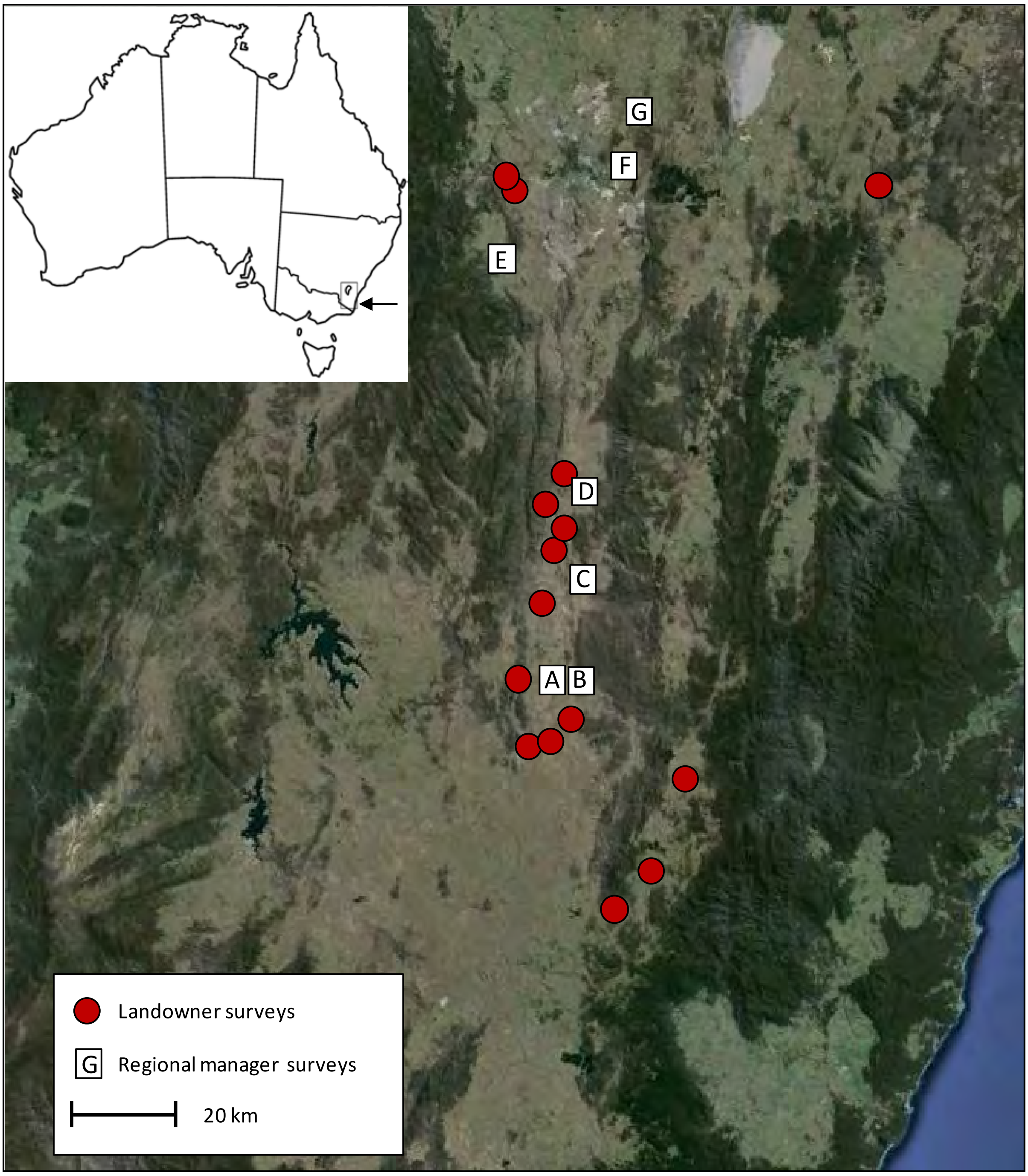


Figure 1. Locations of properties and regions surveyed during the study. White markers indicate the approximate centre of the areas covered under the regional manager survey; A + B = Cooma Shire, C = Bredbo region, D = whole K2C region, E = western ACT (mainly wet sclerophyll forest), F = native grassland , G = box gum woodland of the north-eastern ACT.

# A collaborative approach to the impacts of a changing climate: Early detection of emerging weeds in the Australian Alps

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## Summary

Australian Alpine ecosystems are strongly valued for their biodiversity and cultural assets; however they are restricted in occurrence and are highly vulnerable to climate change. In the Alps, temperatures are on the increase and precipitation and snow duration has decreased. This is a global trend in alpine systems and these changes provide opportunities for new weed species to establish. The number of weed species in the Australian Alps has been on the increase since the 1950's. Infrastructure associated with hydroelectricity and recreational pursuits have provided a conduit for weeds to be transported from surrounding low lying areas. This increase in weed species at higher elevations over the last decade was the catalyst for a program to detect and treat new and emerging weed species in the alpine areas of Kosciuszko National Park (KNP). A weed risk assessment was designed to assess risk in Alpine areas. Weeds considered high priority were mapped on all trails and camping areas in KNP alpine areas. This baseline information is being used to guide weed control programs. The program is part of broader weed management in KNP, integrating with weed control undertaken in the ski resorts. This ensures a consistent approach and helps to prevent re-infestation. Early detection and treatment is the most cost-effective approach and protects the natural environment. The program is a collaborative approach by NSW National Parks & Wildlife Service, Greening Australia and community volunteers, with sponsorship including a bequest from the Milburn Estate and the NSW Environmental Trust.

## Key words

Australian Alps, Kosciuszko National Park, risk assessment, climate change, emerging weeds

## Introduction

Australian mountain systems are important biologically as they support diverse ecological communities and species adapted to extreme climates (Costin 2000, Kirkpatrick 2003). The Australian Alps provide important ecosystem services such as water resources for hydroelectricity and lowland irrigation (Worboys *et al.* 2011). In recent decades land use change has made mountain systems more accessible to agriculture and recreational pursuits and as a consequence weed species are on the rise (Johnston 2005, Becker *at el.* 2005, Pauchard *et al.* 2009). In addition, climate change, increased temperatures, reduced snow cover and duration has been linked to increased weed species richness at higher elevations (Pauchard *et al.* 2009).

The Australian Alps have been identified as a hot spot for future environmental invasion from species already established or from those in low lying areas (Pickering *et al.* 2008, Duursma *et al.* 2013). The Australian Alps have already warmed at a rate of 0.2°C per decade over the past 35 years and snow depth and duration of cover is declining (Hennessy *et al.* 2003, Green 2009). The strong inverse correlation between elevation and temperature has been considered an important part of explaining low richness of weed species in mountain systems (Pauchard and Alaback 2004, Becker *et al*. 2015). But as temperatures increase the ability of a climate filter to be successful may be reduced (Jump *et al.* 2013, Pyšek *et al.* 2011). Combined with changes to soil physical and chemical characteristics following disturbance (Johnston and Johnston 2001, Schroder 2014) there may be no barrier to protect high elevation mountain systems from weed establishment.

In the Australian Alps the increase in weed species richness reflects the change in land use patterns. Weeds associated with cattle grazing in the 1950s have been joined by species used in revegetation and ornamentals grown in high elevation gardens (Clothier and Condon 1968, Mallen-Cooper 1990, McDougall and Appleby 2000, McDougall *et al.* 2005). As part of the snowy hydroelectric scheme and ski resort infrastructure new weed species have also been transported along roadways (Johnston 2005, Jeuch 2006, Mallen-Cooper and Pickering and Hill 2007). A number of studies have been undertaken on the occurrence of weed species in Kosciuszko National Park (KNP) which is part of the Australian Alps. These studies vary in locality and methodology but all demonstrate the increase in species richness at higher elevations over time. In 1898, six species (Maiden 1898) were recorded, by 1954 this had increased to 44 (Costin 1954) by 1986, 132 (Mallen-Cooper 1990) and by 1999, 175 exotic species (Johnston 2005).

Weed management programs within KNP are largely focussed on meeting neighbour and visitor expectations and target recreational areas and roadsides. There are some exceptions. Programs have been implemented for *Hieracium aurantiacum* L. (Caldwell and Wright 2012), *Cytisus scoparius* (L.) (OEH 2012) and *Leucanthemum vulgare* Lam. (pers obs). Weed control priorities within KNP are identified in the Regional Pest Management Strategy for the Southern Ranges Region of the Office of Environment and Heritage. Separate weed management plans have also been developed for the alpine ski resorts (OEH 2014, 2014a). These priorities align with state and local priorities under the *Noxious Weeds Act 1993.* The priorities also align with actions in the Kosciuszko National Park Plan of Management (DECC 2006) regional pest management plans including various Catchment Management Authority Regional Weed Strategies.

Different weeds have various levels of invasiveness based on their traits or the environmental conditions (Richardson and Pyšek 2006). To separate the invaders there needed to be a greater understanding of the species that already occur in the low lying areas and the species which may already occur at higher elevations in KNP but had not reached their full extent. This project is focussed on *invasive* plants capable of spreading over a large area and *transformer* plants with the ability to alter ecosystem function (Pyšek *et al*. 2004).

There has been past attempts to prioritise species in the Australian Alps (DECC 2009, OEH 2012) however these tools were focussed on the whole park and may have missed latent species which are not currently covered in management strategies. As mountains differ in their environmental conditions to low lying areas we considered that existing risk assessment systems may need adjustment to cater for the nuances of an Australian mountain system. We needed a risk assessment suitable for the sub alpine and alpine Australian environment. In addition to developing a risk assessment matrix to identify potential invasive weeds there was a need to collect baseline information on weed occurrence. To achieve this we focussed on developing a collaborative program engaging volunteers to become part of weed management in KNP. Community volunteers have assisted in collecting a baseline data set of existing weed localities in the alpine and subalpine. This information has allowed for the implementation of control programs for priority species.

## Location

This project is located in Kosciuszko National Park which is part of a contiguous group of National Parks straddling a 340km length of the Great Dividing Range in South East Australia. Kosciuszko National Park is the largest park at 690,000 hectares (Figure 1). This project is located in the Alpine and sub-alpine areas of KNP. The alpine represents a small area (0.001%) of the Australian mainland (Costin 2000).

## Methods

### Risk Assessment

We used existing weed species lists (Mallen-cooper 1995, Johnston 2005, McDougall *et al* 2005, OEH 2014, 2014a) and personal communication with NPWS land managers to reduce the existing weed species lists to forty five species. These species were included as they are already occurring or have the potential to invade natural systems. We also included class 1 species (NSW Noxious Weed Act 1993) that are known to occur in other parts of the Australian Alps.

To assist in the prioritisation of on-ground control programs we applied a risk matrix. The matrix included factors which have been identified in other studies as significant predictors of invasive species in mountain systems. We considered that weed species known to be invasive in other Australian or global mountain systems to be an important factor (McDougall *et al.* 2011). Time since introduction is also considered a significant factor (Pyšek *et al.* 2011). Most weed species in the Australian alps have a recent introduction history (Johnson 2005) compared with other mountain systems (Daehler 2005, Haider 2010). Pyšek *et al*. (2011) identified that the longer the time since naturalisation the larger the extent and altitudinal distribution of a weed species.

Specific adaptions are also likely to be important in mountains to combat climate conditions such as, cold tolerant adaptations such as perennial underground storage. Early flowering times at higher elevations where seasons are short (Körner 2003) and the plants ability to grow in particular soil conditions, such as low pH (Pyšek and Richardson 2007) may provide an advantage. Most of the soils in the sub-alpine and alpine areas of KNP have alpine humus and peat soils which are acidic (Costin 1954).

We also included other factors commonly used in other Risk Management systems (Daehler 2004, Johnson 2009) such as, seed dispersal, available control methods and introduction pathways. Based on the risk matrix weeds were divided into four categories. Table 1 identifies the four categories and risks characterising each.

**Table 1. Identifies the specific risk assessment characteristics for each category of weed species**

| | |
|---|---|
| Extreme | Weed species which were listed as a class 1 weed type, notifiable (DPI 2014).<br>A weed species which is already known as a highly invasive weed in Australian mountain systems<br>A weed known to be invasive in endangered ecological communities, i.e. Alpine Bogs<br>For example: *Cytisus scoparius*, *Hieracium spp.* |
| High | Weed species listed as a Class 2, 3 weed type (DPI 2014)<br>A weed known to be invasive in other natural systems in low lying areas or in other global mountain systems.<br>A species with a recent introduction history ( <10 years)<br>A species with specific adaptations suitable to grow in mountain systems, including geophytes, early flowering ( Korner 2003, Grotkopp and Rejmanek 2007)<br>For example: *Verbascum Thapsus* L.. *Potentilla recta* L. |
| Moderate | A species known to be invasive in disturbed areas and is widespread in low lying areas of KNP but currently has a limited distribution in the alpine and sub-alpine areas.<br>A species with an introductory history (<20 years)<br>A class 4 or 5 weed (DPI 2013) |
| Low | A species which has been persistent in in Australian mountain systems for more than a century.<br>A species used in revegetation programs and is already widespread (Cloither and Condon 1968, Johnston 2004).<br>A weed species not considered competitive once established in a natural system (Godfree *et al.* 2004) |

## Collection of baseline data

To collect data on the locality and extent of weed species all main walking tracks and vehicle tracks were walked (Refer to Figure 1). The edge of tracks and trails were surveyed to a depth of 1-5 metres depending on the extent of weed invasion. Watercourses were surveyed to the extent of obvious weed invasion where trails or tracks crossed. Areas around huts, road culverts were surveyed as these localities are the most likely location for weed species given past disturbance (Johnston and Johnston 2004, Johnston 2005, McDougall *et al* 2005, Morgan and Carnegie 2009).

Low priority widespread weeds considered to have only a minor impact to native communities, *Acetosella vulgaris*, *Hypochaeris radicata*, *Trifolium repens* (Godfree *et al.* 2004) or those species previously used in revegetation programs, *Festuca rubra*, *Agrostis capillaris* L. (Cloither and Condon 1968, Johnston 2005) were not included in the baseline data collection.

The field data collected included; plant name, location description, coordinates (easting/northing), photo point and abundance. Abundance included ranking the number of plants at the location (<5, <10, <50, 50+) and an area covered in square metres. This information was then collated and uploaded onto ArcMap™ geographic information system.

Maps were produced to display the locality of weeds and to assist in the prioritisation of on-ground weed control programs.

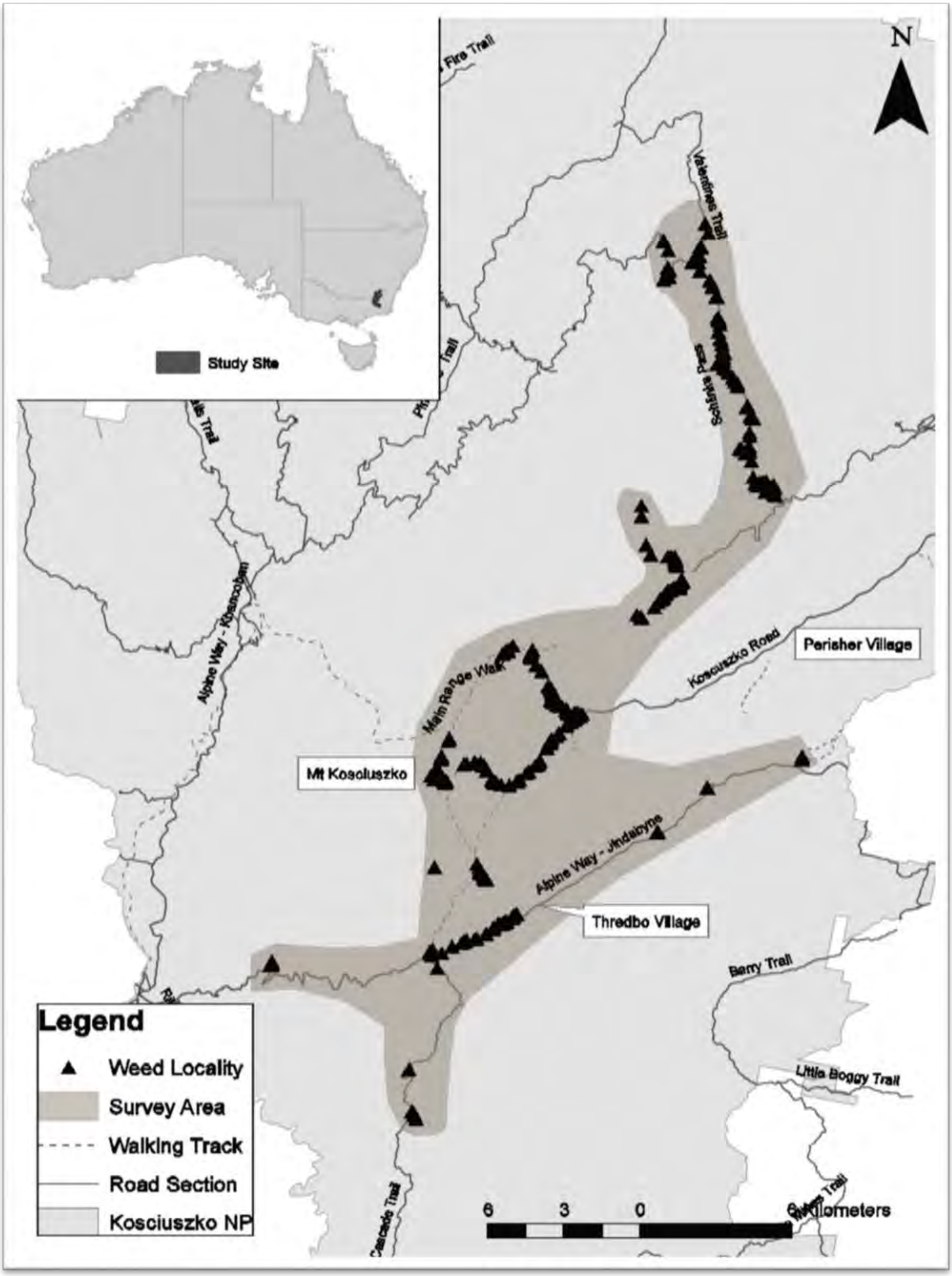


**Figure 1. The location of the study site in Kosciuszko National Park.**

**Community engagement**

The implementation of this program is reliant on a collaborative approach with the community, Greening Australia and the NSW National Parks and Wildlife Service. Interest in volunteering was promoted through local media, stakeholder groups including bushwalking clubs and at field days. Interested volunteers were invited to attend training sessions, to learn how to identify weed species and become involved.

NSW National Parks and Wildlife Service and Greening Australia staff were provided with training and field identification material to identify and report extreme and high priority species.

## Results

### Risk Assessment

All weed species included in the risk assessment are included in Table 2. This table provides information on which vegetation zone the weeds are known to occur in, alpine, subalpine and montane. The table also identifies if the species were mapped in disturbed and undisturbed locations.

**Table 2. Identifies the 45 weed species included in the risk assessment, their location within each vegetation zone and in disturbed or undisturbed localities. The table also includes their overall priority rank.**

| | | Known location | | | Known weediness | | |
|---|---|---|---|---|---|---|---|
| Scientific Name | Common name | alpine area | sub-alpine area | in KNP and surrounds | un disturbed | disturbed | Priority Rank |
| *Achillea millefolium* L. | yarrow/ millfoil | Y | Y | Y | Y | Y | Extreme |
| *Ammobium alatum* R.BR. | winged everlasting | N | N | Y | Y | Y | Extreme |
| *Anthoxanthum odoratum* L. | sweet vernal grass | Y | Y | Y | Y | Y | Extreme |
| *Cytisus scoparius* | scotch broom | N | Y | Y | Y | Y | Extreme |
| *Juncus effuses* L. | soft rush | Y | Y | Y | Y | Y | Extreme |
| *Leucanthemum vulgare* | ox-eye daisy | N | Y | Y | Y | Y | Extreme |
| *Hieracium pilosella* | mouse ear hawkweed | Y | N | N | Y | N | Extreme |
| *Hieracium auranticum* | orange hawkweed | Y | Y | N | Y | Y | Extreme |
| *Salix spp.* | any willows | Y | Y | Y | Y | Y | Extreme |
| *Festuca arundinacea* Schreb. | tall fescue | Y | Y | Y | N | Y | High |
| *Cirsium vulgare* (Savi) Ten | spear thistle | Y | Y | Y | Y | Y | High |
| *Holcus lanatus* L. | yorkshire fog | Y | Y | Y | Y | Y | High |
| *Holcus mollis* L. | creeping fog | N | Y | Y | N | Y | High |
| *Hypericum perforatum* L. | St Johns wort | N | Y | Y | Y | Y | High |
| *Juncus articulates* L. | articulated juncus | Y | Y | Y | Y | Y | High |
| *Juncus tenuis* Willd. | slender rush | Y | Y | Y | N | Y | High |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Lotus uliginosus* Schkuhr | greater bird's foot trefoil | Y | Y | Y | Y | Y | High |
| *Melilotus albus* Medik | white lucerne | Y | Y | Y | Y | Y | High |
| *Myosotis laxa* Lehm | forget me not | N | Y | Y | Y | Y | High |
| *Onopordum acanthium* L. | scotch thistle | Y | Y | Y | Y | Y | High |
| *Phalaris arundinaceae* L. | reed canary grass | N | Y | Y | Y | Y | High |
| *Phleum pratense* L. | Timothy grass | Y | Y | Y | Y | Y | High |
| *Plantago sp. (lanceolata)* | plantain | Y | Y | y | N | N | High |
| *Potentilla recta* L. | cinquefoil | N | Y | Y | Y | Y | High |
| *Rubus sp.* | any blackberry | N | Y | Y | Y | Y | High |
| *Tragopogon dubius* Scop. | goat's beard | N | Y | Y | Y | Y | High |
| *Verbascum Thapsus* L. | common mullein | Y | Y | Y | Y | Y | High |
| *Barbarea verna* (Mill.) Asch. | barbarea | N | Y | Y | Y | Y | Mod |
| *Barbarea intermedia* | | N | Y | Y | N | Y | Mod |
| *Dianthus armeria* L. | sweet William | N | Y | Y | N | Y | Mod |
| | | | | | | | |
| *Chondrilla juncea* L. | skeleton weed | Y | Y | Y | Y | Y | Mod |
| *Collomia grandifloria* Douglas ex Lindl. | collomia | N | Y | Y | N | Y | Mod |
| *Epilobium ciliatum* Raf | glandular willow-herb | Y | Y | Y | Y | Y | Mod |
| *Rosa sp,* | sweet briar | N | Y | Y | Y | Y | Mod |
| *Verbasum virgatum* Stokes | twiggy mullein | Y | Y | Y | N | Y | Mod |
| *Acetocella vulgaris* | sorrel | Y | Y | Y | Y | Y | Low |
| *Agrostis capillaris* | brown top bent | Y | Y | Y | Y | Y | Low |
| *Dactylis glomerata* | cocksfoot | Y | Y | Y | N | Y | Low |
| *Festuca rubra /nigrescens* | fescue | Y | Y | Y | N | Y | Low |
| *Hypochaeris radicata* | cats ear | Y | Y | Y | Y | Y | Low |
| *Prunella vulgaris* L. | self-heal | Y | Y | Y | N | Y | Low |
| *Trifolium repens* | clover | Y | Y | Y | Y | Y | Low |
| *Taraxacum sp.* | dandelion | Y | Y | Y | Y | Y | Low |
| *Trifolium pratense* L. | red clover | Y | Y | Y | Y | Y | Low |
| *Viola arvensis* Murray | field pansy | Y | Y | Y | Y | Y | Low |

**Baseline Data set**

The baseline weed data was collected from February to April 2013. A total of 62km of road and walking trails were surveyed and 518 weed localities recorded. A total of 36 different weed species were detected. Five species not previously considered in the risk assessment were detected. These included *Brassica sp.* (*rapa* or *oleraceus*), *Crepis foetida* L., *Lolium perenne* L., *Medicago sp.* and *Mentha sp.* Figure 2 summarises the number of records for each species that were detected on more than three occasions. The most commonly detected species included: *Achillea millefolium* 21%, *Anthoxanthum odoratum* 19%, *Phleum pratense* 8%, *Epliobium ciliatum* 6% and 5% each for *Cirsium vulgare*, *Verbascum thapsus* and *Juncus articulatus*.

Additional species and new locations continue to be detected by community volunteers and NPWS staff. These will continue to be added to the overall database which will be maintained in the NSW National Parks and Wildlife Service Pest and Weed Information System.

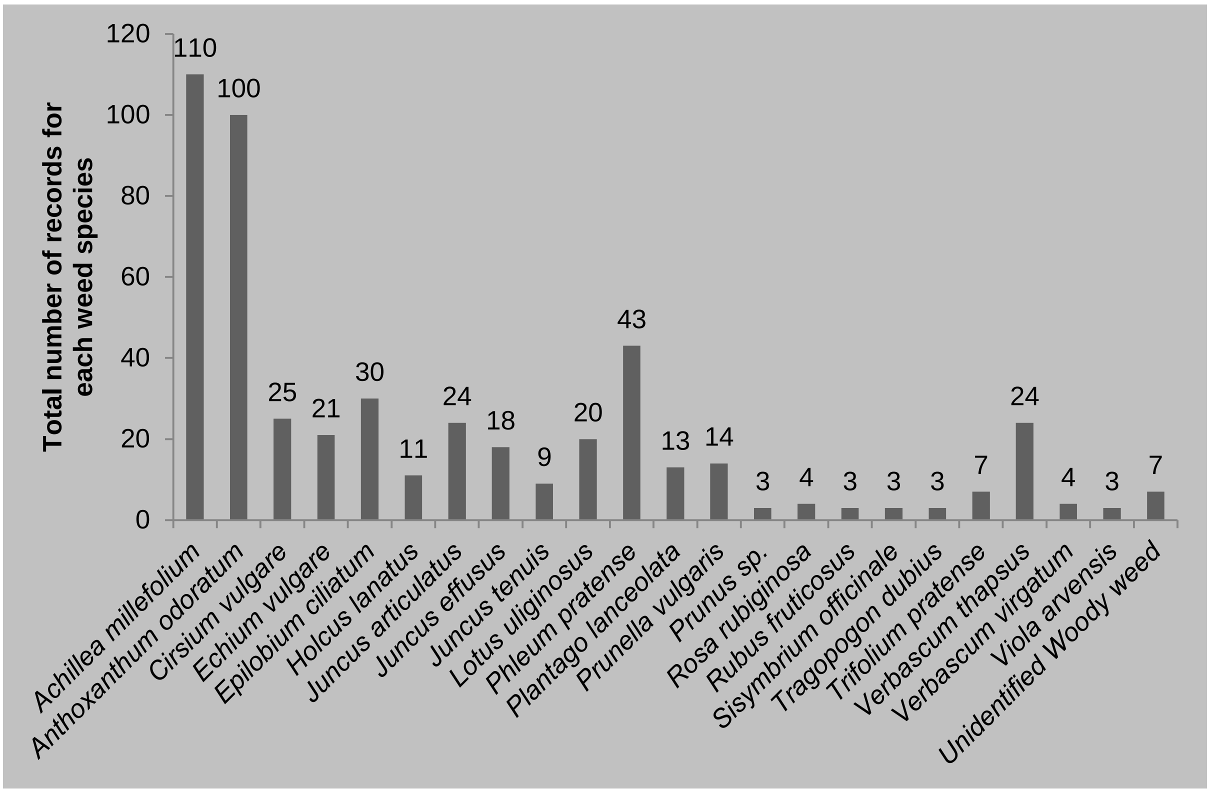


**Figure 2. Total number of detection points for each weed species recorded >3 times.**

## Community and land manager engagement

Community engagement has been a two tiered approach; increasing community awareness about emerging weeds and engaging volunteers to assist with the program. The broader community have been informed about the program through local and regional media. One aim of this was to encourage community participation. There have been 48 enquiries resulting in 30 volunteers becoming part of the program. All volunteers have been provided with training and have participated in weed identification workshops. GA and NPWS staff has provided support to volunteers in detection, control of weeds and revegetation programs. In total there has been 800 volunteer hours which equates to 105 days (7.5 hours per day). In addition a brochure prepared for bush walkers has been developed to encourage park users to report any high priority weed species.

A total of 34 National Parks and Wildlife Service Staff and alpine ski resort staff have received training and information in the identification of emerging weeds. This has led to the detection of high priority species in several remote locations, including *Salix purpurea* L., *Melilotus albus* and *Leucanthemum vulgare*.

**Implementation of programs**

The prioritisation and identification of the weeds was the first step. Following the collation of the baseline data NPWS had to determine what management areas within KNP would be a priority for control. Initial programs have focussed on the alpine main range area. This is due to the ecological significance and high recreational value. Control programs undertaken by NPWS staff and GA have been implemented on extreme and high priority weed species. Weed species have been treated on 21kms of trails.

## Discussion

This program has provided an opportunity to develop a weed risk assessment specific to the environmental conditions of Australian mountain systems. The risk assessment helps to identify those species with the greatest potential to invade natural systems. Being able to identify the weed species that have the greatest potential to impact will assist in the implementation of control priorities (D'Antonio and Chambers 2006, McDougall *et al.* 2011).

This risk assessment considers many weeds not previously included in the broader KNP Pest Management Strategy (OEH 2012) and the Southern Rivers Regional Weed Strategy (SRCMA 2011). Emerging weeds or 'sleeper weeds' are an important management issue particularly in mountain systems where climate change is already occurring and making conditions more conducive for weed establishment and growth (Pickering *et al.* 2008). It is important that these species have been considered to help prevent their future expansion. This will protect both the environment and reduce future costs for control (NRMMC 2007).

The risk assessment may need ongoing review to take into consideration the direct and indirect effects of climate change. This includes an increase in vertebrate pests at higher elevations that may assist weed dispersal pathways or increase soil disturbance (Pickering *et al.* 2009). Or the secondary physical biological effects of climate change which may exacerbate changes such as, increased solar radiation and erratic weather events (Garnaut 2008). Given changes in climate future modelling of weed habitat preferences may also need to be undertaken to determine how changes in climate may affect the constriction or expansion in weed species ranges (Thuiller *et al.* 2008).

Previous studies in the sub-alpine and alpine areas of KNP identified most weeds are associated with infrastructure development (Mallen-Cooper 1990, Johnson 2005, McDougall *et al.*2005). The baseline data collected in this program confirmed this. Most weed species were restricted to roadsides, culverts, walking trails huts and visitor facilities. These locations often contain disturbed soils and have the greatest potential to receive weeds and provide conditions for their establishment (Johnston and Johnston 2004, Pickering and Hill 2006).

The alpine ski resorts in New South Wales provide a potential conduit for new weed species which may then spread to the surrounding intact national park. The species we found to have the greatest frequency are also common in the NSW ski resorts (Schroder 2010, OEH 2015, 2015a). The baseline data from this project can be compared with weed mapping undertaken within the ski resorts to ensure co-ordinated programs are undertaken. Weed mapping is undertaken every five years in the ski resorts. This monitoring has been able to demonstrate trends in weed abundance and determine the effectiveness of control programs. We recommend that baseline mapping in the broader alpine and sub-alpine areas is also undertaken every five years.

The baseline data set provides an important 'snap shot' in time of the location of weed species. Not all species can be targeted simultaneously as part of control programs. This baseline information allows land managers to monitor changes in weed species abundance. Where control programs are undertaken the baseline information will also assist in measuring effectiveness.

Raising community awareness has been identified as an important way to detect emerging weeds in remote localities (McDougall *et al.* 2005). Effective programs like this have been implemented in KNP for *Hieracium auranticum* (Caldwell and Wright 2011). The park is popular for bushwalking and many community members and groups walk in remote areas. Utilising the support of community volunteers who already are undertaking recreational activities increases the chance of identifying remote weeds.

The treatment of emerging weeds is identified as an important goal in weed management (NRMMC 2007) however there are limited resources available for early detection of weed species. This program has allowed for a new weed management approach to protect a sensitive ecological environment vulnerable to climate change. Identifying weeds considered a high risk, detecting those species and implementing control programs through collaboration with community volunteers.

## Epilogue

The value of this program was fully realised in January 2014 when the first occurrence of the invasive weed *Hieracium pilosella* was detected by a bushwalker in a remote area of the main range in KNP. The initial propagules thought to be transported on camping equipment. The infestation was able to be treated within two weeks of detection and within one month community volunteers helped to complete field surveys of the surrounding landscape to ensure there were no other detectable infestations.

## Acknowledgements

We would like to thank the generous bequest from Kenneth Milburn (through Landcare Australia) that allowed this program to commence and provide the resources to engage community involvement. We would also like to thank the many volunteers, including the Canberra Bush Walking club and in particular David and Meredith Hatherly.
The Environmental Trust, NPWS and GA continue to support the next stage of the project by providing the funds to continue to engage volunteers and undertake weed control and monitor the effectiveness of treatment.

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# A Robotic System for Weed Mapping in Precision Agriculture

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## SUMMARY

Research and developments in Precision Agriculture (PA) technology and operations in the last decade have promised to increase the cost-efficiency of herbicide and mechanical weed controls. In particular, Variable Rate (VR) applications of herbicides and microwave weed management can provide both high cost-efficiency and robustness against herbicide resistance. Autonomous weed management systems have been developed with robots such as LadyBird that are more even more cost-efficient and precise than VR spraying. These systems require accurate maps of weed densities in order to be effective. Weed maps made from manual observations are costly and often do not provide an accurate representation of the weed distribution. The use of remote sensing technology combined with GPS-equipped Unmanned Aerial Vehicles (UAV) provide observations of weed densities with far greater accuracy and speed than manual labour. The UAVs are constrained by limited flight-time, and as such often only a small proportion of the field can be sampled. We propose a system to accurately identify and map weed densities in a paddock using crop-planning data and a UAV. The system uses the UAV flight-time efficiently in order to maximise the information gained per weed-density sampled. The system is planned to be coordinated with the LadyBird robotic weeding agent to provide control of the weed densities.

## Introduction

In this paper we present an information system that can produce full, accurate maps using limited day-to-day samples of weed densities by a camera mounted on a UAV. The UAV is controlled in such a way that the uncertainty in the map is constantly decreased by choosing the next site to sample in a smart way. This is based on the principle of maximum information gain, which ensures that the next place to sample will give the system the most information. The map is updated with each additional sample and any missing data is interpolated using Gaussian Process. In addition the uncertainty the estimated map is known. The system can suggest sites to the UAV to sample in order to provide accurate information to the farm manager and weeding agent.

A sample dataset (Haug & Ostermann 2014) is used to demonstrate the process of estimating the weed density using real images and information about the crop and field; this is presented in

Section 1. In Section 2 we introduce the spatially-explicit individual-based simulation that is used to generate the data for the system. Using this information we demonstrate in Section 3 how the sparse weed-density data is combined into a dense map of the entire paddock. Section 4 then shows how the system chooses the next site to sample the weed-density in order to maximise the information gained by taking a single sample. We conclude that the system provides a high-performance and low-cost system for information gathering that is necessary in implementing effective IPM. The system is planned to be implemented alongside the weed-control methods of the Australian Centre for Field Robotics (ACFR) LadyBird robot next year.

## Autonomous Weed Detection

In order to estimate the weed density throughout the field, we use a multispectral camera that can capture both visible light and the Near-Infrared (NIR) spectrum. Close-range aerial photos of the crop rows are processed to identify the vegetation in the photos. This is achieved using the Normalised Difference Vegetative Index (NDVI) image (Fig. 1), in which vegetation appears with high intensity, and backgrounds such as soil appear with low intensity. Using the NDVI image the background is removed and the crop and weed can be isolated, however at this stage the crop and weed cannot be distinguished from each other (Fig2). It is not the purpose of this system to determine which plants in the image are crop and which are weed. In our approach we use the data from the image processing algorithm as well as the physical parameters of the field to estimate the crop density.

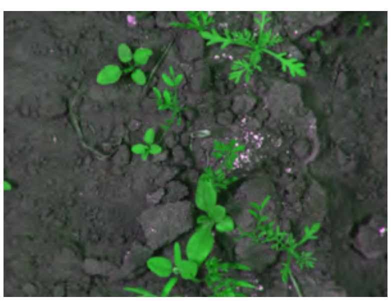
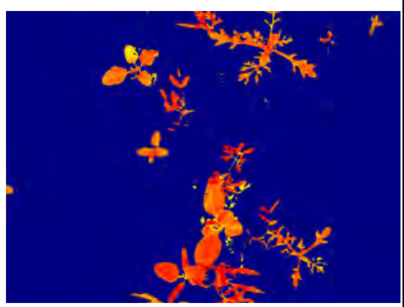
| **Original Image** | **NDVI Image** | **Separated Vegetation** |
| --- | --- | --- |
|  |  |  |

**Figure 1.** The image processing pipeline involved in identifying the vegetation

Using this method the vegetation count for a given block on the grid is known with a small error that is the variance of the measurement that is assumed to be small and constant. The knowledge of the paddock and crop layout provides the nominal count of crop plants per meter of crop row as well as the inter-row spacing. By assuming that all the vegetation detected is either crop or weed, the weed density is then calculated. The weed-density map generated from this process is very sparse and does not estimate the density in the unsampled areas of the map; this is addressed the later section Weed Density Mapping.

## Simulation Model

Because the spatial and population dynamics of weeds is highly variable, a spatially-explicit individual-based simulation model (Berec 2002) is used to simulate the data with which we demonstrate and evaluate our system. This method of simulation has been used to study ecological systems with great success; especially in systems that exhibit complex interactions with the environment (Keeling 2002). Using this methodology we model the spatial distribution, growth and reproduction of individual weeds. Initially a 1Ha field is simulated that is initially void of seeds and established weeds or crops. 100 weed seeds are randomly placed on the field and allowed to grow for 12 weeks in well-maintained soil as would be expected when growing the crop. After the growing period the field is tilled and all the established weeds are removed; the remainder is a seedbed that has been distributed according to the dynamics of the weed and the environmental conditions. In this simulation the weeds are aerially dispersed and are affected by the average daily wind direction and speed. At this point the crop is planted, and allowed to grow for 21 days before the first observations of the field is made. The simulated data at this point is shown in Fig. 2.

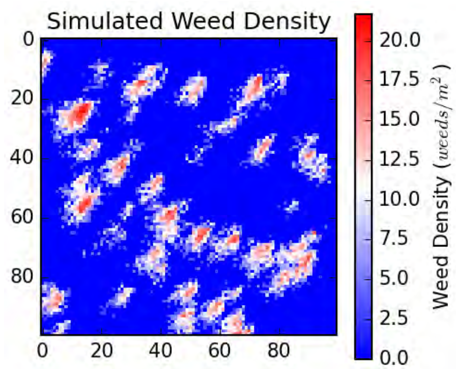



**Figure 2:** The weed density of a simulated weed infestation over 1 hectare.

## Weed Density Mapping

An important operational constraint of the system is that the UAV can only operate for 15-20 minutes continuously, before needing to charge or have its battery changed. In order to maximise the efficiency of the mapping process, it is important to choose the sample locations in such a way that the information gained is maximised. This is achieved in the system by commanding the UAV to take the next sample at the highest entropy unsampled cell in the grid. This strategy is very energy-intensive as max-entropy points are generally not close to the previous sample location, making this strategy inefficient for human laborers to execute. The high mobility of the UAV make this strategy feasible, and its high speed (greater than 10m/s) makes it efficient. In addition, the use of the UAV enables more samples to be taken in comparison to human sampling. In our implementation we sample 1% of the map ($100m^2$ out of $10000m^2$).

To produce an estimate of the unsampled areas of the map, some assumptions are made: Firstly, the average weed density of the field is constant and close to 0 weeds/$m^2$; this is appropriate for the early stages of growth (first 4 weeks after planting the crops) after tillage where existing weeds have been uprooted, and new weeds will be established through the seedbed. The second assumption is that there is a spatial dependence in the weed distribution, which has long been known and studied (Mortensen, Johnson and Young 1993).

The paddock is modelled as a grid of Gaussian distributed variables that have weed-density values that correlate in space. This means that cells close to each other will have similar mean and variance values, while cells that are far apart will have insignificant effect on each other. A Gaussian Process is used to fit the data from the sampled cells in order to estimate the parameters of the underlying ecological process. The estimated process function is then evaluated across the unsampled cells of the grid to produce an estimate of the entire map. Fig. 3 shows the estimated weed density map as the system is running and actively samples 20, 50 and 100 samples.

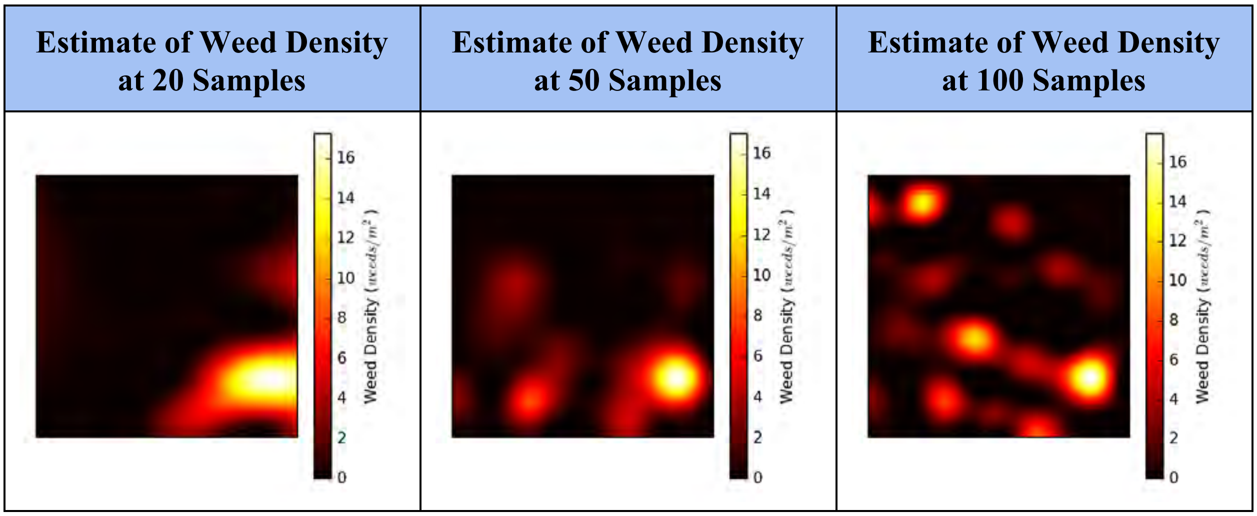



**Figure 3.** The estimated weed density as the UAV continues to take samples.

At any point in time and space the probability of the estimated value is known; probability that the estimated map is correct after 100 samples is shown in Fig. 4(c). Using the estimate values and probabilities the high-probability areas can be identified and used as trusted weed maps. Fig. 4(c) shows the weed density map where the probability of the map being correct is at least 95%. Also from this map the weed count can be identified with 95% probability; in our simulation we can identify the weed count with only 10% error by sampling only 1% of the paddock.

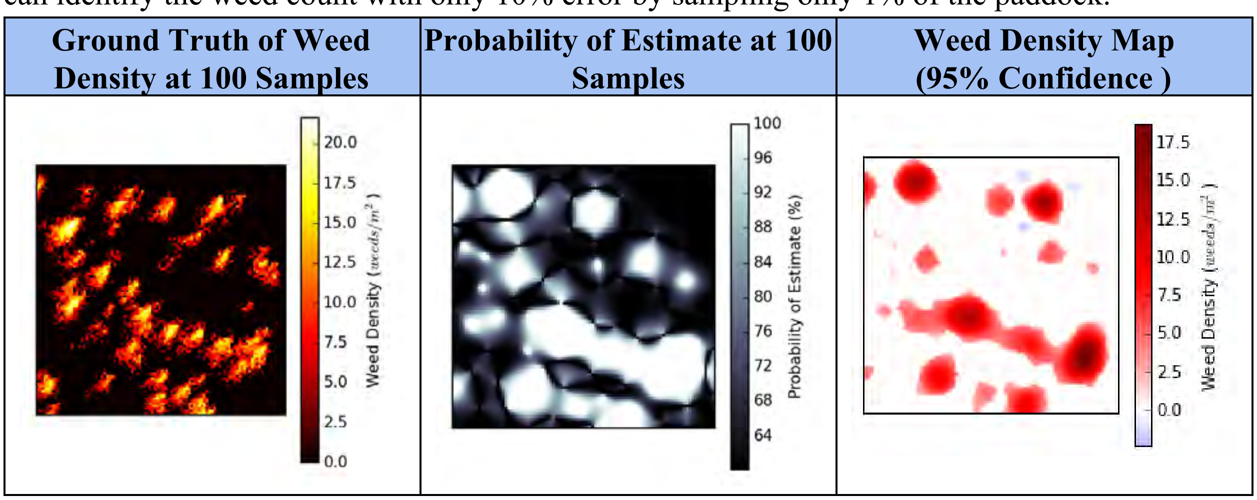



**Figure 4.** Comparison between the ground truth and 95% confidence map

## Conclusion

We present a system that takes advantage of the high mobility and speed of multirotor UAVs to efficiently sample the weed density in a paddock with efficiency and accuracy far beyond human capability. The system can produce estimates for the unsampled sites and produce maps that guarantee at least 95% confidence, which enables the farm manager to make low-variability decisions on pesticide use, or can be given to human or robot weeding agents for use in PA weed control. The estimation system was evaluated to have a 10% error for a map generated with 95% confidence. The fully integrated system is yet to be field tested, however its constituent components have been tested with success giving expectations of promising future results.

## Future Work

The system is currently being developed at the ACFR and will be field-tested on farms in New South Wales and Queensland over the next year. The system is planned to be used in conjunction with the LadyBird robot (Fig. 5) to provide weed control capability.

**Figure 5:** The LadyBird robot developed by the Australian Centre for Field Robotics

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## Afternoon Sessions – Marquee

### Technology - From Drones to Smartphones

| CHAIR | Martin Hughes | Outside Demonstration Area |
|---|---|---|
| 2:00pm | Thermal weed control to remove off target toxicology risks – Jeremy Winer and Kerrie Guppy - Weedtechnics | |
| 2:20pm | Keynote Speaker – Black Dog Institute – James Francis | |
| 2:40pm | Smart phones as environmental awareness raising devices – Mallika Robinson - UNSW | |
| 3:00pm | The IT crowd gets weedy – Elissa Van Oosterhout – DPI NSW | DOW Grazon application |
| 3:20pm | The practical application of state-of-the-art un-manned aerial vehicles and imaging technology to on-farm property management of invasive weeds and pests – Johnathan Lawson – Northern Tablelands LLS | |
| 3:40pm | A collaborative robotic system for weed mapping and control in precision agriculture – Steven Potiris – School of Aerospace University of Sydney | |
| 4:00pm | To drone or not to drone : the timely targeted and terrifying aspects of remote weed mapping – Simon Holloway and Neville Plumb – Palerang Council | Yamaha R-Max |
| 4:20pm | Drones, 8WD's, Apps and Virtual Tours – Steve Taylor, Jenny Connolly and Josh Thomson, ACT Parks and Conservation Service | |

**4:40pm Computer Mapping Iconyx meeting**

# To drone or not to drone – the timely, targeted and terrifying aspects of remote weed mapping.

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## Summary

Remote Pilot Aircraft Systems, or 'drones', are being increasingly used for a wide range of environmental monitoring applications. Their advantages for aerial survey work over traditional manned aircraft and satellites include the ability to rapidly obtain ultra-high resolution imagery when and where it is needed across limited areas.

Natural colour aerial photographs with ultra-high resolution can be obtained at a rate of about 1km$^2$ per hour of field work, then assessed by trained weed officers to identify and map weeds or suspicious plants requiring closer on-ground inspection. The efficiency and effectiveness of broad scale weed inspections can potentially be improved by combining initial aerial surveys with subsequent targeted on-ground surveys, particularly in peri-urban environments.

Privacy concerns are important to the general public, however the limited legislative requirements are readily manageable. Safety concerns are more complex and require a long term commitment to develop in-house capacity, or can be overcome by using CASA-certified contractors. The costs are reducing over time, and for around $15,000 and about one month of labour a Council can potentially establish a basic RPAS capacity suitable for aerial weed mapping.

**Keywords:** drone, RPA, RPAS, UAS, UAV, weed mapping, weed survey

## Introduction

What is a drone? The term 'drone' is often used by the media as a simple term and sometimes to negatively imply uncontrolled technology. The term Unmanned Aerial Vehicle (UAV), or Unmanned Aircraft System (UAS) when combined with ground control components, is more descriptive but can still imply a lack of human control. The terminology increasingly being adopted is Remotely Piloted Aircraft (RPA) and Remotely Piloted Aircraft System (RPAS). An important role of RPAS is to take aerial photos facing vertically downward that are then mosaicked together to create a larger photo map that can be used for a range of applications, including weed surveying if the photos are high enough resolution.

There are two common types of RPA typically used for aerial survey work - multirotors and fixed wing aeroplanes. Multirotors can take-off and land vertically in confined spaces, fly low and slow to take high resolution photos, so are well suited to intensive surveys of small areas (up to about 25ha per hour at 2cm resolution) and in difficult terrain. Planes can fly faster and for longer but need more open space for take-off and landing paths so are better suited to surveying larger areas, up to about 100ha per hour at 3cm resolution and often possible from a single flight.

While sometimes shrouded in technical jargon, a survey RPAS is simply the integration of four basic components:

1. Remote control aircraft – a model aircraft and remote controller, similar to what hobbyists fly at local model airplane clubs;
2. Autopilot – an on-board electronic device to automatically control the plane's flight and photo points from pre-defined missions created on associated software;
3. Survey camera – generally an off-the-shelf consumer camera with trigger mechanism to take aerial photos facing vertically down to the ground;
4. Image processing software – to stitch overlapping images together into a larger mosaic photo map.

RPAS can produce higher resolution aerial photography than that which is readily available from satellites and manned aircraft, allowing more plant species to be potentially identified. Typical resolutions of natural colour aerial photography and their usefulness for weed mapping include:

- ~50cm pixels (eg from Google Earth and NSW Government broad scale program over most rural areas) is only suitable for larger plants such as Gorse and Blackberry;
- ~10cm pixel (often available over urban areas) is sufficient to identify infestations of some smaller plants in particular seasons, like St John's wort;
- ~3cm pixel (RPAS) for identification of most species except individual small plants.

Trees can obstruct the view of lower storey plant species from the air, however they can also restrict access for on-ground inspections.

There are many potential benefits of RPAS for weed management, particularly the ability to obtain ultra-high resolution aerial photos when and where you want them. There are also aspects of RPAS that are terrifying to some people, particularly public concerns about privacy, the legal requirements for flying safely and the costs for a small rural council to access this technology.

Over the last couple of years, mostly in our personal time, Palerang Council weeds management staff have been investigating the potential use of RPAS to:

1. Improve efficiency – Can ultra-high resolution aerial images be obtained and visually assessed by a trained inspector at lower cost than traditional on-ground inspections?
2. Improve consistency - Can more parts of a property be viewed at similar intensity and can barriers such as locked gates and inaccessible areas be overcome?
3. Improve accountability – Can the comprehensive documentation from aerial weed mapping better detect new weeds, monitor progress with weed eradication and reduction programs, aid reporting of project outcomes and help justify invoicing for enforced weed control actions?

## Methods

This project commenced with extensive research into the range of RPAS available and their applications. Their limited application to weed mapping is often focussed on developing algorithms for automatic detection of specific weed species from multi-spectral imagery, however previous experience in remote sensing from satellite and manned aircraft sensors indicated that the accuracy of species-level discrimination is variable depending upon local conditions. This is a potentially useful field of research and development, especially with the introduction of mini hyperspectral scanners, however our interest was in the potential of traditional natural-colour aerial imagery at high enough resolution for a trained vegetation officer to identify different plant species. The added benefit for Council is that the imagery can be used for a broad range of applications beyond weed management, which could also help offset the data acquisition cost.

At the same time the legal issues associated with RPAS use were investigated. Aircraft safety is managed by the Civil Aviation Safety Authority (CASA) and there are a suite of rules that apply to the use of RPAS. The potential invasion of privacy posed by RPAS was also investigated at the national and state levels, although it was more difficult to determine whether the legislation really addressed public concerns so information was also sought from other states and internationally.

## Results and Discussion

Fixed wing RPA are becoming everyday tools in the surveying industry where high costs of equipment and labour are commonplace so the $50-100,000 outlay and ongoing specialised maintenance is justifiable. This is prohibitively expensive for a rural Council like Palerang, and the use of contractors is not practical if we want to start using this technology responsively on a regular basis, so we started looking for alternatives.

There is a huge global community of enthusiasts developing open source hardware and software, sharing information via online forums, and generally feeding the appetite for low-cost practical tools that are simple enough for self-maintenance. With a bit of knowledge picked up online from sites such as DIY Drones you can convert a $100 hobby aircraft into a ready-to-map system for around $1500. This is a more difficult route, but if you are prepared to put some time into research and development, want the ability to maintain the systems yourself with the flexibility for customisation and accept the limitations of free image processing software, then this approach is feasible.

A practical compromise is emerging in the form of a new breed of commercial products available from overseas suppliers in the $3,000-10,000 range. These are based on cheap remote control hobbyist aircraft and open-source electronic components that can be more readily self-maintained. Example suppliers include 3DR (developers of open-source autopilot hardware and more recently complete RPAS) and commercial production members of Conservation Drones (Hornbill Surveys, Flight Riot) currently offer practical products.

There are two main legal issues to be considered with RPAS use – privacy and safety.

Privacy tends to be the biggest concern from the public, Councillors and even well-intentioned colleagues. This issue needs to be managed carefully as a couple of complaints to Councillors could suddenly result in a Council 'no drone' policy.

Legally this does not appear to be a major issue for government agencies who have powers of entry and photographic evidence collection under various Acts, such as the NSW *Noxious Weeds Act 1993,* and must comply with privacy legislation based around the collection and use of 'personal information' (IPCNSW, 2014). However, public concerns and the complexities of this issue were recently highlighted in a parliamentary inquiry and the resulting *Eyes in the sky* report (PCA, 2014) included recommendations to improve privacy legislation and guidelines on the appropriate use of RPAS by law enforcement agencies.

Privacy issues relating to RPAS are being considered both nationally (Pilgrim 2014a, 2014b) and at state levels. The Information and Privacy Commission NSW does not currently provide guidance material on RPAS use, however have advised that they recognise this is an emerging issue even though it does not appear that the use of RPAS would normally be covered by the *Privacy and Personal Information Protection Act 1998*.

The Queensland Office of the Information Commissioner has published guidelines (OICQ, 2013a, 2013b, 2013c) that indicate how RPAS may be appropriately used for compliance monitoring in that state. Using this advice as a guide (subject to legal advice specific to NSW legislation) it appears that if a weed inspection notice of entry includes information about the use of RPAS and how that data will be managed, then the RPAS can be legitimately used for this legal purpose. Further, if the aerial photos cannot identify an individual, or the information collected is not about an individual, there are no privacy implications, however any resulting information that a particular property owner has not complied with their legislative obligations would be considered personal information of that individual and must be confidentially managed as such.

Palerang's plan is to start by only taking photos to map weeds on public land, and publicising the benefits such as for monitoring control works by Green Army teams. We will trial the documenting of private land subject to enforced weed control orders with the usual data security in place, with potential use for other investigations such as illegal development and dumping. Subject to any privacy concerns being appropriately managed and further guidance from the state and federal governments, the aim is to then trial this technology on a broader scale for routine weed inspections. We will be guided by data security protocols already established by Council for the collection and management of photographic evidence.

Safety is the greater legal concern and is administered by the Civil Aviation Safety Authority (CASA). There are stringent rules that apply to the use of RPAS and this is where many Councils might decide that it is easier to use professional contractors. CASA distinguishes between 'hobbyist' and 'commercial' operators. If you are going to use images taken by RPAS for any purpose, internal or external, you are classified as a commercial operator subject to certification. CASA is undertaking reforms in this area and you should check their current requirements (CASA, 2015a), however the following summarises the situation for commercial operators at the time of writing:

1. Each remote pilot must have a UAV Controllers Certificate. This includes a flight radio operators licence and flight experience involving at least one week of intensive coursework and costs $3,000+ per pilot,
2. The organisation needs an Unmanned Operator's Certificate which currently takes about 9 months to obtain due to the high demand. This costs ~$3,000 and includes:
    a. An Operations Manual based on the CASA template, specifying safety procedures and nominating the Chief Pilot and Maintenance Controller;
    b. A Flight Manual for each aircraft type that you want approval to use;
    c. Manual and automatic flight tests for each aircraft type;
    d. Additional permissions to fly within specific areas (eg near aerodromes).
3. Detailed procedures must be followed and signed off for each mission plan and flight.

Note that this is a complex, time-consuming and costly process. In order to progress this initiative Council staff took the approach of obtaining the personal controllers certificates, flight simulator, practice aircraft and experience at our personal expense. We also developed the other documentation mostly in our own time, so the main cost to Council in addition to the equipment was the ~$3,000 application for the Operator's Certificate (charged at $4,000 up-front with a refund expected depending upon the complexity of the application).

If you decide to use a contractor you should obtain a copy of their Operator's Certificate plus Controller's Certificate for the pilot in command of the RPA. You can search the CASA online database of operators to confirm their certification (CASA, 2015b). Imagery taken by anyone else has not been obtained legally.

So can this technology be used for broad scale weed inspections? To be cost-effective we've set a target of being able to map one square kilometre per hour at a high enough resolution that most weeds can be identified, or suspicious plants at least mapped for further on-ground assessment. Being close to Canberra, Palerang has a large area of peri-urban development with around 2,100 properties across 215km$^2$ in the E4 Environmental Living planning zone. While in theory approximately 20 properties could be inspected on-ground per day, with landholder appointments this averages out to about 10 properties per day covering ~1km$^2$.

One locality identified as having good potential for RPAS supplementation is Royalla, just south of Canberra off the Monaro Highway to Cooma, where there are about 200 private properties plus public land across 13km$^2$. The locality is a 45 minute drive from head office and one inspector would typically spend around 20 days in the field to inspect all properties, including time spent talking to those residents who wish to be present. Subject to suitable weather conditions and minimal technical delays, two pilots with some concurrent flying of two aircraft should capture imagery over the entire locality in two days. A few more days would be needed to process and visually assess the imagery to map target weeds and suspicious plants.

Assuming that 1/4 of properties also required on-ground inspections, either because landholders requested advice or suspicious plants were identified from the imagery, an on-ground inspector would still spend about five days in the field in Royalla.

The benefits are potentially a 2/3 reduction in vehicle use, 1/4 reduction in labour, accurate mapping of weeds backed by consistent reference imagery, and improved safety through targeted property inspections. The costs are relatively low for the ongoing maintenance of equipment and certification once the capacity is established in-house, or subject to negotiation if using contractors to obtain the imagery. There are also broader uses of the imagery across Council (eg asset management, identification of unapproved development and unregistered pools, state of the environment monitoring) and potential use by other landowners for property management planning.

The benefits of RPAS for general inspections appear to reduce as average property size increases, due to on-ground inspection rates (km$^2$/day) increasing with larger properties tending to be more accessible with less appointment delays. Trials are planned to review the cost-benefits of adding RPAS surveys in different land use and terrain types.

## Conclusion

Palerang Council weeds officers have determined that RPAS are an important tool for the future of weed management in the Palerang area, along with a wide range of other applications across Council's operations. A typical Council can establish a basic in-house RPAS capacity for less than $15,000 and about one month of labour, although it could take up to 12 months to become fully certified for legal operations. Alternatively, there are an increasing number of certified aerial survey contractors who can provide services and this is a practical way to trial the benefits of this technology.

The ability to obtain ultra-high resolution imagery suitable for identifying most weeds at about one square kilometre per hour is feasible, when and where it is needed. Improvements in camera technology will also improve the quality of aerial photos over time. While the need to manually interpret the aerial photos to identify and map weeds is not as efficient as using automatic algorithms, through the eyes of an experienced vegetation officer the results can be more accurate with the added potential to offset image acquisition costs through multiple uses of the natural colour photos.

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# Drones, 8 Wheel Drives, Apps, Web Maps & Virtual Tours

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## Technological optimist?

Limited resources combined with ever-increasing invasive weed issues – how can we get ahead? Some of the new technology that is helping:

- Yamaha RMAX weed spraying Un-manned Aerial Vehicle (UAV) or 'drone'
- 8WD amphibious Argo All Terrain Vehicle (ATV)
- Off-line mapping apps, eg. Memory-Map & Collector
- Web Maps
- Weed id apps, eg. Environmental Weeds of Australia & NSW WeedWise (includes control information)
- Virtual tours that allow more detailed photo monitoring

## Yamaha RMAX

Access problems lead to higher weed control costs. One solution is the RMAX UAV or drone http://rmax.yamaha-motor.com.au/ . ACT Parks and Conservation Service (ACTPCS) have made use of the RMAX, operated by Remote Aerial Services, for spraying blackberry and St John's Wort in the Lower Cotter Catchment.

Photo of RMAX spraying Blackberry and St John's Wort (photo courtesy of the Canberra Chronicle)

Advantages of the RMAX include low spray height and rotor down wash that minimises off-target damage.

The RMAX has allowed control work to go ahead that was previously impractical or too expensive. ACTPCS have put it to good use where:

- There are extensive thickets of blackberry
- The terrain is not suitable for a 4WD

- The non-target trees and shrubs are well spaced

## 8WD Argo Amphibious ATV

Another cost effective solution for difficult terrain is the 8WD amphibious Argo http://www.argoatv.com.au/ . ACTPCS employs CoreEnviro Solutions, a contractor in the ACT region, who operates the 8WD Argo.

The 8WD Argo is a valuable tool for:

- Weed control along waterways that requires spraying from the water back towards the land, and manoeuvring back and forth from the river bank to the water
- Avoiding soil compaction and protecting sensitive sites
- Negotiating steep and rocky terrain
- Very sandy or water logged sites

Another advantage of the 8WD Argo is its streamlined body design which reduces locations where weed seed can lodge. Thus it is a lower risk for accidentally spreading weed seed, compared to other spray vehicles like 4WDs and Side by Side ATVs.

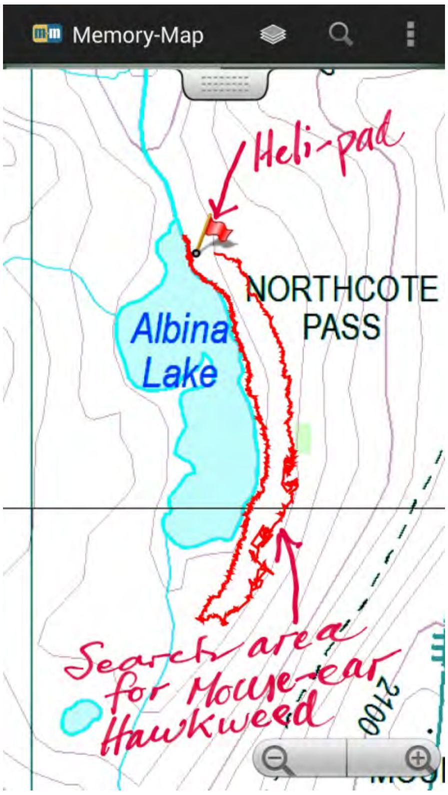
Photo courtesy of the Cotter Depot ACTPCS. The 8WD Argo on-route to a Blackberry spraying task.

## Mapping using Smartphone apps

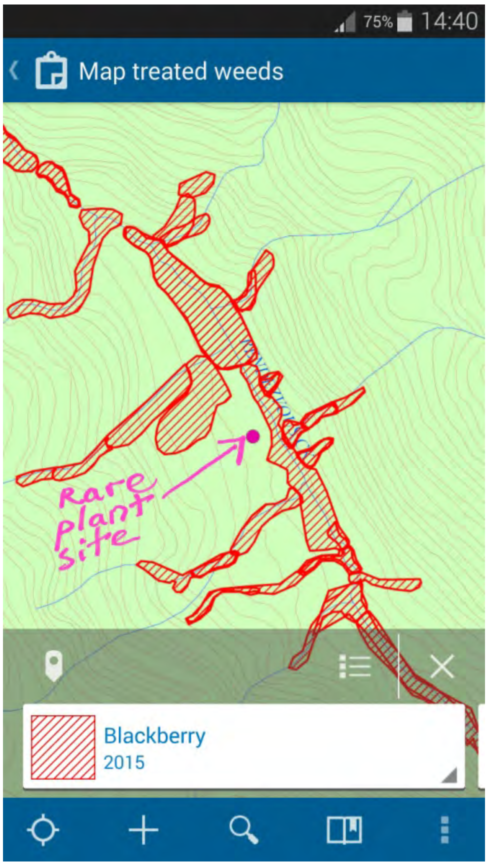
The most useful weed management apps have the following features:

- Can work off-line or on-device that is without mobile data or WiFi, eg. Collector and Memory-Map
- Mapping apps that sync (when a data signal is available) with ArcGIS On-line, eg. Collector
- Mapping apps that allow person to person gpx file sharing, eg. Memory-Map
- Mapping apps with drop down lists, eg. Collector, Weed Spotter
- Weed id apps allow for easy sharing of information such as control methods, eg. NSW WeedWise
- LUCID keys in weed id apps, eg. Environmental Weeds of Australia (EWA)

Apps used by ACTPCS for weed management.  Of the mapping apps, Memory-Map and Collector are most commonly used.



Gpx track produced during the multi-agency Mouse-ear Hawkweed deployment in February 2015.



Annotated screenshot of Collector app using on-device mode, showing weed control in the ACT's Namadgi National Park.

## Overview of Collector App and ArcGIS On-line

The Collector app is produced by ESRI and it syncs drop-down data fields with ArcGIS On-line https://www.arcgis.com/home/. This app works on both Android and iPhone/iPad. It is designed to work either on-line or off-line. Off-line is the most useful, when combined with on-line, WiFi or 4G syncing. There are a number of steps that have to be followed carefully to set up a device for off-line use, but once completed it is a simple to use mapping app. However it is not 'bug free' as occasional syncing errors occur. Hopefully these will be fixed in future updates.

## Setting up Collector App and ArcGIS On-line

You will need to have a licence with ESRI for ArcGIS, which also allows you to use ArcGIS on-line. The shapefiles or feature classes from ArcGIS are then published to ArcGIS on-line. Drop down lists for feature classes have to be created in ArcGIS before publishing across to ArcGIS on-line. Feature classes are called feature layers on ArcGIS on-line. When you sign into the Collector app it will marry-up with what appears on ArcGIS on-line.

The off-line map for use with Collector is a tile package or .tpk map. ACT Parks and Conservation Service (ACTPCS) use a topographic map that contains all the relevant tracks and trails. As you zoom in more details of the off-line map appear. When creating the base map you need to decide on the map scale will be at the fully zoomed in level. An off-line .tpk topographic map with tracks and trails that can zoom to 1:6,000 covering around 300,000ha will require 700mb of storage. The off-line .tpk maps is copied into the ArcGIS Collector folder that appears on Android devices. Then download is selected twice on the device and once sync appears next to the map, then Collector is ready to be used off-line.

The procedure for setting up iPhones/iPads is similar but there are some additional steps required. The ESRI ArcGIS resource centre provides assistance with the set up for iPhones/iPads.

The latest version of Collector allows feature layers (that appear on ArcGIS on-line) to be turned on and off. If using older versions of Collector – then it is important that you do not have too many layers on the web maps on ArcGIS on-line, because older versions of Collector cannot turn on-off feature layers. Edits to the feature layers can be done in off-line mode and accumulate to be synced when a data signal is available. The user decides when to sync.

## Overview of Memory-Map App

The Memory-Map app is a mapping and navigation app. It produces gpx files (marks, routes and tracks) that can be shared by email, and then uploaded to ArcGIS on-line. It is designed to work off-line, and then gpx files are shared by email on-line when WiFI or 3G/4G data connection is made. It is easy to set up, but not as simple to use as Collector. However it is very useful for adhoc mapping and navigation.

## Setting up Memory-Map App

Create an account on the Memory-Map web site http://memory-map.com.au/. Then you purchase the 1:25,000 topographic maps for the state/territory that you require. The maps can be zoomed to 1:5,000 scale. You receive two licences for US$60, or US$30 per device. For this price you get all the maps for the state/territory chosen. Visit the Google Play or iTunes app stores to download the Memory-Map app. There is a small charge for the iTunes version of the app. Log into the app with your account id and the Memory-Map store will recognise that you have a licence for the purchased state/territory topographic maps. Once you view an area on the device, the viewed portion of the map is stored on the device - and available for future off-line mapping. So the trick is the make sure you have scrolled across the entire area you will be working in to ensure the maps will be available for off-line use.

## Web Maps

ArcGIS on-line has the option to create web maps with an app builder. These are interactive maps that can be made publicly available. The map link can be embedded into existing web sites, or simply emailed as a standalone report. The web maps can also have links to other web sites built-in. Two examples of ACTPCS web maps are given below:

| | |
|---|---|
| 2014-15 Treated Invasive Weeds | http://actgov.maps.arcgis.com/apps/webappviewer/index.html?id=d89fa9407afb453c92201991589cd3fb |
| 2013-14 Treated Invasive Weeds | http://actgov.maps.arcgis.com/apps/webappviewer/index.html?id=65cefbeaec8a40bfa20371f6766589f8 |

## Web based on-line reporting

In the ACT there are also web based plant and weed reporting web sites. These are: Canberra Nature Map http://canberranaturemap.org/ for reporting and identification of native plants and weed species; and the Atlas of Living Australia http://www.ala.org.au/ and Weed

Spotter (ACT and Southern Tablelands) http://root.ala.org.au/bdrs-core/act-esdd/home.htm for weed infestation and control reporting.

Data from these sources is combined with the ACTPCS ArcGIS On-line data to inform the planning of the annual invasive weeds control program.

Automatic alerts to email can be set up on Canberra Nature Map and the Atlas of Living Australia for reports of new and emerging weed species.

## Virtual Tours

Photo monitoring points are a quick way to assess effectiveness of weed control work. Their downfall is they only show a small part of the site. Rangers are often asked to provide more information on vegetation cover but do not have the time for cover abundance surveys.

Virtual Tour software, in the latest Smartphones, eg. Samsung Note 4, helps solve this dilemma by creating an interactive video for the entire site in about a minute or two, depending on the detail required.

One frame from a 360 degree Virtual Tour. Un-treated blackberry dominates.

This next image from the Virtual Tour reveals successful St Johns' Wort control but extensive blackberry thickets requiring control.

This screenshot is the next frame from the Virtual Tour. It shows thorough St John's Wort control. About 20 frames make up the 360 degree Virtual Tour.

The Virtual Tour photos can be converted to video format for computers or devices that cannot read virtual tour files. However these converted video files lack the review functions of the virtual tour files.

## Acknowledgments

Thank you to Ryan Lawrey ACTPCS and Alan Bendall ACTPCS for assistance with the initial Collector app set up.

**6:30pm Conference Dinner**
**Multi-Function Centre**

**MC – Jim Walker-Broose**
**Guest Speaker – Mr Glenn McGrath**
**Entertainment – Hip Replacements Band**
**Award Presentations – Buercnerk, Stephenson & Industry Awards**

## DAY 3 Thursday 15 October 2015 - Cooma Multi-Function Centre

### Morning Sessions

| | **Studies** | **Management** |
|---|---|---|
| CHAIR | Angie Ingram | Luke Pope |
| 8:30am | Rivers of Carbon : Upper Murrumbidgee Demonstration Reach – Anita Brademann | Staring down the Oxeye Daisy – Elouise Peach – NSW OEH NPWS |
| 8:50am | Working Support Skills – Providing employees with essential support skills for work and everyday life – Jennie Keioskie – Rural Mental Health | Ox-eye Daisy, (Leucanthemum vulgare): Biological control as a potential management tool in NSW (and Australia) – Andrew McConnachie – NSW DPI |
| 9:10am | Fireweed control in Shoalhaven City – What price will we pay for success – Ian Borrowdale, Shoalhaven City Council | Eradication of Kudzu from Boundary Creek Penrith – Anthony Schofield – Hawkesbury River County Council |
| 9:30am | Controlling blackberries in and around grapevines – Tony Cook, NSW DPI | Topical Soda Apple in the Macleay Catchment – Bill Larkin – Kempsey Shire Council |
| 9:50am | Weeds in the agricultural social context - a look at the personal barriers to good management – Ted O'Kane -Rural Resilience Program NSW DPI | Hawkweed eradication from NSW: Could this be 'the first'? – Mark Hamilton – NSW OEH NPWS |

**Rivers of Carbon Upper Murrumbidgee River- tackling the challenges of riparian weed control**

Organisation: Upper Murrumbidgee Demonstration Reach

Riparian zones are areas of high connectivity in the landscape. They are also areas which can share many adjoining landholders across a range of land tenures. These aspects provide unique challenges for implementing long term weed management.

The Rivers of Carbon- Upper Murrumbidgee River project aims to rehabilitate a 6km stretch of riparian corridor in the Bumbalong Valley to link the high quality riparian and aquatic habitat found in the Bredbo and Colinton Gorges. Practically, the project will involve controlling rampant infestations of blackberry and willows to either rehabilitate remnant native vegetation or prepare for native plantings. These actions alone however, only provide the skeleton for successful rehabilitation of the riparian corridor. Implementing follow up weed control, encouraging maximum participation, landholder commitment and ownership, using the most efficient and appropriate methods, people and organisations working together, adequate funding, increasing riparian vegetation resilience and management supported by monitoring are all key ingredients needed to ensure success of the project in the long term.

This presentation will discuss how the Rivers of Carbon-Upper Murrumbidgee River project is seeking to meet the challenges of ensuring successful long term riparian weed control to support riparian rehabilitation.

# Weeds Presentation

## The Battle to Control Fireweed in Shoalhaven City - What Price is Success

My presentation deals with the struggle by Shoalhaven City Council and the Shoalhaven community to control Fireweed and the cost to keep this noxious weed under control.

Fireweed, Senecio madagascariensis is a poisonous and invasive weed of coastal pastures in eastern Australia. It is native to the KwaZulu-Natal region of South Africa which has been introduced to Australia. It has also invaded parts of the world, including Argentina, Uruguay, Brazil, Japan and Hawaii.

Fireweed has been established on the north coast of New South Wales for a considerable time. It was first sighted in the Shoalhaven in the late 70s where it was thought to have been introduced in stock food, mainly hay that was imported into the Shoalhaven area during a prolonged drought. It was noted to occur in the Worrigee area of central Shoalhaven and since then has spread extensively to most areas of the city.

## Identification.

Many species of plants have been given the name Fireweed, however in Australia; this plant derived its name from its ability to spread like wildfire, or its appearance soon after a major bushfire. In addition to the introduced species, there are several native Senecio species, which belong to the Asteraceae family. All these plants have yellow daisy-like flowers that look similar to Fireweed.
The main identifying features of the introduced species are:

a small woody plant commonly growing 30-40cm tall with a profusion of bright yellow daisy-like flowers, 1 to 2 centimetres in diameter, leaves are bright green and alternate along the stem. The leaves are narrow and slightly curved with finely-toothed edges leading to a pointed tip.

The flowers mostly have 13 petals, 8-14mm long. The flower comprises of 20-21 long narrow vertical bracts. The number of bracts is the main identifying feature of Fireweed as many other Senecio species have flowers with 13 petals.

The seeds of Fireweed are small and light and are readily dispersed by wind. Each flower head may contain up to 120 seeds which are small and light. Each seed is attached to a pappus of white hairs which makes the seed easily dispersed by the wind. Each plant may contain up to 200 flowers per plant which gives this weed an amazing ability to reproduce and spread easily to distant areas. When a highly infested field of Fireweed has reached maturity, the air can take on a silvery sheen when the Fireweed seed is lifted from the plants, by the wind

Fireweed plants have a shallow, branched tap root with numerous fibrous roots that grow 10-20cm deep. The plant is relatively easy to pull out of the ground, if the soil is reasonably moist.

Most Fireweed plants germinate between 15-27$^{o}$C soil temperature. The bulk of Fireweed germinates on the south coast from early autumn through to early spring. Most Fireweed plants adopt an annual life-cycle, however in cool moist summers; some Fireweed plants have the ability to become perennial and have grown and flowered through a full 12 month period, even into a second year.

Fireweed has now spread inland and has become established in the NSW northern and southern tablelands as well as parts of southern Queensland. Fireweed has been reported to be growing at Dubbo Zoo, probably introduced there by contaminated hay and I have seen a photo of a Fireweed plant growing in snow, in the Snowy Mountains.

## Why is it a Problem?

Fireweed contains the pyrrolizidine alkaloids or PA for short. If grazing animals are forced to consume Fireweed when there is insufficient pasture in the paddock or when there is a high infestation of Fireweed in the pasture, the PAs will accumulate in the liver of the animal causing damage. This damage is particularly noticeable in young stock and may lead to death in severe cases. The PAs are still active in hay or silage; this makes Fireweed, contained in conserved fodder more palatable to livestock.

PAs pose a higher risk to cattle and horses than to sheep and goats, which are now commonly used to control Fireweed in some situations. Once cattle are familiar with the weed they tend to avoid grazing it and the PAs will be excreted from the body after a period of time if no more of the weed is ingested. I have had reports of skin irritation being caused through humans, hand-pulling Fireweed, particularly in sensitive areas, such as the face and inside of forearms. It is always advisable to wear gloves for protection when hand-pulling Fireweed as the PAs can accumulate in the human liver and some research has been research by the Health Department into the movement of PAs into the human food chain by ingesting milk or meat products from cattle that have extensively grazed on Fireweed infested pastures. To my knowledge there has not been any positive information released on this subject.

There is also an economic cost to control Fireweed. A survey released by the University of New England indicated that half the land owners surveyed, spent more than 50 hours or $1,000.00 annually controlling Fireweed. On the South Coast the figure is higher, as landowners are still trying to prevent fireweed from becoming established. This coupled with the cost of herbicides is significant in a farm budget. In addition there is the loss production in dairy and beef farms as a result of the PA consumption, reduced carrying capacity as a result of high Fireweed densities overtaking productive native and introduced pastures. There has also been a reported downturn in the demand for conserve fodder such as hay and silage being purchased from properties in known Fireweed infested areas of the South Coast. This also applies to turf farms in known Fireweed locations. Real Estate agents have reported a reduction in the values of properties known to be infested with Fireweed.

There is also a cost to gear up to control Fireweed. Some farmers have had to purchase boom spraying equipment and all-terrain vehicles such as quad bikes. Other lands owners who have resorted to using sheep and goats as a method of Fireweed control, have had to invest considerable capital in fencing their properties, purchasing shearing equipment and stock yards associated with using these animals. I am informed that the sale yards at Bega have been expanded to cater for the sale of sheep and goats which have become a popular method of Fireweed control in this area.

Added to the above-mentioned cost there is the cost to local government imposed by the need to enforce Fireweed control on properties where this weed is declared noxious. The same property may need to be inspected several times in a growing season to ensure that the property owner is successfully controlling Fireweed as required by the Noxious Weeds Act. The failure to completely control Fireweed will lead to a prolific amount of seed being retained on the property and spread to adjoining properties, thus leading to a proliferation of the weed.

## Social Impact

The need to control Fireweed has become obsessive with many land owners in Shoalhaven. Many property owners have controlled Fireweed on their property, through high expenditure and hard labour. They expect their neighbour to carry out Fireweed control of a similar standard. This is not always the case, particularly where absentee land owners, or hobby farmers, are involved. There is considerable pressure placed upon the neighbour to control and on Council to enforce control, using the provisions of the Noxious Weeds Act to ensure control of any recalcitrant property owner. This becomes a greater burden on Council's resources, often straining them to a breaking point.

## The Shoalhaven Example

When Fireweed was first noted in the Shoalhaven it was thought to be just another weed that had been introduced during the drought. As it quickly spread, land owners became more aware of its weedy potential and once the plant was identified by the Herbarium, examples from the north coast, quickly alarmed property owners. There was a growing call for Council and the then Department of Agriculture to do something to control this weed before it completely infested the whole of the city area. A petition was presented to Council calling for Fireweed to be declared noxious in Kangaroo Valley to protect dairy farms and the then lucrative Rye Grass seed industry in this area. Council responded by holding a public meeting in Berry which was attended by up to 200 people from the Shoalhaven and Illawarra areas. The Mayor of Kiama Shire, who was a dairy farmer, spoke against declaring Fireweed a noxious weed and it is still not declared a noxious weed in Kiama Shire to this day. The Regional Director of Agriculture also spoke against having Fireweed declared stating that Council's resources and indeed the Department's ability to provide funding would severely limit the success of having Fireweed declared a noxious weed. The majority at the meeting convinced the Shoalhaven Council to make an application to have Fireweed declared noxious and this declaration was enacted in 1989, but only for the Kangaroo Valley area and for a trial period of 3 years.

In 1992 this declaration was reviewed and the declaration area was also extended to encompass the southern part of Shoalhaven City. At this time, Fireweed was also declared noxious in the adjoining shires of Wingercarribee and Eurobodalla but not in Kiama as previously mentioned. Sometime later when declarations of weeds were being reviewed state wide. Fireweed was declared for the whole of Shoalhaven City after Shoalhaven Council received a 3,000 signature petition calling for a city wide declaration. This city-wide declaration further stretched Council's resources to enforce control and Council requested that Fireweed be declared in two different control categories throughout the City. Fireweed was declared a W2 weed in Kangaroo Valley and Southern Shoalhaven, and a W3 weed in all other areas of the Shoalhaven. Although the control wording has changed, this split declaration is still in force today. This allowed Council to establish what is termed a control zone where Fireweed must be completely controlled in accordance with the Category 3 wording "the plant must be fully and continuously supressed and destroyed" as opposed to the management zone which is Category 4 "the growth of the plant must be managed in a manner that continuously inhibits the ability of the plant to spread'.

This latter category adequately reflects the control carried out by many land owners in this area such as slashing, mulching or grazing with sheep or goats.

The delineation of these zones has been difficult. In the early days it was done by using parish boundaries, which was a good guide to land owners as their parish name was included on their rate notice, however this practice has since ceased and the latest method of describing the zones has been achieved by using a latitude line that coincides with a prominent road, so property owners can easily identify which zone their property is situated in.

## Local Innovation and Adaptation

A group of local farmers and land owners met with the Minister for Agriculture in Berry. The Minister committed to providing funds for a project officer to investigate methods that would be successful in controlling Fireweed on the South Coast. The project officer worked in Shoalhaven and Bega Shire and had established grazing and herbicide trials in both areas. Unfortunately the project officer resigned from the position and it was not filled until a group of Shoalhaven land owners met with the Chairman of the Noxious Plants Advisory Committee in Kangaroo Valley Mr Reg Kidd. Mr Kidd committed to revitalising this project and filling the project officer position. This was done with a slightly different slant, the new project officer joined with the district agronomist from Orange, who had conducted a successful program in the Orange area to build weed resistant resilient communities. This project was very successful involving a group of Kangaroo Valley landowners and culminated in a very successful public information day being held in Kangaroo Valley and the purchase of a rope wick applicator for the use of the project participants.

About this time Fireweed was declared a weed of national significance, and Bronwyn Wicks from the Department of Agriculture was given the task of convening a Fireweed strategic planning workshop, which was held in Coffs Harbour in May 2012. A broad cross section of people who had been successful in the control of Fireweed or who had done research in the control of Fireweed were invited to this workshop, including myself. Two days were spent defining problems proposed by this weed and coming up with solutions for successful control. An important initiative coming from this workshop was the producing of a "Best Practice Management Guide for Australia Landholders to assist in the control of Fireweed. This guide was produced by Brian Sindall and Michael Coleman from the University of New England. Further to this a report on Fireweed control research was released in December 2012 also produced by Brian Sindall and Michael Coleman and Phoebe Barnes from the School of Environmental and Rural Science at the University of New England.

## What Price Success

As you can see from this presentation there has been a considerable amount of effort and funds invested in the control of Fireweed and in researching successful methods to control Fireweed. This has been done on several levels ranging from community groups and local land owners, local Councils, The Department of Primary Industries, research and University groups.

In Shoalhaven, Council expends approximately 25% of its roadside weed control budget on Fireweed and uses approximately 35% of its inspectorial resources in enforcing the control of Fireweed across the control and management zones. As these practices have been ongoing for several years the expenditure of resources and funding on controlling Fireweed is considerable.

In my opinion we are holding our own in Kangaroo Valley, we are slowly losing the battle against Fireweed in Southern Shoalhaven and Fireweed infestations in the management zone are beyond economic control.

This leads me to ask the question what price are we are willing to pay for success………

Acknowledgements:

A Best Practise Management Guide for Australian Landholders
Brian Sindal & Michael Coleman

Fireweed Control Research, Final Report
Brian Sindal, Michael Coleman & Phoebe Barnes
School of Environmental and Rural Science, University of New England

Fireweed Primefact
Invasive Species Unit
NSW Department of Primary Industries

Reference:

Johnston WH 2007, scoping a management program, for fireweed on the South Coast of NSW
NSW Meat and Livestock Australia

# Controlling blackberries in and around grape vines

Tony Cook, Stephen B. Johnson and Mark Scott

It is important to be a good neighbour to control weeds so that they do not spread, and to use herbicides in a way that does not impact on others. Often when someone fails to control weeds on their farm, then the risk of these weeds spreading to surrounding farms is increased. This has legal implications if the species is declared noxious. It is a legal requirement to manage all weedy blackberries (from the former species aggregate *Rubus fruticosus*) as Class 4 noxious weeds across New South Wales. The use of herbicides to manage weedy blackberries also has legal implications. Both of these issues are examined at the beginning of this paper.

This paper provides advice on how best to manage weedy blackberry species once included in the species aggregate *Rubus fruticosus* (European blackberry). These recommendations do not apply to other weedy blackberry species, for example those of Asiatic origin such as white blackberry/Mysore raspberry (*Rubus niveus*) which is found in the north coast of New South Wales.

Best management advice for weedy blackberries is available from a number of sources. These are outlined. The paper then focuses on the management of weedy blackberries around grapevines, since grapes are particularly sensitive to many of the herbicides that are effective against weedy blackberries. Factors to consider when: controlling blackberries around grapevines; using herbicides that are registered for use in these situations; and using non-chemical methods for controlling weedy blackberries in and around vineyards are all considered. The paper concludes with a site assessment template to enable the development of an effective herbicide treatment plan.

## Legal aspects of blackberry control

It is important to be a good neighbour and control weeds so that they do not spread to other areas, and to use herbicides in a way that does not affect others.

### Noxious Weeds

If someone fails to control weeds on their farm then the risk of these weeds spreading to surrounding farms will increase. This has legal implications. In particular, certain weeds that pose a threat to primary production, the environment and/or the community which includes diverse areas such as infrastructure, human health and cultural heritage, and have not spread throughout their potential range may be declared 'noxious' by the Minister for Primary Industries.

Declaration of a weed as 'noxious' occurs under the New South Wales (NSW) *Noxious Weeds Act 1993*.
Four of the five declaration classes are:

- State Prohibited (Class 1) and Regionally Prohibited (Class 2) weeds are targets for eradication across the state and areas of the state, respectively;
- Regionally Controlled (Class 3) weeds are targets for full and continuous suppression and destruction in certain areas;
- All blackberry species formerly within the species aggregate *Rubus fruticosus* except certain cultivars are Locally controlled (Class 4) weeds across NSW.

Landholders are legally required to manage the growth of these plants in a manner that continuously inhibits the ability of the plant to spread. In addition, plants and plant material are not to be sold, propagated or knowingly distributed.

### The use of herbicides

Only herbicides registered or permitted for use in NSW can be used for controlling blackberries in the state. Registrations and permits are approved by the Australian Pesticides and Veterinary Medicines Authority (APVMA). All users of registered and permitted products in NSW must follow the approved label or permit directions, respectively.

Under the *Pesticides Regulation 2009* of the *Pesticides Act 1999*, all commercial applicators must have a current chemical user training qualification (renewable every 5 years) and make a record of all spray applications.

Following the label or permit directions will help avoid off-target damage, including to native vegetation, threatened biodiversity, as well as protect workers and neighbours.

## Management of blackberries

Advice on how to manage blackberries is available from a number of sources. These include your local council weed and/or environmental officers, staff from the Department of Primary Industries and from a variety of printed and internet sources (see below).

## Publications/Internet links

For information on blackberry – the former species aggregate *Rubus fruticosus,* see the NSW DPI Weed Wise link at
http://weeds.dpi.nsw.gov.au/Weeds/Details/18

(and/or NSW DPI, Primefact 1014 'Blackberry')

NSW DPI, Factsheet 1137 'Blackberry control on organic farms', also available on the internet at
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/415900/Blackberry-control-on-organic-farms.pdf

Australian Government, *Blackberry Control Manual*, available on the internet at the 'Blackberry Weeds of National Significance' site
http://www.weeds.org.au/WoNS/blackberry/

Current declarations (on NSW WeedWise)
http://weeds.dpi.nsw.gov.au/

# Treatments for controlling blackberries near grape vines

## Some upfront rules-of-thumb for controlling blackberries

- Blackberries are rarely controlled with a one-off treatment (Figure 1). Repeated applications are often required (Figure 2).
- Herbicides are very handy, but are not the only solution.
- Several types of herbicide are registered for control of blackberries.
- Herbicides can be applied in various ways, potentially reducing drift.
- Larger blackberries are generally harder to control.
- Timing of application (time of day, season, growth stage, moisture stress etc) is critical to effective control
- The method of control is usually limited by situation.
- Most effort is required in the first year with reduction in herbicide/effort required thereafter.
- Integrated weed management is the key: combine chemical and non-chemical options if possible.

Figure 1. Typical results from herbicide application on blackberries where the bush appears to be fully controlled.

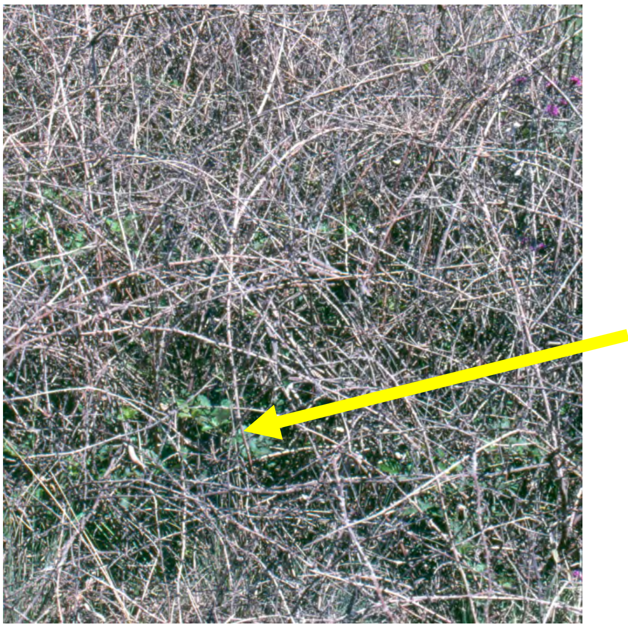


Figure 2. Closer inspection of dead blackberry canes reveals new foliage and canes at ground level. Always inspect treatment performance no later than 12 months after application as the need for re-treatment is likely.

## Things to consider near grape vines

- Grapes and blackberries have similar seasonal growth patterns.
- Grapes are sensitive to herbicides registered for the control of blackberries. Hormonal herbicides (picloram, triclopyr, aminopyralid) are the most potentially damaging, with metsulfuron-methyl not much safer.
- Grapes are more sensitive to herbicides in spring/early summer, and adverse effects diminish in autumn.
- Establishing vines are more sensitive than established vines.
- There are some varietal differences with respect to herbicide tolerance.

- Drift damage potential is affected by the:
    - Method of application (e.g. Figures 3 and 4);
    - Distance of non-target objects from spray applicator;
    - Type of herbicide (glyphosate is less damaging than hormonal herbicides);
    - Formulation of herbicide (e.g. ester versus amine);
    - Droplet size;
    - Wind speed;
    - Wind breaks / buffer zones / trap crops;
    - Wind direction (Figure 5);
    - Release height of droplets;
    - Humidity; and
    - Growth stage of grapes compared with that of blackberries.
- Consider non-chemical options the closer blackberries are to grapes.
- Make the likelihood of blackberries establishing on a property low. Remove refuges such as fallen large branches/logs and improve pasture competitiveness.
- Develop a plan that considers all aspects of weed management. Grapes are not the only sensitive items on a farm. Take into account aquatic habitats, public access areas, residential zones, endangered species, other sensitive crops etc.

All herbicides registered to control blackberries have the potential to damage grapevines. Wind borne drift of all the herbicides in Table 1 will damage vines. Both picloram and triclopyr can also damage vines by leaching from the soil. Autumn, following harvest, is usually the optimum time to control blackberries in and around vineyards. At this time of year, the grapevines are less susceptible to damage, while the blackberries are vulnerable just as they are about to enter winter dormancy.

Figure 3. A small blackberry bush close to vines. Cut and swab is the recommended herbicide application in this situation.

## Herbicide application equipment

The following section outlines a number of herbicide application techniques. Herbicides that are registered for weedy blackberry control in and around vineyards are outlined in Table 1.

*Cut and swab*: cut the cane close to the ground and swab immediately. There is a low risk of damage to grapevines especially if using glyphosate. This is the recommended for application within vineyards.

*Knapsack sprayers*: these are suitable only for small blackberry bushes.

*Powered hand wands/guns*: these are effective for large bushes. There is a risk of drift and also soil contamination due to excessive run-off on the exterior of bushes when achieving good coverage of interior and canes. Pumps should be fitted with regulators and pressure gauges so that low spray pressures can be set and monitored. Nozzles should be chosen or adjusted to deliver a coarse spray. This equipment is not recommended close to, or within vineyards.

*Gas/splatter guns*: reduce the drift risk by applying large droplets in bands, using a concentrated herbicide mixture. This application method is preferred to powered hand guns if large bushes are close to vineyards.

*Spray Booms*: are suitable in vineyards for the application of glyphosate; they are not recommended for other blackberry herbicides in this situation. Booms can be used on smaller blackberry bushes with a range of blackberry herbicides, provided the bushes are well away from the vineyard. Spray booms have a similar drift and soil contamination risk profile to powered hand guns, but more so, given greater volumes are involved. Coarse sprays and low pressures are recommended.

Figure 4. Blackberry in neglected vines; cut and swab with glyphosate is the only recommended herbicide application.

Table 1. Herbicides registered for blackberry control in and around vineyards.

| HOW IT WORKS | ADVANTAGES | DISADVANTAGES | COMMENTS |
|---|---|---|---|
| *Metsulfuron-methyl* | | | |
| Absorbed through the foliage and roots; stops cell division and plant growth; rapidly translocated. | Cheap.<br>Half life in soil approx. one month. | Damaging to grapevines at low rates of active ingredient.<br>Repeat applications generally necessary. | Good for treatment of large infestations, provided they are not close to grapevines. |
| *Glyphosate* | | | |
| Absorbed through the foliage and rapidly translocated. | Cheap.<br>Inactive in soil.<br>Aquatic friendly formulations can be used near water. | Not as effective as other herbicides.<br>Non-selective: damages other vegetation. | Effective on small infestations.<br>Good for cut and swab treatments.<br>Preferred treatment for small infestations within the vineyard itself. |
| *Triclopyr* | | | |
| Absorbed by foliage and translocated; causes rapid, uncontrolled cell division and leaf curl. | Cheap.<br>Half life in soil of 46 days.<br>Very effective, especially in combination with picloram. | Damaging to vines at low rates of active.<br>Highly mobile in soil.<br>Repeat applications may be necessary. | Good for treatment of large infestations, provided they are not close to grapevines.<br>DO NOT use around vineyards situated on steep slopes, especially if run-off from storms is likely. |
| *Picloram* | | | |
| Absorbed by foliage and translocated; causes rapid, uncontrolled cell division and leaf curl; soil active and inhibits root growth. | Very effective, especially in combination with triclopyr. | Damaging to vines at low rates of active ingredient.<br>Residual in soil; half life of 90 days.<br>One of the most mobile in-soil herbicides.<br>Can leak from treated weeds to nearby grapevine roots. | DO NOT use within the vineyard, any closer than 5 m from grapevines.<br>DO NOT use around vineyards situated on steep slopes, especially if run-off from storms is likely. |
| *Aminopyralid* | | | |
| Absorbed by foliage and translocated; causes rapid, uncontrolled cell division and leaf curl; soil active and inhibits root growth. | Increases residual activity of triclopyr/ picloram mixtures. Most effective blackberry control formulation. | Damaging to vines at low rates of active.<br>Persists in off-target vegetation, e.g. pasture (see label restraints). | DO NOT use within the vineyard, any closer than 5 m from grapevines.<br>DO NOT use around vineyards situated on steep slopes, especially if run-off from storms is likely. |

## Non-chemical methods for weedy blackberry control in and around vineyards

A number of non-chemical control methods for the control of blackberry in and around vineyards are examined in Table 2.

Table 2. Non-chemical methods for blackberry control in and around vineyards.

| WHAT THE PROCESS IS | ADVANTAGES | DISADVANTAGES | COMMENTS |
|---|---|---|---|
| *Control methods for within the vineyard* | | | |
| *Hand removal* | | | |
| Hand pulling top growth and digging up roots. | Prevents treating larger bushes later. Little soil disturbance. Fast and requires no heavy equipment. | Can only be used on seedlings not greater than 1 m long. | Can be carried out between grape rows. Ideal strategy if done regularly. Must know likely places where blackberries establish. |
| *Slashing* | | | |
| Removal of the foliage to reduce the vigour of the plant. | Thins blackberries if used regularly. Allows fast easy access to many thick infestations. No soil disturbance. | Not suited to all types of terrain and only applicable where no logs/rocks are under bushes. Follow-up treatments required. | A useful, easy alternative to reduce biomass of bushes without using herbicides or to achieve effective follow-up with herbicides. Can be easily applied between grape rows. |
| *Biological control* | | | |
| Use of leaf rust and other agents to reduce vigour of bushes. | Little management required. No cost and suited to infestations regardless of terrain. | Variable results due to seasonal conditions. Unlikely to kill bushes. May select for more tolerant blackberry species. Suited to thick infestations in higher rainfall regions. | Biological control of blackberries will reduce plant vigour and reproductive capability. This should lead to reduced spread of the weed only. |
| | | | |
| *Control methods for outside the vineyard* | | | |
| *Grubbing* | | | |
| Use of backhoe or excavator to dig plants up roots and all. | Very effective and fast. | Soil disturbance (erosion, and risk of other weeds infesting) with the need to dispose of bush remains. Not suitable adjacent to waterways or steep ground. Need to refill hole after grubbing. | Suitable option for all sized bushes. |
| *Scalping* | | | |
| Using a root rake to drag roots to the surface from a depth of 20 to 30 cm. | Less soil disturbance than grubbing. | Not suitable adjacent to waterways or steep ground. May leave root fragments that might re-establish. | Suitable option for the occasional larger bush. |

| | | | |
|---|---|---|---|
| *Cultivation* | | | |
| Digging up or turning the soil to prepare a seed bed. | Suited to scrambling, low growing canes. Reduces vigour of blackberries quickly. | Cannot be done over large established bushes. Does not effectively remove root fragments and will lead to emerging blackberries. | Must ensure that follow-up treatments such as spot treating emerging blackberries and pasture establishment are done. |
| *Large earth moving equipment* | | | |
| Usually bulldozers used that drag bushes and roots. | Refer to comments for grubbing. However, it is a faster removal tactic than grubbing. | Refer to comments for grubbing. Costly and will need rehabilitation of disturbed ground. | Occasionally used, but suited to open flatter ground. |
| *Grazing by goats* | | | |
| Preferential foliage removal by goats. | Can be used for control in steep, rocky terrain. Low labour costs and can result in a cash return (sale of goats). | Must fence goats away from grapes. Goats will eat other desirable species. Results may take 3 to 5 years depending on stocking rates. | Ideal for use on blackberries that are less than 1 m tall, for example, post-slashing or spraying uses. |
| *Pasture Management* | | | |
| Robust competitive pastures that prevent blackberries establishing. | Ideal preventative option. Initial cost returned by increased stock productivity. Prevents other weed species. A tactic that is complimentary to most blackberry killing strategies. | Not suitable to control existing infestations. Underestimated by many affected growers as a form of blackberry management option. | Obtain local agronomic advice that best suits conditions specific to your property. |
| *Burning* | | | |
| Use of fire to cause rapid defoliation and cane destruction. | Cheap, fast way of gaining access to thick infestations. | Not allowed in total bush fire ban. Has little effect on control and will damage pasture species. May cause damage to nearby desirable species. | Usually completed approx. 6 months after herbicide spray. |

Note: All these options require no chemical treatment and therefore have the advantage of posing no threat to grape vines from herbicide injury/contamination.

Figure 5. A large blackberry bush distant from vines. This could be cover sprayed when the wind is blowing away from vines.

### Site assessment for blackberry control near grape vines: developing an effective and low risk spray plan

To determine what control methods are appropriate (chemical and/or non-chemical), what herbicide to use (if any), what application equipment to use (if applying a herbicide), when to implement the control methods, and how to manage any relevant risks, work through the site assessment (overleaf). Go out to where the blackberries are growing, have a thorough look around and consider the various options outlined in the preceding comments. This will enable you to develop an integrated weed management plan, including a spray plan if a herbicide is applied.

*1. Assessing the property*

Total area:

Landscape aspects (slope/soil type etc):

Pasture condition (any stock? what type?):

Water bodies:

Neighbours:

Native flora/fauna:

Organic/non-organic:

Grape vines (main sensitive area):

  Area planted:

  Growth stage:

  Proximity to nearest blackberries:

  Variety:

Other sensitive crops in site:

*2. Assessing the infestation*

Growth (stages/sizes):

Health (moisture stress/diseases/physical damage):

Describe distribution (especially if near sensitive areas):

*3. Assessing all sensitive areas (in proximity to the property)*

Water bodies (type, proximity to blackberries, aquatic life etc):

Public access near blackberries (likelihood of people eating fruit or touching treated bushes, being sprayed etc.):

Any organic farms nearby, if so describe proximity:

Neighbouring farms with sensitive crops (list):

Other public areas nearby (schools, parks, roads etc):

Desirable native species (native trees, shrubs potentially threatened by treatment(s)):

*4. Specifying treatments to be used*

Spray application method:

To which section of blackberries will this apply?

Why it was selected?

When will it be used (timing, only if weather is suitable, yearly?)

List follow-up treatment(s):

Will it/they be integrated with other methods? If so, describe.

If using herbicides – how will drift be managed?

Any risk of off-target damage apart from drift, e.g. soil residuals, leaching?

Any risks associated with this treatment not already considered, e.g. OH&S?

Any other precautions required?

# Abstract for 18th NSW Weeds Conference
# Cooma 12-15th October 2015

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## Staring down ox-eye daisy in Kosciuszko National Park

Ox-eye daisy (*Leucanthemum vulgare*) is a perennial herb from Europe that spreads primarily by seed, but also by shallow creeping roots (rhizomes). Seeds are long-lived and are produced in large numbers (up to 26,000 per plant). Plants grow in dense populations that exclude native plants.

Ox-eye daisy (OED) is a significant environmental issue in a number of areas around NSW. Once established it is hard to eradicate. With orange and mouse-ear hawkweed, it is considered the biggest weed threat to the alpine region.

Within the Tantangara Area of Kosciuszko National Park, the OED population has boomed since bushfires in the area in 2007.Unlike many other OED infestations, present on disturbed roadsides and cleared land, at Tantangara, OED has inundated subalpine grasslands, snowgum woodlands and wetlands, in both disturbed and undisturbed locations. Kellys Plain, adjoining Tantangara Dam, is the epicentre of OED and contains extremely dense populations. It contains six known populations of threatened flora and a sphagnum bog endangered ecological community.

Extensive trialling of herbicides and application methods have been undertaken, with the aim of controlling OED with minimal impact to native flora. A variety of methods for controlling remote and dense daisy populations have been successfully implemented over the last few years. Methods include helicopter boom and spot spraying and the use of fly-in Quick-Spray units.

NPWS is also investigating rehabilitation methods to assist native flora to compete with OED. This will include harvesting and spreading of native seed in combination with herbicide treatment. Options for biological control are also being investigated overseas.

Containment and asset protection are the dual aim of the program and efforts are also underway to educate stakeholders and community about the impact and spread potential of OED. The program is coordinated by NPWS and

management is undertaken with stakeholders including Essential Energy and Snowy Hydro Ltd.

## Biography of Presenting Author:

**Elouise Peach**

I have worked as a Ranger for the National Parks and Wildlife Service, Southern Ranges Region for 9 years. The area I manage is mainly within northern Kosciuszko National Park, and Yaouk and Scabby Range Nature Reserves within the Yaouk Valley .

In addition to weed control programs my work involves pest animal and fire management, visitor liaison, community education, historical and cultural heritage management.

Prior to working in Tumut I worked in the Illawarra Area with the National Parks and Wildlife Service as a Ranger, and earlier as a Discovery Education Program Coordinator and Environmental Educator and TAFE Outdoor Education Teacher.

# The initiation of a biological control programme as part of an integrated strategy to manage the weed ox-eye daisy, *Leucanthemum vulgare* Lam. (Asteraceae), in New South Wales, Australia

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**Summary**

**Ox-eye daisy, *Leucanthemum vulgare* Lam. (Asteraceae) is a rhizomatous perennial that is native to Europe and which has become an invader in over 40 countries (including Australia and New Zealand). Mature plants can produce up to 26,000 seeds, which are dispersed by animals, vehicles and water. Seed longevity is high and up to 80% of propagules are viable for six years (with some reportedly up to 39 years). The weed is not palatable to cattle and affects pastoral lands by reducing carrying capacity. Dense infestations exclude other plant species, leading to soil erosion and depletion of soil organic matter. A declared noxious weed in Victoria, in New South Wales (NSW) ox-eye daisy is found in the highland regions of the Northern Tablelands, Barrington Tops, the Central Tablelands and the Southern Alps. Within the Tantangara area of Kosciuszko National Park, there has been a marked increase of the invader (density and spread) since the 2007 bushfires. The species appears to thrive in disturbed areas such as roadsides and cleared land, however, of greatest concern is its ability to aggressively invade areas of conservation importance: sub-alpine grasslands, snow gum woodlands and wetlands in Kosciuszko National Park. While mechanical and chemical control can be successfully implemented to manage localised infestations of ox-eye daisy, there is an urgent need for the sustainable management of this invasive plant at the landscape level, especially in conservation areas. In 2008, a programme was initiated to investigate the prospects for the biological control of ox-eye daisy in North America. Over the last seven years CABI Switzerland have identified and studied several promising biological**

**control agents on behalf of their North American funders, including a root-feeding moth, *Dichrorampha aeratana* Pierce & Metcalfe (Lepidoptera: Tortricidae), a root-feeding weevil *Cyphocleonus trisulcatus* Herbst (Coleoptera: Curculionidae) and a flower head-mining fly, *Tephritis neesii* Meigen (Tephritidae). Of these, *D. aeratana* seems to hold the most promise in terms of specificity and is being developed further as the first biological control agent for North America. In early 2015, a programme to investigate prospects for the classical biological control of ox-eye daisy was initiated for NSW. An agreement has been reached with CABI Switzerland to facilitate field visits and collection of a starter culture of *D. aeratana* in the summer of 2015/2016. A QC3 insect quarantine facility is in the process of being certified at the NSW Department of Primary Industries at Orange Agricultural Research Institute. The programme will include biology, host range and impact testing, as well as ecoclimatic and degree-day modelling, and Life Cycle Assessment for *D. aeratana*.**

**Key words:** biological weed control, *Dichrorampha aeratana*, *Cyphocleonus trisulcatus*, *Tephritis neesii*

## Introduction

*Leucanthemum vulgare* (Vaill.) Lam. (Asteraceae) (Figure 1A), commonly known as ox-eye daisy, is a diploid, perennial herb native to Europe (Figure 2a). It is a shallow-rooted, herb that spreads by rhizomes and seeds. Plants are 30 to 90 cm tall, with basal stems prostrate and capable of rooting, while other stems are erect and simple or slightly branched. The erect stems are glaborous to pubescent. The leaves are dark green, often glossy, sessile and spirally arranged on the stems (Mitich, 2000). The stem leaves are narrowly lanceolate or ligulate and coarsely toothed, often with lobes at the base (Figure 1F). The flowers are comprised of bright yellow disc florets (Figure 1 C) and white ray florets (Figure 1 B). The heads are 2-7 cm in diameter and occur in a solitary arrangement at the tips of the stems and long branches (Clements *et al.* 2004). The achenes are grey to black in colour, ribbed, and have no pappus (Figure 1 D). The seeds are long-lived and produced in large numbers (up to 26 000 per plant) (Mitich 2000). Seed longevity is high and up to 80% of propagules are viable for six years (with some reportedly up to 39 years) (Toole and Brown 1946).

*Leucanthemum vulgare* has been recorded from 40 countries outside its native range (Figure 2b). It is widely distributed throughout southern Canada and the United States of America; it is especially common in the north-eastern states and in northern states down to California (Clements *et al.* 2004). *Leucanthemum vulgare* is a weed in in both natural and agricultural environments outside its native range (Benson 2012). It is considered a major pasture weed, being not palatable to cattle and negatively affecting carrying capacity (Mangold *et al.* 2009). If consumed by dairy cattle their milk has an unpleasant flavour (Clements *et al.* 2004, Parsons and Cuthbertson 1992). Dense infestations exclude other plant species, leading to soil erosion and depletion of soil organic matter (Mangold *et al.* 2009, Mitich 2000). *Leucanthemum vulgare* has numerous environmental impacts. It forms dense populations that are able to reduce native species diversity (Mitich 2000, Khuroo *et al.* 2010). The weed has also been found to harbour several species of polygalous gall-forming *Meloidogyne* spp. nematodes that are damaging to a wide range of plant species (Clements *et al.* 2004, Jacobs 2008). Studies have also found a significant decline in species richness in quadrats that were highly invaded by *L. vulgare* (Mitich 2000). It has also been shown to cause homogenisation of species composition, with lower values of species richness in invaded sites. Further, it is thought to have a potentially inhibitory role in limiting the natural regeneration of seedlings on forest floors (Khuroo *et al.* 2010).

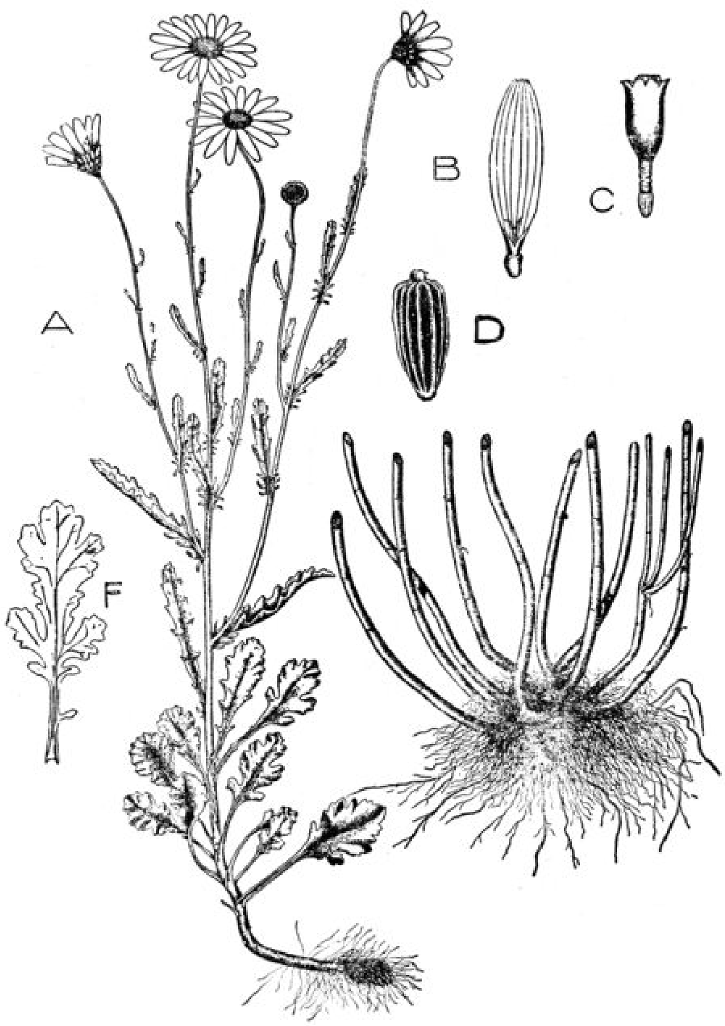


**Figure 1. Leucanthemum vulgare, ox-eye daisy (Jay Cole, Jefferson County Weed District, Montana, U.S.A.).**

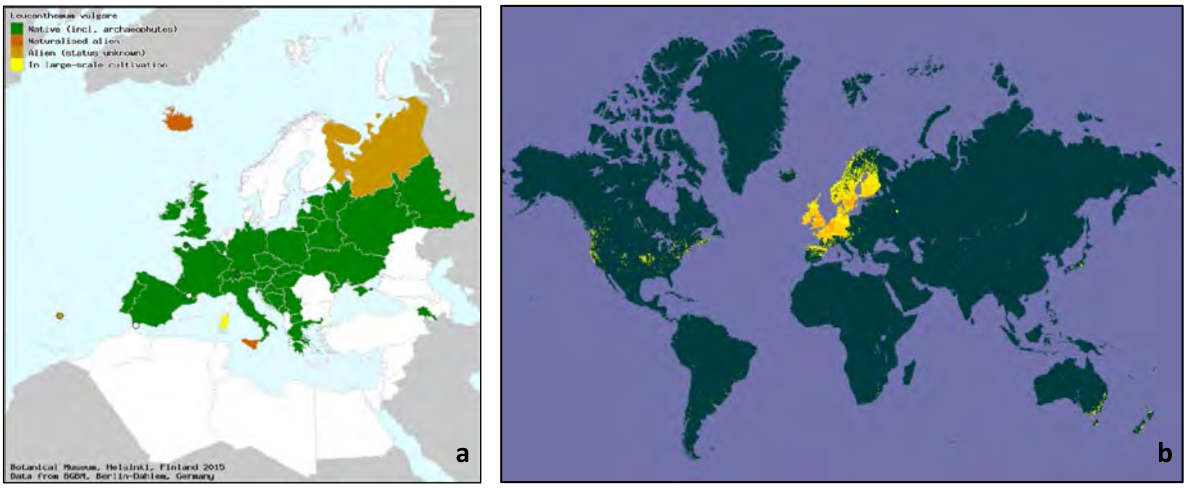


**Figure 2. Distribution of *Leucanthemum vulgare*; (a) in its native range (green) in Europe (Euro+Med PlantBase, accessed 5 June 2015), (b) global distribution [Global Biodiversity Information Facility (GBIF), accessed 10 June 2015].**

Ox-eye daisy has expanded across the world as a garden ornamental due to its attractive flowers and hardiness (Benson 2012). How and when *L. vulgare* was introduced into Australia remains unknown. Introduction to Australia was probably as a garden plant and with the earliest records, from the Adelaide Botanic Gardens in 1858 (Parsons and Cuthbertson 1992). The earliest record in the Australian herbarium is of a specimen that was collected in 1900, in the Hobart area (McDougall *et al.* 2013). Collections were made in the following decade south-east of Melbourne, in south Gippsland and the Blue Mountains west of Sydney (McDougall et al. 2013). Ox-eye daisy was first recorded in the Victorian Alps in 1976 at Mt Hotham (McDougall et al. 2013). Twentieth century records for the weed in the Alps Bioregion, is a herbarium collection made in January 1961 on Tantangara Rd (McDougal *et al.* 2013). *Leucanthemum vulgare* is currently a declared noxious weed in Victoria, while in New South Wales (NSW) it is not declared. It is found in the highland regions of the Northern Tablelands, Barrington Tops, the Central Tablelands and the Southern Alps (Figure 3a). Records are also reported from South Australia. The weed invades a variety of land-use types, including nature conservation areas, pastures (both modified and native), plantations and forestry areas (Figure 3b).

Risk assessments undertaken for conservation areas by the NSW National Parks and Wildlife Service (NPWS – unpub data) suggest that this weed is a very high risk to open bushland, grassland, alpine and sub-alpine vegetation. However, the feasibility of landscape control is low given it is widely distributed in NSW. Therefore, NPWS currently undertakes a number of localised control programs across the Great Dividing Range of NSW (Turner *et al.* 2013), including in Blue Mountains, Kosciuszko and Barrington Tops National Parks.

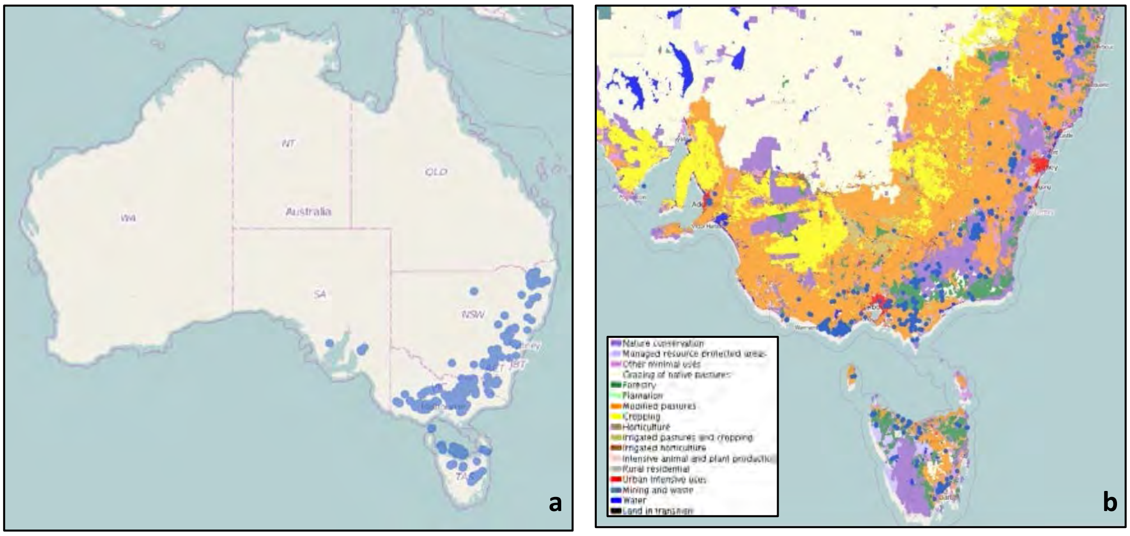


**Figure 3. Distribution of *Leucanthemum vulgare*; (a) in Australia, (b) in relation to land-use types (Atlas of Living Australia, 928 records, accessed 5 June 2015).**

It is possible that the species was introduced to KNP through earthworks associated with the construction of Tantangara Dam (McDougal *et al.* 2013). Having said this, ox-eye daisy is not currently present in the Kiandra village area, or at Currango Homestead. Places with gardens in the early years of settlement in the KNP area had numerous garden escapes (Schroder *et al*. in press). A second collection was made at the Happy Jacks Township site which was established in 1965. This is most likely associated with ornamental gardens in the township (McDougall *et al*. 2013). Although the species may have been present in KNP earlier, it is unlikely that it was abundant or widespread at that time. With its large conspicuous flowers it would have often been collected were it was abundant. Despite this, most collections in the Kosciuszko area have been made in the last decade (e.g. see Schroder *et al.* in press).

In the late 1990s, the species was common along parts of Tantangara Rd, especially in the vicinity of the Nungar Creek crossing (McDougal *et al.* 2013). Scattered plants were occasionally observed in treeless areas in the following years (e.g. Nungar Plain and headwaters of Gang Gang Creek), but the species was of little concern at that time and not the subject of a control program. Following a wildfire in 2007, ox-eye daisy began to appear in natural vegetation west of Tantangara Rd in the vicinity of Kelly's Plain and was locally dominant by the summer of 2010/11 (Figure 4). It was probably becoming established because of feral pigs and horses in the Kelly's Plain area before the 2007 fires but the fires caused the populations to significantly increase and spread. Ox-eye daisy has continued to spread in and beyond this area, now common in the vicinity of Wares Yards and on Nungar Mountain. It was not observed near Wares Yards between 2002 and 2004 when floristic plots were sampled for the vegetation classification of treeless vegetation of the Australian Alps (McDougall and Walsh 2007). Ox-eye daisy has been recorded at numerous sites in northern

KNP, especially in the last 5 years. Most observations have been along roads and tracks. The extent of ox-eye daisy invasion in KNP is currently about 1000 $km^2$, extending from the Bogong Peaks Wilderness Area to the northern edge of the Jagungal Wilderness Area. Most records have been made between Lake Eucumbene and Tantangara Dam (Figure 4). It appears that ox-eye daisy took roughly 50 years to attain local dominance in the Tantangara (Kelly's Plain) area. It also appears that fire was the trigger for its sudden increase in abundance. Ox-eye daisy, which was initially thought to have been associated with the gardens of the Happy Jacks Township, has become more prominent at this site after a 2003 fire, leading to attempts to control it along Happy Jacks Road.

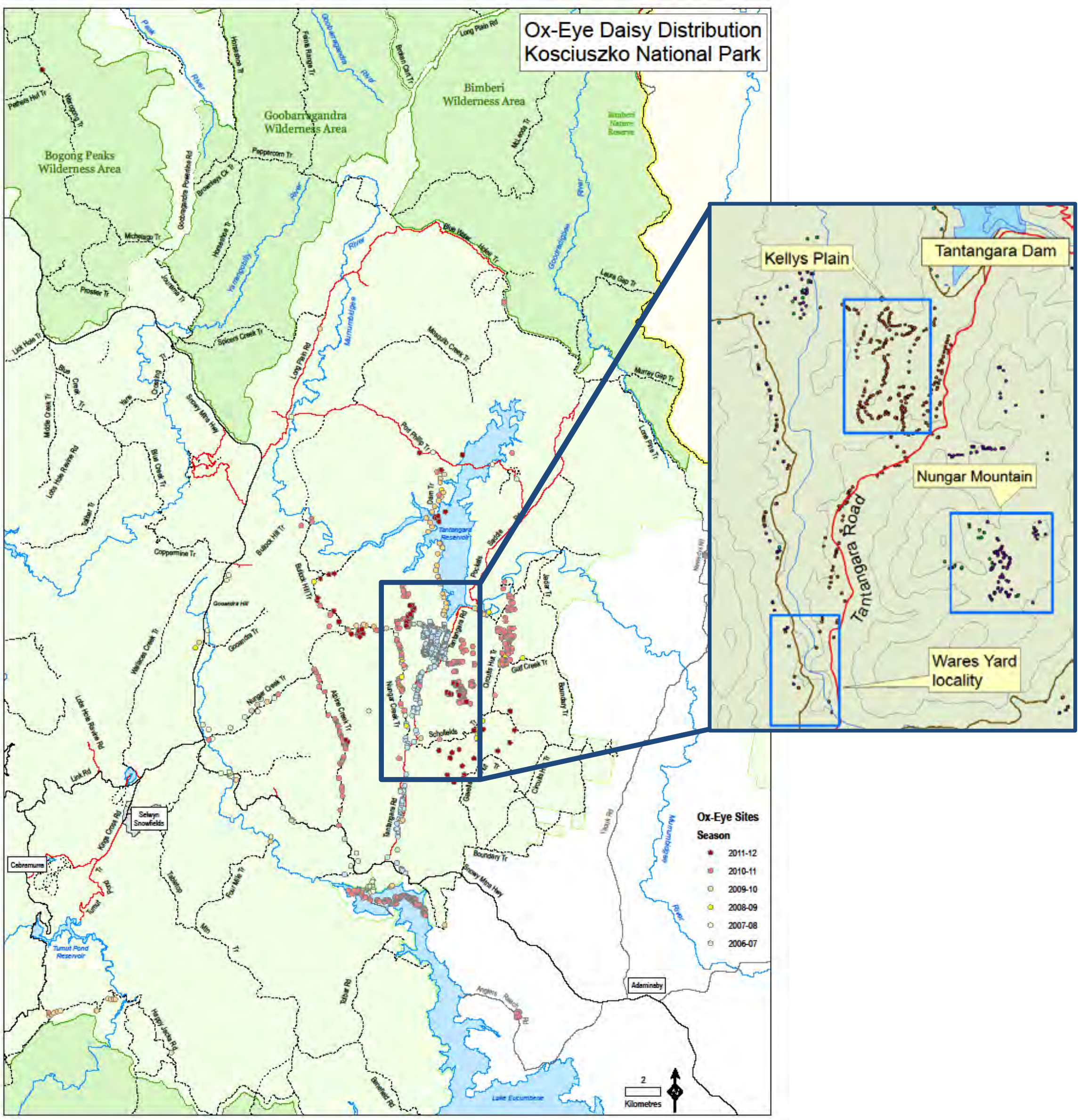


**Figure 4. Distribution of Ox-eye Daisy in and around Kosciuszko National Park (McDougal *et al.* 2013).**

**Current management approaches**

Despite NPWS investing heavily into control programs aimed at reducing its impacts at key sites as well as containing it within the current extent (Turner *et al.* 2013), a number of characteristics of ox-eye daisy including prolific seeding and dispersal via various mechanisms are proving difficult management challenges. In addition, many of the current management approaches are not suitable for conservation areas due to their potential off-target damage.

To date, the management of *L. vulgare* has largely relied upon mechanical and chemical approaches. In North America, mechanical control has had variable success. Hand pulling, grubbing, and hoeing have been effective in controlling small, isolated populations of *L. vulgare* (Jacobs 2008). Chipping has also been used effectively in KNP under the same conditions (Miles, pers. comm.). However, for any of these techniques to be effective as much of the rhizome needs to be removed as possible. Annual mowing of *L. vulgare* in Europe (with removal of hay) resulted in an increase in weed abundance, however, was effective in reducing seed spread if timed correctly (Jacobs 2008). Cultivation can be very effective in reducing populations of *L. vulgare* (hence the observation that it is rarely a weed of cultivated crop fields), however, it may also act as a mechanism of spread either within a crop field or between fields (Jacobs 2008). In a 28 year study in Sweden, annual burning of grasslands did not negatively affect populations of *L. vulgare* (Wahlman & Milberg 2002). In fact, frequent fires may deplete soil nitrogen which in turn favours the weed's competitive ability over other species. Due to its bitter, acrid taste, livestock (cattle and pigs) generally avoid grazing of *L. vulgare*. As a result, heavy grazing in infested pastures reduces the competitive presence of other beneficial species, so resulting in a significant increase in *L. vulgare* populations (Olson and Wallander 1999). Therefore, prescribed grazing management (favourable timing, frequency and intensity) should be part of a sustainable management approach of this weed (Krueger and Sheley 2003, Jacobs 2008). Any other pasture practices which increases the competitiveness of desirable plant species and communities, e.g. conservation crop rotation, nutrient management, conservation cover, critical area planting, should be encouraged to reduce the environmental suitability for *L. vulgare* survival and spread.

Chemicals have been used to manage *L. vulgare* in pastures, rangelands and wild lands in North America and Canada, albeit temporarily (Jacobs 2008; Clements *et al.* 2004; Mangold *et al.* 2009). Several herbicides have provided effective control of the target, including aminopyralid, metsulfuron-methyl, picloram, and 2,4-D. In a study conducted in Montana, United States of America, a combination of metsulfuron and aminopyralid provided the most consistent control of *L. vulgare*, at the lowest concentrations, after one year (Mangold *et al*. 2009). Glyphosate is also effective in controlling *L. vulgare*, however, is only suitable for use in croplands or areas to be revegetated due to the off-target damage it causes. Reports of herbicide resistance have come from the United Kingdom and New Zealand (Howarth and Williams 1968; Taylor 1981). Because ox-eye daisy is a poor plant competitor, reinvasion following herbicide treatment may be further supressed by the planting of desirable species (Mangold *et al*. 2009). In addition, repeated application of nitrogen fertiliser was almost as effective in managing ox-eye daisy as spraying with 2,4-D or picloram after seven years (Jacobs 2008). The recommended rate of nitrogen application was 90 $kg.ha^{-1}$. The results of this study suggest that ox-eye daisy is not competitive with grasses, particularly under high nitrogen conditions.

*Leucanthemum vulgare* is viewed as a potentially more invasive Asteraceous weed than *Hieracium aurantiacum* (Asteraceae, orange hawkweed) which is rated as one of New Zealand's worst weeds (Benson 2012). However, ox-eye daisy has a much wider distribution in Australia than orange hawkweed (Hamilton *et al.* in press). In this context, it is surprising that the seriousness of the invasion has not received greater attention, especially considering that if left unchecked, vast tracts of the NSW Tablelands and Alpine zones are potentially at risk. The world acclaimed Biosphere Reserve, KNP is already under threat with exploding populations of the weed, especially in the Kelly's Plain area. As Benson (2012) warns;

"…this has raised the alarm bells about the weed's potential to rapidly invade large tracts of KNP and tableland agricultural lands."

McDougal *et al.* (2013) outline a management plan developed by the NSW Office of Environment and Heritage (OEH), through their NPWS for northern KNP to try and contain the weed to the Kelly's plain area. This plan hinges upon the use of herbicides (picloram, triclopyr, aminopyralid and metsulfuron methyl) under a minor use permit. Areas targeted using these herbicides includes trails (due to bush walker seed spread risk), powerlines (due to risk of spread by maintenance vehicles and personal) and isolated populations (for containment). Because ox-eye daisy populations in the park co-occur with (and as a result directly threaten) the main populations of threatened plant biodiversity such as: *Calotis pubescens* (F.Muell. ex Benth.) (endangered); the only NSW population of *Glycine latrobeana* (Benth.) (Fabaceae) (vulnerable - Environment Protection and Biodiversity Conservation Act); several populations of *Calotis glandulosa* F.Muell. (Asteraceae) (vulnerable); *Prasophyllum retroflexum* D.L.Jones (Orchidaceae) (vulnerable); *Prasophyllum innubum* D.L.Jones (Orchidaceae) (critically endangered); and the Montane Peatland endangered ecological community, herbicide work in KNP has focussed on minimising off-target damage (McDougal *et al.* 2013). The management strategies of prevention, eradication, containment and asset protection have all been employed within KNP to manage the impacts of *L. vulgare*.

**Biological Control**

Globally, weed species in the family Asteraceae, pose a control challenge, e.g. parthenium weed (*Parthenium hysterophorus* L.), Siam weed or chromolaena (*Chromolaena odorata* (L.) R.M. King and H. Robinson), pompom weed (*Campuloclinium macrocephalum* (Less.) DC): ox-eye daisy (*Leucanthemum vulgare*) is no exception, with increasing world research showing that the plant resists a number of control measures. But with high economic costs for these control measures, herbicide resistance, and the non-target impacts of chemicals in environmentally sensitive areas, a more suitable control approach is urgently required. Enter biological control: in 2008, efforts were made to initiate a biological control programme on *L. vulgare* by CABI Switzerland, with support from the British Columbia Ministry of Forest and Range (Schaffner *et al*. 2008), and subsequently from the Montana Noxious Weed Trust Fund via Montana State University (Schaffner *et al.* 2011). In 2012/2013, additional funding was provided by the Canadian Agricultural Adaptation Program with support from the Wyoming Biological Control Steering Committee, the Alberta Association of Agricultural Fieldmen, Canadian Pacific, Endbridge Pipelines Inc., and the Peace Region Forage Seed Association (Stutz *et al.* 2014). The outcomes of this funding included surveying the native range of *L. vulgare* for natural enemies associated with the plant, identifying suitable candidate agents, assessing their host range, biology and impact, and compiling comprehensive annual progress reports (e.g. Stutz *et al*. 2015).

*Overseas exploration*

The native range of *L. vulgare* extends throughout Europe north to Scandinavia, the British Isles, south to northern Spain and Italy, and east to the Urals and the Caucasus (Howarth and Williams 1968). Surveys for natural enemies in the plants native range were conducted in Switzerland, Germany, France, Spain and the Czech Republic by CABI Switzerland (McClay *et al.* 2013). Of all the insects associated with the target, the following species were identified as having the most potential based on their field and laboratory host range and impact; the root-mining moth *Dichrorampha aeratana* Pierce & Metcalfe (Lepidoptera: Tortricidae), the root-mining weevil *Cyphocleonus trisulcatus* Herbst (Coleoptera: Curculionidae), and the flower-head-feeding fly *Tephritis neesii* Meigen (Diptera: Tephritidae) (McClay *et al.* 2013). *Dichrorampha aeratana* is the most extensively studied of the above list of available natural enemies, and has been recommended by CABI researchers to be the most suitable starting agent for importation into Australian quarantine. The root-mining weevil, *C. trisulcatus*, would be a good second option, based on the fact that it seems to have a greater impact on *L. vulgare* but is not host specific as *D. aeratana* (U. Scaffner, pers. comm.).

*Dichrorampha aeratana*

According to the literature, 15 *Dichrorampha* species are reported to develop on species in the genus *Leucanthemum*; of these, the root-mining moths (*D. aeratana* and *D. baixerasana*), and the shoot-mining moth (*D. consortana*) were considered to be monophagous on ox-eye daisy (Stutz *et al.* 2015). A good population of *D. aeratana* was encountered by CABI researchers in 2008 in the south of Switzerland, therefore, much of the early research focussed on this species (Stutz *et al*. 2015). Larvae of this moth are active root feeders and utilize this resource to overwinter. In late winter/early spring, larvae exit the roots and pupate in the soil. Adults eclose (emerge as an adults from the pupae) mid- to late spring and fly during the first two months of summer.

Extensive work has been completed by CABI on the biology, host range and impact of this agent (Stutz *et al.* 2015). No-choice host range studies have been conducted on 55 test species and varieties. While the majority of test species did not support larval development, a couple were recorded from several species outside the genus and all Shasta (ornamental *Leucanthemum* hybrid) daisy varieties. Open-field tests demonstrated restricted feeding to the genus *Leucanthemum*, with only a few larvae on Shasta daisies (Stutz *et al.* 2015). Impact studies using *D. aeratana* demonstrated significant negative impacts ox-eye daisy below-ground biomass and number of flowers produced, while no significant impacts were recorded on the one particular Shasta daisy variety tested.

**Eco-climatic and degree-day modelling**

Eco-climatic modelling is an approach whereby global meteorological datasets and process-based niche modelling algorithms are interfaced to project species potential distributions in relation to novel climates with more confidence than empirically based regression models (Kriticos and Randall 2001). A robust and widely used eco-climatic model is CLIMEX ([Hearne Scientific Software, Melbourne, Australia, (Sutherst & Maywald, 1985; Sutherst *et al*. 2007)]).

Using CLIMEX, the eco-climatic suitability of Australia for both *L. vulgare* and *D. aeratana* will be assessed. Models will be developed using native range distribution data (for *L. vulgare* and *D. aeratana*), invaded range distribution data (*L. vulgare*) and laboratory derived parameters from the literature (*L. vulgare*) and the quarantine developmental studies (*D. aeratana*). A degree-day model will be compiled using data obtained from developmental threshold studies, which will allow for the prediction of the number of generations that the insect will be able to complete in Australia throughout the invaded range of *L. vulgare*.

**Life Cycle Assessments (LCAs)**

Life Cycle Assessments allows an assessment of the environmental impacts associated with the development of a product from cradle to grave. By utilising LCAs, a narrow outlook on environmental concerns can be avoided by: (1) compiling an inventory of relevant energy and materials inputs and environmental releases; (2) evaluating the potential impacts associated with identified inputs and releases; and (3) interpreting the results to help make a more informed decision (US EPA, 2015).

In this project, a LCA will be used to explore the environmental impact (global warming potential, eutrophication, and fossil fuel consumption) of developing and using a herbicide as a management tool for *L. vulgare*, as opposed to developing and implementing a biological control agent. This will be an extremely valuable exercise, both from an environmental impact and a management perspective, but may even be a world first in assessing the real costs of managing environmental and agricultural weed issues.

**Discussion and Conclusions**

More than a century after being introduced to Australia, *L. vulgare* is now widespread in Tasmania and Victoria, and is becoming more abundant in NSW. Climatic modelling suggests that given time, this weed will invade vast tracks of the NSW Tablelands and Alpine zones if an integrated strategy is not developed and implemented soon. At risk are sensitive environmental areas (e.g. KNP, a world Biosphere Reserve), natural and planted pasture systems, woodlands, plantations and roadside reserves.

Research conducted by the NSW OEH, through NPWS has been instrumental in determining not only the extent of the invasion in KNP, through regular mapping, but also through conducting herbicide trials (considering target and non-target effects). Were it not for their efforts, significantly more areas in KNP would now surely be invaded by *L. vulgare*.

Studies conducted on *D. aeratana* in its native range suggest that it has suitably high levels of host specificity and impact, an important consideration for a potential agent for import into quarantine in NSW. An agreement has been reached with CABI Switzerland to facilitate field visits and the collection of a starter culture of *D. aeratana* in the summer of 2015/2016. This culture will be imported into a QC3 insect quarantine facility, which is currently in the process of being upgraded and certified at the NSW DPI, Orange Agricultural Research Institute.

With several other promising agents for consideration in the weed's native range, the prospects for the integrated control of *L. vulgare* look promising and without such tools the impacts of ox-eye daisy are likely to increase across vast areas of NSW.

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# Eradication of *kudzu* from Boundary Creek Penrith

## Kudzu (*Pueraria lobate)*

Kudzu is an aggressive deciduous, perennial, woody vine which forms dense mats that often smother supporting vegetation Its stems can grow up to approximately 30 metres long and can scramble over the ground or climb over other vegetation and structures. Kudzu produces large underground tuberous roots which can extend for 5m into the ground. Reproduction is by seed and vegetative tuberous roots. Kudzu generally flowers over summer, normally after reaching three years old.

Kudzu is a generalist growing in a variety of habitats, however it prefers open and disturbed habitats with fertile, well-drained soils. It is an opportunistic plant that is quick to colonise and dominate forest edges, abandoned fields and roadsides. Kudzu can grow in a wide variety of soil types, including soils that are nutrient-deficient. Survival and growth on poor soils is enhanced by its ability to fix atmospheric nitrogen within specialised nodules on its roots (rhizobium), however it doesn't grow well in wet or high pH soils. Kudzu is sensitive to frost, losing its leaves as a response and dying back in winter, however due to its invasive nature it is quick to recover.

Kudzu is capable of very rapid growth and can grow up to 10–30 m per growing season (up to 2.5 cm thick) and can grow up to 30 cm in a day. Kudzu can disperse both by seeds and vegetatively which seems to be the primary mode of dispersal with new roots being produced wherever trailing stems touch the ground.

Total Earth Care (2012)

Native to parts of Asia, from China and Japan to south eastern Asia and New Guinea (DPI 2015), Kudzu is a huge problem in southern USA where it is known as "the plant that ate the south"(Turnbull & Storrie 2004). Kudzu is also a problem in South Africa, Hawaii and New Zealand (Csurhes 2008).

Kudzu is a significant weed in Coastal New South Wales and is a declared noxious weed in these areas. It is also beginning to cause significant problems in several locations throughout South East Queensland (Total Earth Care 2012).

Kudzu infestations throughout the Hawkesbury-Nepean are not widely documented, however it is considered a very high threat to biodiversity and is an emerging weed in Sydney (Total Earth Care 2012). Prior to February 2014, Kudzu was not a declared noxious weed in Sydney .

## Boundary Creek, Penrith: Site Challenges

The affected site is approximately 300 metres length of Boundary Creek, between Castlereagh Rd and the Nepean River, Penrith. The creek flows through an industrial area with 2 landowners on the northern bank and one landowner on the southern bank. Up to 50 Ml/day of treated wastewater are discharged into the creek by Sydney Water upstream of the site.

The kudzu is likely to have been present for several decades and was possibly introduced as a means of addressing severe bank instability. Unless removed it has the potential to spread into the main river and establish in other areas.

Controlling the plant has proven extremely difficult due to severe bank instability compounded by continuous discharges from the upstream sewage treatment plant (STP). Under Sydney Water's Replacement Flows Project, STP discharges into Boundary Creek increased from 21Ml per day to an average of 43Ml per day.

**Replacement Flows Project**
Completed in September 2010 and costing more than $235 million, Sydney Water's Replacement Flows Project involved the construction of a reverse osmosis plant at St Marys and over 70kms of new and refurbished pipeline connecting Quakers Hill and Penrith STPs to the new plant.

Wastewater from Penrith and Quakers Hill STPs is sent to St Marys Water Recycling Plant (SMWRP) where it undergoes a reverse osmosis process. The highly treated recycled water is sent to Penrith where it is released into the Hawkesbury-Nepean River via Boundary Creek. This highly treated wastewater replaces up to 18 gigalitres per year of drinking water that was previously released from Warragamba Dam into the Hawkesbury-Nepean River (as environmental flows). UGL (2015)

## Project Scoping & Planning

In November 2009 the Office of the Hawkesbury-Nepean (OHN) established a working group to examine the causes of the erosion and facilitate a cost sharing arrangement for rehabilitation of the creek, including bank stabilisation and removal of the kudzu.

It was impossible to address the weed issue without addressing the erosion, and the working group's initial focus was to identify and quantify the causes of erosion.

The three affected landowners each contributed $4000 towards rehabilitation, including an independent study to examine the causes of erosion and recommend options for stabilisation. The OHN and Penrith City Council also contributed $4000. Sydney Water contributed $60,000.

Civil engineers were engaged to investigate options for weed removal and stabilisation of the creek. Their report identified two options for remediation of the creek, both of which involve piping the STP flows for the length of the creek. The preferred option was estimated to cost $5.137 million, including $725,000 for removal of vegetation and revegetation of the site.

An independent geomorphological assessment of the creek was also undertaken, which identified the following factors contributing to the erosion;

changes in net discharge and available stream power acting upon inherently unstable floodplain fill sediments, including

1. the advent of constant base flow from Penrith STP
2. progressive increases in discharge from Penrith STP, and
3. discharges from impervious surfaces within the catchment as a consequence to urbanisation (Johnston 2011)

Attempts were made to develop a cost sharing arrangement but negotiations faltered for a number of reasons including the announced closure of the OHN in early 2012.

Following heavy storms in March 2012, one of the landowners, Virbac Animal Health, engaged environmental consultants Total Earth Care to undertake emergency bank stabilization work in order to protect their buildings & property. Total Earth Care had previously undertaken management of kudzu for Wyong Council.

This presented an opportunity for some additional works focused on eradicating the kudzu. OHN commissioned Total Earth Care to undertake some initial weed removal and prepare a Weed Management Plan, outlining a strategy to eradicate the weed.

When the OHN closed in July 2012, $40,275 remained from the original pool of funds. These funds were transferred to the Hawkesbury River County Council (HRCC) and quarantined specifically for rehabilitation (weed treatment and revegetation) of Boundary Creek. The Sydney Weeds Committee agreed to contribute an additional $33,605 in Weeds Action Program grant funds towards treatment of weed (not rehabilitation), bringing the available funds to $73,880.

An agreement was reached with the three landowners whereby Virbac Animal Health would assume a “lead” role and take responsibility for engaging and paying for works and providing invoices to HRCC for re-imbursement.

## Description of works

Controlling the weed required a combination of herbicide applications and physical removal. The site was also revegetated with native plants. Some additional works were also needed to stabilise the banks which collapsed after a storm event during the project. These works were funded separately by the landowners.

May 2012 – February 2014

- Multiple herbicide applications (8 treatments from May 2012 to February 2014) using splatter gun and high volume sprayers.
- Seeding with annual ryegrass – (6 applications from June 2012 to February 2014)

- Glyphosate 450 biactive initially used to provide access paths to the entire site so that inaccessible areas could be checked for Kudzu.
- Combination of Brush-off and Garlon used for kudzu in riparian and native vegetation areas.
- Grazon used for pasture areas. See table 1.

**Table 1: Kudzu herbicide treatment**

| SITUATION | HERBICIDE / RATE |
|---|---|
| Riparian areas & native vegetation | Metsulfuron-methyl:<br>10g per 100L spray volume, plus non-ionic surfactant<br><br>Triclopyr:<br>*Knapsack/4 wheelmotorbike:*<br>50mL per 15L water<br>*High volume:*<br>330 mL per 10 L spray volume |
| Pasture | Picloram + Triclopyr<br>500 mL per 100L spray volume |

Source: McGahey 2014

This initial period saw a number of heavy rain events, continued erosion and the collapse of two large sections of creek bank. By June 2014 the majority of kudzu plant material had been removed. However, a small number of plants showed signs of re-growth, and plants growing in 2-3 treetops had yet to be treated. There was also concerns about dispersal of kudzu roots/stems due to erosion/collapse of some parts of the bank. A final phase of works was planned and approved.

July 2014 to September 2014

- Removal of dead weed debris to access remaining live kudzu plants
- Application of herbicide to eradicate the Kudzu along the entire reach (a motorised sprayer and two operators and splatter guns used)
- Reshaping two sections of creek bank where erosion is causing Kudzu roots and stems to be washed into the creek and subsequently washed downstream offsite.

After nearly five years, including two years of intensive works, and at a total cost of around $110,000, the site at Boundary Creek is now largely free of Kudzu. This result could not have been achieved without the cooperation amongst the three affected landowners.

In February 2014, Kudzu was declared a class 2 noxious weed in the Sydney region and the landowners have committed to long term monitoring and management of the site. Total Earth Care have been retained to provide ongoing monitoring and weed control.

As the local control authority, Hawkesbury River County Council will need to monitor this site and sites downstream in the Nepean River for many years to come before claiming that Kudzu has been completely eradicated.

## Conclusion

The project took nearly five years to complete and will probably take another five or more years of monitoring and suppression before eradication can be claimed. However, the project serves as an excellent example of what can be achieved when landowners work together with Local and State government as well as the private sector.

Many individuals contributed to the success of the project, most notably staff from Virbac Animal Health, Total Earth Care, the Office of the Hawkesbury Nepean and Hawkesbury River County Council. The success of the project was acknowledged in a number of news articles published by the local media.

Finally, the project demonstrates the need for long term funding programs, such as the NSW Weeds Action Program, which recognise the length of time needed to properly address priority weed issues.

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# Strategies Utilised to Combat Tropical Soda Apple (*Solanum viarum*) Infestations in the Macleay River Catchment Area

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## Abstract

Tropical Soda Apple (TSA), a Class 1 Noxious Weed, was first officially identified in Australia in the upper Macleay River catchment in August 2010. Three flood events in 2013 rapidly spread the TSA infestation throughout the Macleay River system's riparian zone, posing a severe agricultural and environmental threat to the Macleay catchment. Post-flood mapping by Kempsey Shire Council identified TSA outbreaks in 130km of the Macleay riparian zone. Through a partnership between Kempsey Shire Council, the Mid North Coast Weeds Coordinating Committee and North Coast Local Land Services (NCLLS), a project aimed at responding to this rapid increase was implemented in late 2013. The severity and extent of the infestation, and the limited available resources, prevented a direct control approach. Instead, the project focussed on the development and implementation of innovative and strategic project techniques to build landholder capacity, motivation and awareness to manage TSA. These techniques included extensive community consultation and landholder engagement through various forms of media, followed by the identification and establishment of "landholder sub-catchment groups", the development of associated landholder property management plans, and TSA landholder workshops. These capacity building actions were coupled with an on-ground project component, with targeted direct control by professional contractors in critical and difficult-to-access areas. Follow up mapping of the area of infestation 12 months after commencement of the project indicated a significant reduction in the extent and intensity of TSA, along the Macleay River system, indicating that strategies implemented in the project were successful. This project has continued into an equally successful second year, and continues to reduce the serious biosecurity threat posed by TSA in the Macleay catchment.

## Introduction

Tropical Soda Apple (*Solanum viarum*) is a perennial shrub native to Brazil and Argentina and a member of the plant family Solanaceae. TSA was first recorded in Florida in 1988 and the infestation had spread to 10,000ha by 1990 and 500,000ha by 1995. By 2007 TSA had spread to nine other states in the USA (Byrd et al 2004). TSA has also naturalised in Africa, India, Nepal, West Indies, Honduras, Mexico, and outside of its native range in South America (Department of Primary Industries 2014).

TSA is a shrub growing up to 2m high and 1.5m wide. It has a woody stem with spines up to 2cm long. The leaves are ovate and contain sharp spines on both surfaces (Akanda et al 1996). The flowers are white, producing yellow mature fruits 2 to 3cm in size, and immature fruits being a mottled whitish light green to dark green (Byrd et al 2004). Mature fruits produce 400 to 500 reddish brown seeds and each plant is capable of producing 200 fruits per year, so production of 45,000 seeds per plant is possible (Ferrell et al 2006, Bryson and Bryd 2007). Seed germination is approximately 70% from mature fruits and seeds can remain viable in the soil for two years. However it has been reported that germination has occurred from dormancy of several years (Bryd et al 2004, Bryson and Bryd 2007).

Herbivory of the leaves by livestock is deterred by the sharp spines and unpalatable nature of the leaves. However the sweet smell and slightly bitter taste of the fruit leads to consumption by livestock and wildlife. Experiments have shown that TSA seeds can stay in the digestive tract of bovine livestock for up to 10 days after fruit consumption with approximately 60% germination occurring after expulsion (Ferrell et al 2006). Aside from the detrimental ecological damage caused by TSA through displacement of native flora and disruption of ecological integrity, the economic impacts of TSA can be significant. It was estimated that TSA control costs in Florida in 2006 resulted in economic losses of approximately $15,000,000 to cattle producers and supporting business sectors (Salaudeen et al 2013).

In NSW cattle movement is currently the major vector of spread however seed can also be spread by feral animals and birds that feed on the fruit, contaminated produce, soil and equipment and via water (DPI 2014).

TSA was first identified in Australia in the upper Macleay Valley, near Kempsey in August 2010 and is believed to have been present in the location for a number of years prior to this. Since the original discovery of TSA, further infestations have been found in areas of Wingham, Grafton, Bellingen, Coffs Harbour, Bonalbo, Casino, Murwillumbah and Wauchope (DPI 2014). Three major flood events on the Macleay River in Kempsey occurred during 2013 (Kempsey Shire Council 2013). It is believed that the flood vectors resulted in rapid spread of seed throughout the riparian areas of the Macleay River system. On 28$^{th}$ of February 2014 TSA was declared a State Prohibited (Class 1) weed by Weed Control Order 2014.

The TSA infestations established within the Macleay River riparian zone following the flood events during 2013, posed a significant agricultural and environmental threat to the Macleay catchment. A rapid response project which implemented various innovative control methods was required in order to achieve successful suppression of the TSA infestation. A partnership project between Kempsey Shire Council, the Mid North Coast Weeds Coordinating Committee and North Coast Local Land Services (NCLLS) aimed at responding to the rapidly increasing TSA infestation was implemented in late 2013. The project had limited available resources which restricted the application of direct control methods. Other constraints included the large extent of the project area which was a 120km stretch of the Macleay River riparian zone, and topographical restrictions limiting access to some areas. Development and implementation of innovative and strategic project techniques were a major focus of the project. These aimed to build landholder capacity and awareness for the ongoing management of TSA, and have led to the appointment of a specific `Class 1 Noxious Weed Inspector' for the Kempsey Shire. Capacity building actions were complemented with on-ground direct control techniques, and infestation mapping and monitoring methods. This paper discusses project techniques and strategies that were and are currently being utilised to reduce the significant threat to biosecurity posed by TSA in the Macleay Catchment.

## Project Methods

Implementation of various strategic methods was required to respond to the rapidly increasing TSA infestation along the Macleay River riparian area. These included mapping and monitoring, landholder engagement and direct control.

Prior to the commencement of the project the TSA riparian infestation was mapped from Blackbird Flat (western boundary of the Kempsey Shire) to Nelsons Wharf (7km upstream of

Kempsey traffic bridge). The mapping commenced in July 2013 with the length of the mapped stretch of the Macleay River totalling 120km. Both banks of the Macleay River riparian zone were mapped, totalling a length of 240km. A rapid assessment technique was used, with sighted TSA plants being marked with a hand held GPS, marks then downloaded onto Councils GIS system and overlayed onto an aerial photography layer. Due to access and topography, the riparian areas were accessed by canoe, and steep banks and escarpment bases were mapped from the river. River flats and shingle areas were traversed on foot. The mapping was to provide a baseline snapshot of the infestation. Due to time constraints, only the immediate riparian area within the zone of river rise was mapped, with the width varying depending upon the height and topography. The entire length was re-mapped commencing August 2014 after the project had been running for 12 months, using the same methodology. The 2014 re-mapping was carried out at the same time of year as the 2013 mapping. The re-mapping data was overlayed with the original data to determine areas which had achieved successful control and areas which infestations were still occurring 12 months later.

In August 2013 every landholder who had property (280 properties 180 landowners) within the Macleay River riparian zone (within the Kempsey Council Shire, upstream of Kempsey) was sent a letter and TSA information package, consisting of a situation report on the infestation, information on control obligations, recommended control methods and contacts for assistance. During the course of the TSA mapping each property that contained a TSA plant was sent a letter from Council informing of the TSA plant or plants that were detected on the property and the obligations of the landholder to control TSA.

Three TSA workshops were held in strategic locations in the Macleay catchment (Kempsey, Willawarrin and Bellbrook). Letters were sent to all 180 landowners in the project area inviting them to the workshops. The workshops were also advertised through local media. The workshops covered background and updated information on the Macleay TSA infestation, the current Class 1 Noxious Weed status and the associated legal obligations, mapping, control methods and the control program, formation of sub-catchment groups, assistance with advice, inspections and property management plans. The workshops also encouraged open discussions and sharing of landholder control methods and innovative ideas on control.

Council set up stalls with TSA signage and distribution of information at various field days including Pro Ag, the Kempsey Show and the Kempsey Saleyards. Media releases were prepared and published in local papers and `The Land' newspaper. Additionally, interviews were carried out on local community radio and the ABC Rural Report.

Follow up property inspections were and are currently being carried out with a focus on the properties that were identified with heavy infestations and difficult to access areas. The focus of current inspections is targeting properties that have been identified in the 2014 mapping as still containing TSA infestations.

A property management plan template was developed by North Coast Local Land Services and property inspections by Council gathered site-specific information to develop a property management plan. Landholders were encouraged to sign and implement the plan following the Community Based Social Marketing (CBSM) principle of encouraging the landholder to make formal commitment to controlling Tropical Soda Apple. The TSA property management plans identify specific management actions for properties and a landowner agreement is signed by the property owners to carry out the management actions. Council purchased a quantity of herbicide for TSA control and offers incentives of free herbicide to landowners who sign property management plans. The amount of herbicide issued to the landholder is dependent on the length of riparian area that the property contains.

As part of the TSA project, the area between Black Bird Flat and Sherwood was divided into eight sub-catchment groups. A further three sub-catchment groups were identified upstream of the Kempsey Shire boundary, which is managed by the New England Weeds Authority (NEWA) as part of the NEWA TSA project. The aim of the sub-catchment groups was to establish a coordinated and cooperative TSA program for the Macleay catchment, the idea being that in the majority of cases, control will be most effective when working as a group or when control is coordinated between landholders. Kempsey Council monitors and facilitates group activity, and offers assistance with advice, inspections, property management plans and loan of specialist equipment to carry out works, complying with a further CBSM objective of facilitating a group `peer support' network.

A component of the project funding was for direct control of TSA. A strategic control program targeting TSA in high risk pathway, riparian areas and difficult to access areas such as bases of escarpments was commenced in December 2013. Studies by Bryd et al (2004) and Bryson and Bryd (2007) indicate that TSA seed can remain viable in the soil for two years. With an established seed bank in the soil of the riparian areas of the Macleay River the scientific rationale behind the control program design was to exhaust the existing soil seed bank in these areas. Direct control has been carried out within the full extent of the project area, with a minimum of three passes and some areas receiving more follow up control works. The majority of control works were carried out by specialist contractors, however a 10km stretch of the Macleay riparian zone was controlled by members of the Mid North Coast Weeds Coordinating Committee which included weeds officers from Kempsey, Great Lakes, Port Macquarie/Hastings, Taree and Crown Lands. Due to the topography and difficulty of access in some areas of infestation, works were carried out on foot with knapsack spray units or cut and paint methods. In some areas four wheel drives with quick spray units were able to be utilized, however due to difficult access and terrain the majority of the riparian areas were accessed by canoe and foot. A `work for the dole' Landcare group was formed in early January 2014 at Bellbrook, providing a further dimension and partnership for the program. The group was specifically formed to target TSA and Council (through Macleay Landcare affiliation) was able to assist the group to develop a TSA control strategy and provide the group with equipment and herbicide. The group regularly controls an area of river bank approximately 4km in length immediately upstream and downstream of Bellbrook Bridge. All the works carried out by the group are documented in a log book.

## Results

The 2014 mapping results showed significant reduction of 2013 mapped TSA infestations within the project area as illustrated in figures 1,2 and 3.

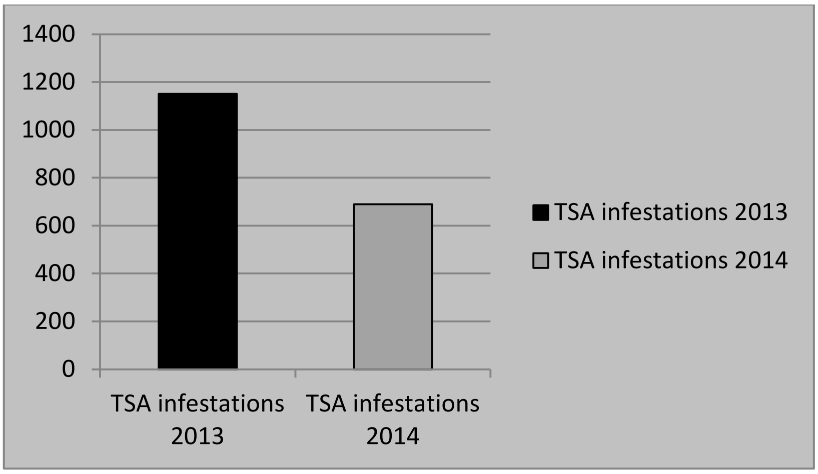


Figure 1. Blackbird Flat to Bellbrook TSA infestation 2013/ 2014 comparison

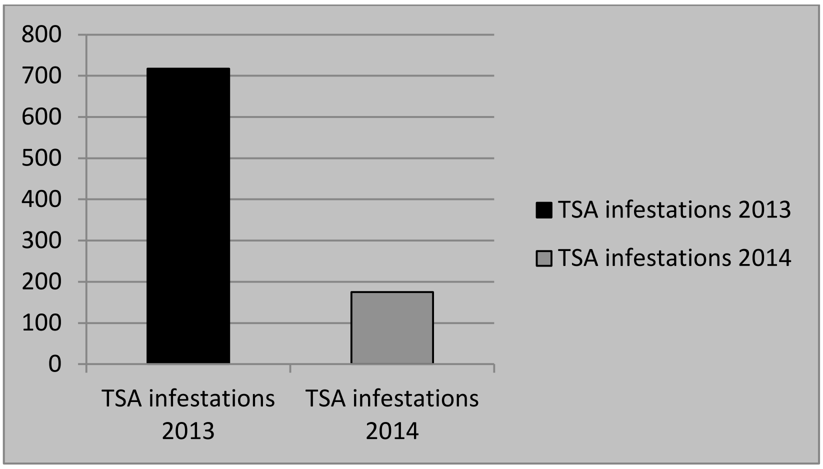


Figure 2. Bellbrook to Nelsons Wharf TSA infestation 2013/2014 comparison

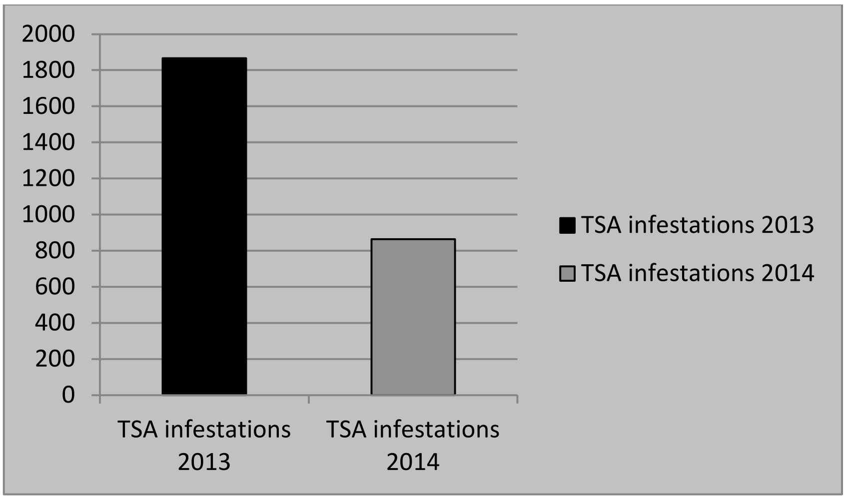


Figure 3. Overall project area (Blackbird Flat to Nelsons Wharf) TSA infestation 2013/2014 comparison

Table 1. TSA infestation percentage reduction over project area

| Project Area | Length (km) | Percentage reduction of mapped TSA in 2014 in comparison to 2013 |
|---|---|---|
| Blackbird Flat to Bellbrook | 35km | 40% |
| Bellbrook to Nelsons Wharf | 85km | 76% |
| Overall length of project area | 120km | 54% |

A number of landholder engagement and capacity building activities were carried out with the project, engaging a wide range of land owners and managers.

Table 2. TSA landholder engagement and capacity building activities

| Type of Activity | Quantity |
|---|---|
| Letters and TSA information packages sent to land holders, letters sent regarding workshops, letters sent informing of infestations | 252 Letters sent |
| Media releases | 6 media releases in local papers |
| Interviews on local radio and ABC radio | 9 (8 Local Radio 1 ABC radio) |
| Promotional activities at field days, Ag shows, saleyards | 8 promotional activities |
| TSA workshops (three workshops held) | 131 Land owners/managers attended workshops |

The project's plan development component has resulted in a significant amount of land in the project area being covered by TSA property management plans.

Table 3. Land under management of a TSA property management plan

| Number of properties under a TSA management Plan | Area in hectares under TSA management plan |
|---|---|
| 31 | 13,751ha |
| 6 (property management plan not yet signed) | 2100ha |

Direct TSA control activity has been carried out along the entire length of the project area within the riparian zone of the Macleay River.

Table 4. Land directly controlled for TSA

| Length of the Macleay River riparian area treated for TSA (km) | Area (ha) of riparian area treated |
|---|---|
| 240km | 480ha |

## Discussion

The mapping results (Figures 1, 2 and 3 and Table 1) indicate a significant reduction in TSA infestations within the Macleay River riparian area since commencement of the TSA project. The mapping results show an overall reduction of 54% along the length of the project area. Project zones upstream and downstream of Bellbrook differ significantly, with upstream having a reduction of 40% and downstream having a reduction of 74%. This is likely to be attributed to the properties upstream of Bellbrook generally being large holdings with extensive frontage to the Macleay River and one property manager. The initial TSA infestations in the 2013 mapping were also considerably worse in the area upstream of Bellbrook. The majority of the properties downstream of Bellbrook are smaller holdings and generally landowners have a smaller area of riparian TSA infestation to control. The 2014 infestation mapping identified priority areas for more efficient resource allocation, and informed strategies to target specific properties and landholders.

The outcomes of the TSA workshops were beneficial for capacity building and community awareness. Attendance levels for the workshops were high with 131 people attending out of the 180 targeted landholders with the project area (Table 2). The workshops were complemented with regular media releases, letters and information packages, radio interviews and other promotional activities. It is likely that this capacity building, and raising the awareness and knowledge of landholders, greatly contributed to the reduction in TSA within the project area.

TSA property management plans have been carried out for 31 properties and a total of 13,751ha of land is now covered by a TSA property management plan (Table 3). This is a substantial amount of land in the high risk TSA areas with a signed agreement from the landholders to manage in accordance with a site specific plan. The provision of incentives with TSA control chemicals and advice has been a beneficial strategy in persuading landholders to sign agreements and manage their property in accordance with a property management plan.

Direct control of TSA along 240km of riparian area and 480ha of land (Table 4) has significantly contributed to the decline of TSA in the Macleay catchment. The main source of spread of TSA to the lower catchment was the 2013 flood events. Control was strategically targeted at the lower catchment areas first (as the infestation was confined to the riparian flood zone), in an effort to control plants prior to seed set thus pushing the infestation back upstream to the core area above Bellbrook. The funding only allowed three passes over the project area. However, this greatly reduced the TSA infestations in most areas, allowing landowners to carry out follow up control. Contractors were able to control TSA in areas that were inaccessible to landholders (such as bases of escarpments and gorges) using canoes.

Difficulties establishing the formation of identified sub-catchment groups were experienced throughout the project. Many neighbouring properties have been working together to control TSA. However, it appears that there are too many differences in perspectives and capacity for landholders to work together in larger groups. Dividing the project area into eight subcatchment groups, however, has been beneficial for inspection programs and segregation of catchment areas for result comparisons and the identification of target areas.

Overall, the project has been successful and the strategies used have led to a significant reduction in TSA infestations, and much greater community awareness within the Macleay catchment. The project is continuing into the second year, utilising the same methodology and further developing new strategies which aim to achieve further reduction and eventually eradication. This will require continued building upon the successes of the project in order to remove this major biosecurity threat from the Macleay catchment.

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# Hawkweed eradication from NSW: Could this be 'the first'?

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## Summary

There are currently no documented weed eradications from New South Wales. Hawkweeds (*Hieracium* spp.) are perennial herbs native to Eurasia that are serious weeds in many temperate and subalpine areas of the world. Three hawkweed species are present in Australia, and modelling indicates at least 27 million ha of south east Australia is susceptible to invasion by orange (*H. aurantiacum*) and mouse-ear hawkweed (*H. pilosella*). In New South Wales, small infestations of the Class 1 Noxious Weeds, orange hawkweed and mouse-ear hawkweed are present in subalpine and alpine regions of Kosciuszko National Park (KNP), the only known location in New South Wales. Since 2003, 8.21 ha of OHW has been found in a remote and rugged area of the Great Dividing Range that extends across approximately 8,951 ha.

The NSW National Parks and Wildlife Service with a range of partners are working to eradicate hawkweeds from New South Wales, finding and destroying every last plant. This involves strategic surveillance and rapid response to prevent reproduction and control infestations, including repeated follow-up control. Surveying treated sites is critical because orange hawkweed seed viability is up to 5 years and, in the past, herbicide efficacy proved variable due to limited translocation through stolons. However, through extensive monitoring, evaluation and adaptive management, a suite of control methods are now resulting in efficient and effective hawkweed control. Concerted efforts have reduced orange hawkweed from 1.36 ha extant in 2010 to a total of 0.02 ha extant in 2015. However, all known sites across the 8.21 ha management area are surveyed several times each season to ensure no plants re-emerge and reproduce. The key to hawkweed eradication now lies in finding the very last plant, which means the remaining large, remote areas must be surveyed. New and innovative tools are being employed to ensure delimitation, such as using unmanned aerial vehicles to detect plants over large areas, and training weed eradication detector dogs to 'sniff out' the hard-to-find plants. These techniques have reliably detected orange hawkweed in trials and will be operational in the 2015/16 season. This paper details the New South Wales hawkweed eradication program and how these new tools may allow us to make orange and mouse-ear hawkweed the first documented weed eradications from New South Wales.

## Introduction

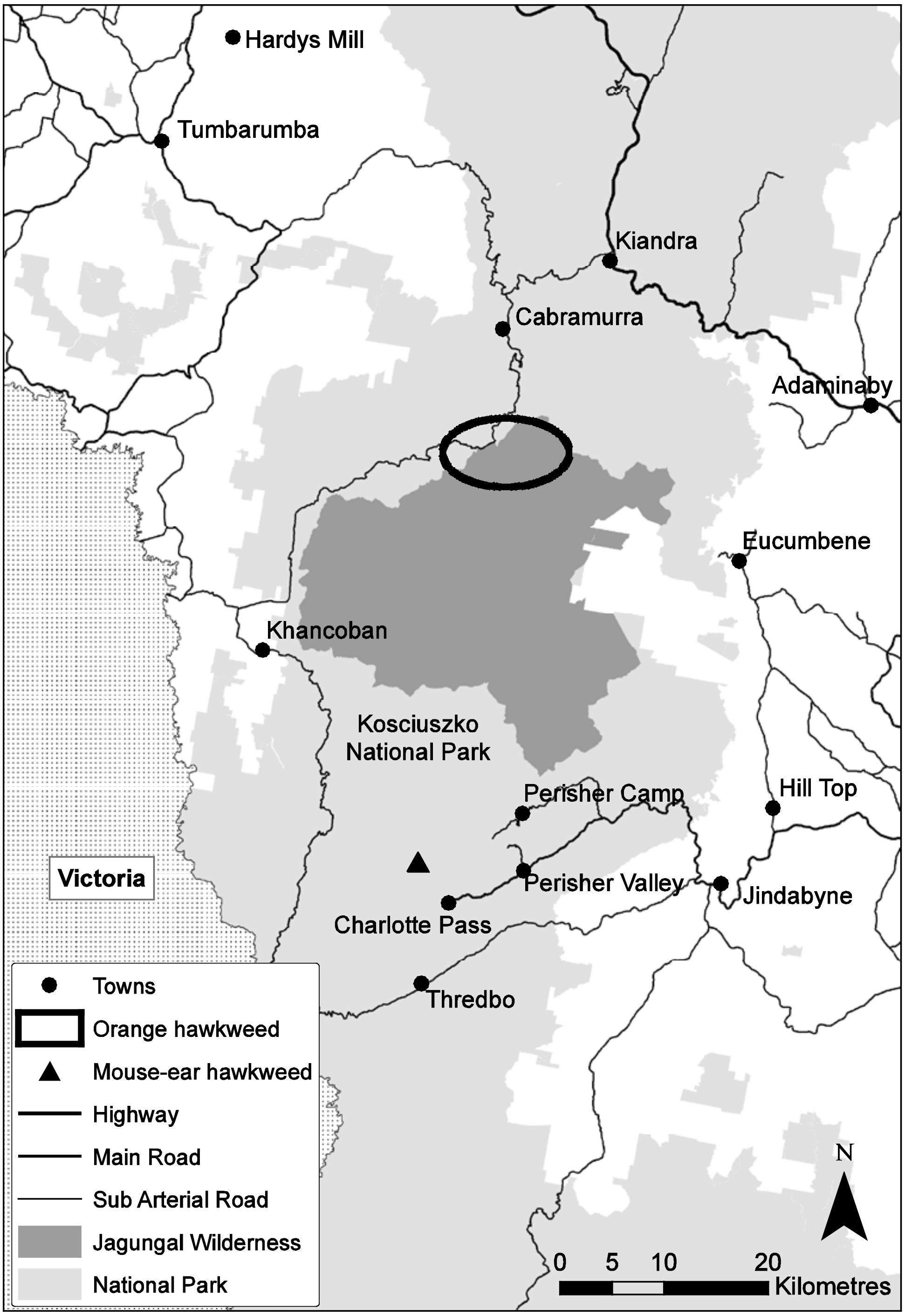
Eradication is the complete and permanent elimination of all wild populations of an organism from a defined area in a given timeframe (Bomford and O'Brien 1995). For eradication of plant species, the key operational objectives are to delimit the infestation, halt reproduction, treat all aboveground matter, and completely exhaust the seedbank. Eradication can only be declared successful when the species is not detected for a period equal to or greater than its seed longevity.

Eradication is a weed management strategy that is particularly appealing because other alternatives (such as containment or impact reduction) require permanent, ongoing investment of resources. This is supported by the Natural Resources Commission's recent review of weed management in NSW, which highlighted a need to improve responses to new weed incursions, as early and effective responses can be the difference between successful eradication versus ongoing management (NRC 2014).

Orange hawkweed (*Hieracium aurantiacum* L.) and mouse-ear hawkweed (*Hieracium pilosella* L.) are Eurasian stoloniferous perennial herbs in the Asteraceae family that have recently invaded natural vegetation in the Victorian and New South Wales Alps (Williams and Holland 2007). Under the New South Wales *Noxious Weeds Act 1993*, all hawkweed species are Class 1 State Prohibited Noxious Weeds. Orange hawkweed is also on the national Alert List for Environmental Weeds, a list of 28 non-native plants at the early stages of establishment with high potential impacts and feasibility of eradication, and recognised nationally as an Agricultural Sleeper weed (Cunningham *et al.* 2003). Both species produce wind-dispersed seeds that may travel large distances, and may occasionally be dispersed by animals, vehicles and humans (Rinella and Sheley 2002). Though, Stergios (1976) suggests long-distance dispersal is a rare event, and William and Holland (2007) found most seed is deposited within 2 m of parent plants In addition to occasional long distance dispersal, hawkweeds can become locally abundant through stolon growth that can form a dense mat, exclusive of other ground cover (Morgan, 2000; Espie 2001).

These biological traits have contributed to hawkweeds becoming major weeds in the United States of America, Canada, Japan and New Zealand. In New Zealand, hawkweeds have invaded more than 6 million ha of the South Island and have significantly decreased carrying capacity over large areas (Espie 2001). In Australia, hawkweeds are at the early stages of establishment, with small populations found in Tasmania, Victoria and NSW but if left unchecked, invasion of south east Australia could have disastrous ecological (Worboys and Good 2011) and economic impacts. For example, 27 million ha are susceptible to invasion by orange hawkweed (Cunningham *et al.* 2003), and economic modelling shows a conservative potential annual loss to the grazing sector of $66 million (Brinkley & Bomford 2002 and adjusted to account for CPI [RBA]).

In New South Wales, *H. aurantiacum* only occurs in nine distinct locations in sub alpine regions of central Kosciuszko National Park, centred on the Jagungal Wilderness. *H. pilosella* occurs as a small population on the Main Range of Kosciuszko National Park (Figure 1); this population is not linked to the H. aurantiacum populations. Kosciuszko National Park is the largest conservation reserve in New South Wales and is significant for its unique landscape and biodiversity values. Since detection of orange hawkweed in NSW in 2003, the NSW National Parks and Wildlife Service (NPWS) has invested heavily in surveillance, treatment, trialling herbicide techniques, increasing awareness and understanding weed ecology. The Victorian government is also working towards eradication of orange, mouse-ear and king devil (H. praealtum Vill. ex Gochnat) hawkweeds (Curran and Primrose 2012), and Victoria and New South Wales sit on the National Hawkweed Working Group that coordinates efforts towards national eradication.



Hardys Mill
Tumbarumba
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Adaminaby
Eucumbene
Khancoban
Kosciuszko
National Park
Perisher Camp
Hill Top
Victoria
Perisher Valley
Jindabyne
Charlotte Pass
Thredbo
Towns
Orange hawkweed
Mouse-ear hawkweed
Highway
Main Road
Sub Arterial Road
Jagungal Wilderness
National Park
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0 5 10 20
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**Figure 1.** Location of orange hawkweed (*Hieracium aurantiacum*) and mouse-ear hawkweed (*Hieracium pilosella*) infestations in Kosciuszko National Park, New South Wales.

Notwithstanding many eradication attempts (disregarding the common misuse of this term), unlike pest animals, there are few documented examples of successful weed eradications (Simberloff 2003). In New South Wales, there are no documented cases of statewide eradications, and very few examples exist Australia wide (Panetta 2009). In New South Wales, hawkweeds (*Hieracium* species) are the subject of an eradication program that the authors believe has a high likelihood of success. This paper outlines the NPWS eradication program for orange and mouse-ear hawkweeds, the progress to date, and the innovative control and detection techniques currently being employed to achieve eradication success. Note, though this paper largely deals with the orange hawkweed eradication program, the eradication progress to-date of the recently discovered mouse-ear infestation will also be covered.

## Eradication progress

Eradication attempts require significant commitment and resourcing. Panetta *el al.* (2011) suggest that the average time to eradicate a Class 1 weed from Queensland was 18.2 years, and the average total cost of eradication was estimated at $2.997 million per weed. Thus, there is a great need to evaluate the progress towards the eradication objective (Panetta and Brooks 2008).

From 2003, initial NPWS control efforts were devoted to treating *H. aurantiacum* infestations at Round Mountain, the first infestation to be discovered. As new invasion foci were discovered at Ogilvies Quarry, Ogilvies Airstrip and Cool Plain, and the nature and scale of the problem became clear, a dedicated program coordinator was employed in 2009 and the program became increasingly well-resourced. This greater coordination and resourcing enabled increased delimitation efforts, and greater frequency of return to sites to ensure reproduction was prevented and herbicide efficacy was monitored.

The current NPWS hawkweed eradication program is comprised of six key activities: 1) treating known infestations; 2) revisiting known infestations at regular intervals to ascertain further control requirements and to remove reproductive material; 3) searching for new infestations using wind dispersal data, with the assistance of staff and volunteers; 4) undertaking monitoring to determine herbicide efficacy and to adaptively manage; 5) collaborating with researchers to understand hawkweed biology, and 6) improving public understanding and support for the eradication program.

A total of 9 distinct orange hawkweed locations have now been identified across an extent of 8 951 ha (the management area currently totals 8.21 ha). This extent was determined using the minimum convex polygon method (Mohr 1947), a simple technique used to determine a species' spatial extent or home range based on available point locations. For orange hawkweed, this represents a rough approximation of the area over which the species *may* occur, and is useful in directing surveillance efforts. However, the likelihood of the species occurring across this extent is *variable*, due to dispersal pathways, and habitat preferences that includes disturbed areas associated with prior Snowy Hydro-Electric Scheme infrastructure.

At the end of the 2014/15 season, the area of extant orange hawkweed amounted to 0.02 ha. This is a notable achievement and represents a 98.5% reduction in hawkweed area since 2010/11 (Figure 2.). In addition, the *cumulative* area of orange hawkweed infestations (being the area of all infestations discovered since 2003, despite most being controlled), totalling 8.21 ha, has increased very little since 2010/11 (Figure 3.). This constancy of cumulative infested area over time is one of the best measures of whether delimitation is occurring (Panetta and Brooks 2008), and has occurred with a concomitant increase in surveillance effort. The corollary of this is that, due to a potential 5-year seedbank, the effort required to revisit all sites at sufficient frequency throughout the season has increased substantially.

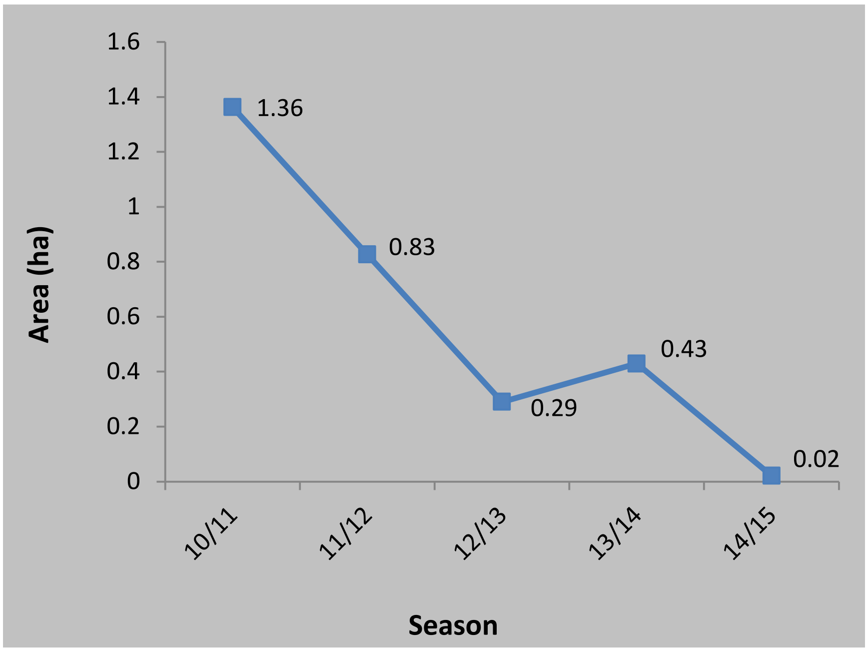


**Figure 2.** Change in area of managed orange hawkweed (with aboveground biomass) (*Hieracium aurantiacum*) from 2010/11 to 2014/15.

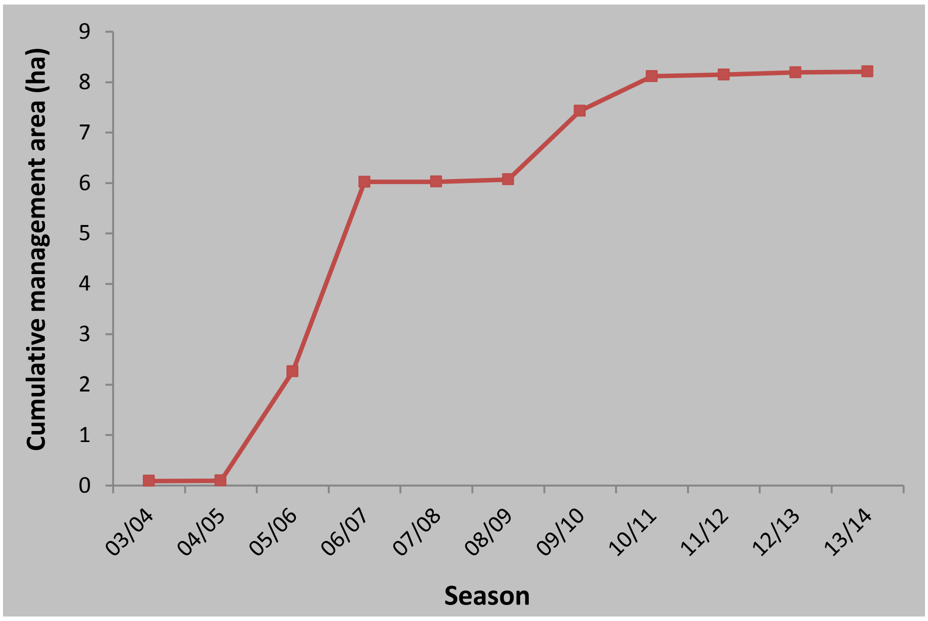


**Figure 3.** Change in cumulative area of orange hawkweed (*Hieracium aurantiacum*) from 2003/04 to 2014/15. Note, this represents the cumulative area of all infestations found, despite most of this area now having no extant hawkweed due to control efforts.

The NPWS has utilised volunteers and field staff to conduct ground surveillance for hawkweed. Approximately 1 197 ha has been searched for orange hawkweed since 2010 with the assistance of over 285 volunteers. Importantly, as surveillance efforts have ramped up, the hawkweed detection rate has decreased. That is as more ground is searched, fewer hawkweed sites are being discovered. Figure 4. illustrates this trend, as a decreasing proportion of new sites is being discovered over time. Almost half of all orange hawkweed sites are now classified as 'inactive' (Figure 4.), meaning sites require monitoring for hawkweed emergence but no treatment as no aboveground hawkweed is present. The proportion of 'inactive' sites is increasing over time, and 2014/15 was the first year that a small proportion of sites (4%) were classified as 'locally eradicated', being sites where hawkweed has been absent for 5 years or more (the period equal to seed longevity). This trend is expected to increase, with the greater herbicide efficacy that the program is now achieving.

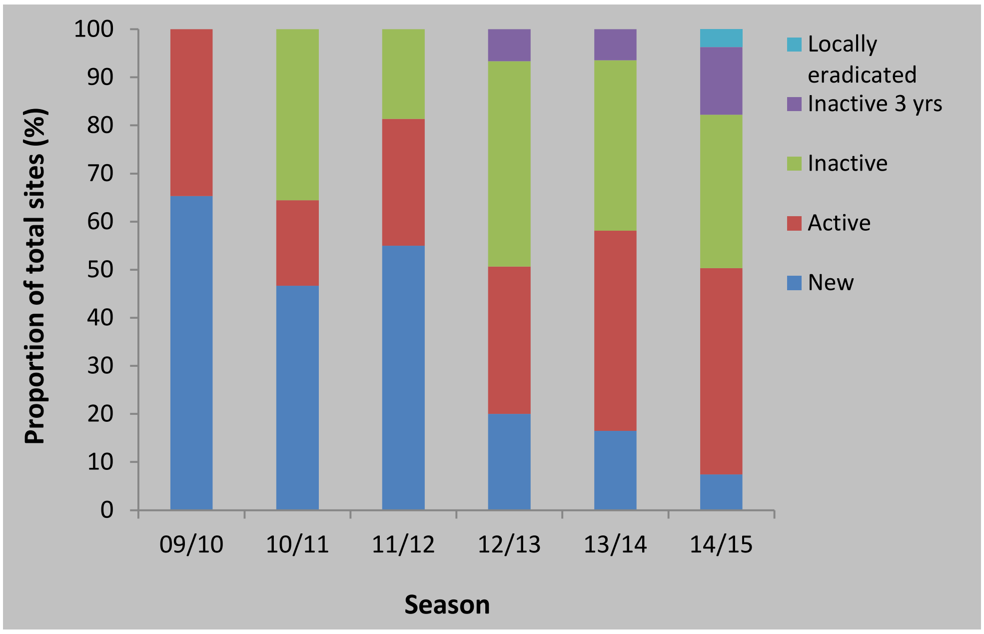


Figure 4. Status of orange hawkweed (*Hieracium aurantiacum*) infestations from 2009/10 to 2014/15. Infestations are 'active' if orange hawkweed was detected there during the season, 'inactive' if no hawkweed was found during surveillance, and 'locally eradicated' if undetected for 5 or more years.

The above progress towards eradication is in part due to the great strides towards herbicide efficacy that have been achieved. As with many new and highly invasive weeds, early NPWS control efforts resulted in varying plant kill rates, namely due to the inability of herbicides to translocate through stolons, limited control options in sensitive semi-aquatic areas, and the species' ability to remain undetected in environments with dense tussock vegetation (Caldwell and Wright 2014). Herbicides trials in a range of vegetation and semi-aquatic communities have resulted in Picloram-based Tordon Granules being used as a follow up control to ensure sustained herbicide activity; the Clopyralid-based and broad-lead selective Lontrel being used in semi-aquatic areas; and greater spray buffers being applied to hawkweed plants to ensure herbicide application to all rosettes and stolons. NPWS research into alternative herbicides and control methods has improved control success (Caldwell and Wright 2014), thus improving the chances of eradication.

### *Mouse-ear hawkweed*

In January 2015, a small infestation of mouse-ear hawkweed was discovered near Blue Lake, on the Main Range (2033 m elevation) in Kosciuszko National Park. Like the Victorian mouse-ear hawkweed population, the infestation is thought to have been inadvertently introduced by bushwalkers on clothing, boots or camping gear, after visiting New Zealand or Victoria. Knowing the devastation this weed has caused in New Zealand, within 6 days the NPWS had controlled the infestation, surveyed the surrounding area, quarantined the area to prevent potential spread, and established monitoring to determine the species' response to herbicides.

A detection and control strategy has been put in place by NPWS. The population is thought to have been present for 5 or more years, and plants had seeded before their discovery, meaning secondary dispersal to other areas may have occurred. Using tools developed for orange hawkweed, a search of other high risk areas was undertaken in February 2015, with over 112 ha searched. To-date, the original infestation remains the only known location. It covered 0.015 ha, which although controlled, will require follow-up treatment as seeds may germinate from a seed bank. Seeds are viable in the soil for up to 5 years, although most seeds are only viable for 2 years with 2.3% viable after two years (Roberts 1986). Continued surveillance of high priority areas will be needed to ensure no plants establish elsewhere or adjacent to the treated area.

## Improved surveillance methods

As described above, the suite of herbicides and control methods now available are considered sufficient to extirpate all known orange hawkweed infestations. However, due to the size and remote and rugged nature of the search area, greater efforts are required to delimit the infestation. Until recently, the eradication program relied on humans undertaking ground surveillance, which is resource intensive over large areas. C. Hauser (unpublished data) determined that humans searching for non-flowering orange hawkweed in heath vegetation achieved very low detection probabilities; in addition, unassisted ground searching becomes less effective when the weed population becomes sparse (Chandler 2014). More efficient surveillance techniques involving unmanned aerial vehicles
(UAVs) and specially trained dogs are now being trialled for hawkweed. The combination of these novel surveillance techniques should enable larger areas to be surveyed at lower cost and with greater accuracy.

Trials of unmanned aerial vehicles or drones to detect orange hawkweed are currently underway in New South Wales (Hung and Sukkarieh 2015). The process involves the drone collecting aerial images and the development of a machine learning algorithm, to analyse the image data and identify potential hawkweed infestations. Results suggest hawkweed flowers can be detected reliably at 15 m elevation using a Falcon 8 UAV with a Sony Nex 7 camera (Hung and Sukkarieh 2015). Whilst promising and providing proof of concept, a higher flying UAV with higher resolution sensing and a faster frame rate may achieve detection from higher elevations, therefore enabling greater coverage per flight. Further trials will soon be underway to determine the feasibility of orange hawkweed detection outside the flowering season using only leaf characteristics.

Dogs have long been used in the detection of illicit substances by police forces around the world but their olfactory abilities are increasingly being used for conservation work. Goodwin *et al.* (2010) showed dogs outperformed people in detection of rare weeds, both more accurately and more efficiently over larger areas. In 2014, the Victorian Government began trialling the use of a hawkweed detector dog. Initial findings suggest a dog can be trained to detect orange, mouse-ear and king devil hawkweed rosettes, stolons and rhizomes, with no false positives or false negatives (Hannigan and Smith 2014). Using the same professional dog trainer, the NPWS has begun training two dedicated detection dogs for orange and mouse-ear hawkweed. The dogs are being trained to detect hawkweed in field situations, and to distinguish hawkweed from other plant species. Preliminary results indicate that the dogs successfully detect orange hawkweed in both controlled environments and *in situ* in Kosciuszko National Park. It is envisaged that detection dogs will more efficiently and reliably find hawkweed to accelerate eradication of hawkweeds in New South Wales.

The final surveillance method NPWS is employing is use of aerial insertions in remote areas. Due to the constraints posed by the remoteness of the area, the rugged terrain and, in places, dense vegetation, helicopter insertion of surveillance crews has increasingly been employed to great effect. Helicopter insertion surveys have resulted in the discovery of a disjunct orange hawkweed location close to the Tumut River, and to survey 70 ha for mouse-ear hawkweed.

Depending on the results of further UAV and detector dog trial results, it is envisaged UAVs may assist detection across large areas whilst dogs may being used to improve localised detection and to verify hawkweed absence in an area.

## The ‘case’ for eradication

Much research into the variables that affect eradication success has occurred since the seminal study of Rejmánek and Pitcairn (2002). However, many subsequent studies (Myers et al. 2000; Panetta and Timmins 2004; Pluess *et al.* 2012; Panetta 2014) agree that a combination of the following factors are important to eradication success: i) the ability to prevent re-invasion ii) biological factors such as time to maturation and seed longevity of the target weed; iii) total gross area of the infestation; iv) number of infestations; v) availability of effective controls; vi) target must be detectable at relatively low densities; and vii) socioeconomic factors that include clear lines of authority, commitment and sufficient program resourcing.

If resourced adequately, orange and mouse-ear hawkweed are at a stage where eradication is feasible. We describe below how most factors above have been met for orange and mouse-ear hawkweeds in New South Wales.

The chance of reinvasion of hawkweeds to New South Wales is considered low: their deliberate or accidental importation into Australia is now prohibited, the sale of hawkweeds is prohibited in New South Wales, and there is little evidence that hawkweeds are grown ornamentally. The Victorian Government has and continues to invest heavily in their eradication from Victoria and hygiene protocols are in place in New South Wales to prevent accidental hawkweed spread during management.

Rinella and Sheley (2002) state that orange hawkweed can mature from seed in approximately 5 months. Though a longer time to reproduction period would be desirable, the reduced growing season in the Australian Alps means that at most only one full life cycle (from germinating seed to a fruiting plant) could be achieved per year. However, time to maturation through rosettes produced from stolons is likely to be much shorter than 5 months. To prevent reproduction in the NPWS hawkweed eradication program, sites are revisited 3-4 times per season.

There is considerable uncertainty regarding the long-term viability of soil-stored seeds of *Hieracium* species. Hawkweed seed longevity has been quoted as being as high as 7 years (Williams and Holland 2007), though Bear (2009) points out this seems to be an erroneous citing of Panebianco and Willemson (1976), who state that 'hawkweed seeds are probably not viable in soil for a long period of time'. Bear *et al.* (2012) find little evidence to suggest a long-lived soil seedbank, which is supported by Rowland (2012), who inferred that orange hawkweed soil seedbanks in Kosciuszko National Park were likely to be transient or short-term. However, unpublished NPWS research suggests that some orange hawkweed seeds could be viable for up to 5 years, though this is based on field-based experiments (where windblown seed contamination could not be ruled out) and not laboratory controlled conditions. As stated previously, mouse-ear hawkweed seeds are viable in the soil for up to 5 years, although most seeds are only viable for 2 years with 2.3% viable after two years (Roberts 1986).

The total gross area of infestation or the area requiring searching for the target species amounts to 45.3 ha, being the search area (a 20 m-radius area) around each hawkweed infestation found since 2003. However, despite delimitation appearing within reach (Figure 3.), there is the possibility the total gross area of infestation is greater. To overcome this issue, targeted surveillance for orange hawkweed has occurred across 1 197 ha since 2010. Yet, despite the large area surveyed, there are still significant areas to search, but the likelihood of hawkweed presence in these areas should be lower as the highest priority areas have already been searched. Additional outlier priority surveillance areas will be targeted in the coming seasons and the ability to search a greater area more efficiently will become available with the assistance of drones and dogs.

Orange hawkweed infestations occur in nine distinct locations within the 8 951 ha extent. Infestations appear strongly associated with areas that have experienced prior disturbance (e.g. Snowy Hydro Electric Scheme activity) and areas immediately to the east of infestations, suggesting dispersal on the prevailing westerly winds. Though present across a large extent, known hawkweed infestations mostly exhibit clumping centred on the nine distinct locations.

As discussed above, there is now a suite of herbicides and control methods available that are ensuring much greater plant kill rates. In terms of hawkweed detectability at low densities, much of the surveillance effort occurs in the flowering season, when hawkweeds are detectable with high confidence. To increase detection confidence, self-auditing of surveillance efforts occurs and volunteers and staff are trained to detect hawkweeds when only rosettes are present, resulting in many infestations being found during the non-flowering stage. This does not discount that humans conducting ground surveillance can produce false negatives, as found by C. Hauser (unpublished data). NPWS drone and detector dog trials suggest greater detection certainty, and perhaps may assist evaluate the detection certainty of human-conducted ground surveillance.

For both orange and mouse-ear hawkweed, the lines of authority for management are clear, with infestations only being found on NPWS estate. Strong partnerships are also in place with surrounding land managers that include local weeds officers, natural resource management staff, the community and park user groups. Recently there has been a significant amount of publicity concerning hawkweeds, resulting in increased community awareness of hawkweeds, the NPWS program and general hygiene practices. Orange and mouse-ear hawkweed eradication are the most critical priority weed eradication programs for NPWS. The NPWS has shown commitment to drive the NSW eradication program with the assistance of funding provided by the NSW Department of Primary Industries (Weeds Action Program) and the Australian Government. However, therein lies the key to eradication success, program resourcing.

With the efforts of NPWS, Victorian Government agencies, volunteers and other partners there is an opportunity to eradicate hawkweeds from mainland Australia. Hawkweed eradication from NSW can only be achieved when every last individual plant is located, controlled and the weed seed bank exhausted. The total area of orange and mouse-ear hawkweed in the 2014/15 season was 0.022 ha and 0.015 ha respectively, and the development of innovative new tools that will enable delimitation will become operational in 2015/16. For the reasons outlined above, the probability of eradication is considered relatively high, so we ask again, could this be 'the first'?

**Acknowledgements**

The authors would like to thank Jo Caldwell and Greg Cullen for their valuable comments on the manuscript and for their hard work on the orange and mouse-ear hawkweed eradication program. Many thanks also to the myriad volunteers that have contributed their time to the 'Hunting Hawkweed' program and hence contributed to the progress described in this paper. The work described above was partially funded by the New South Wales Department of Primary Industries (Weeds Action Program), the Australian Government, and UAV trials are funded through the Northern Tablelands Local Land Services.

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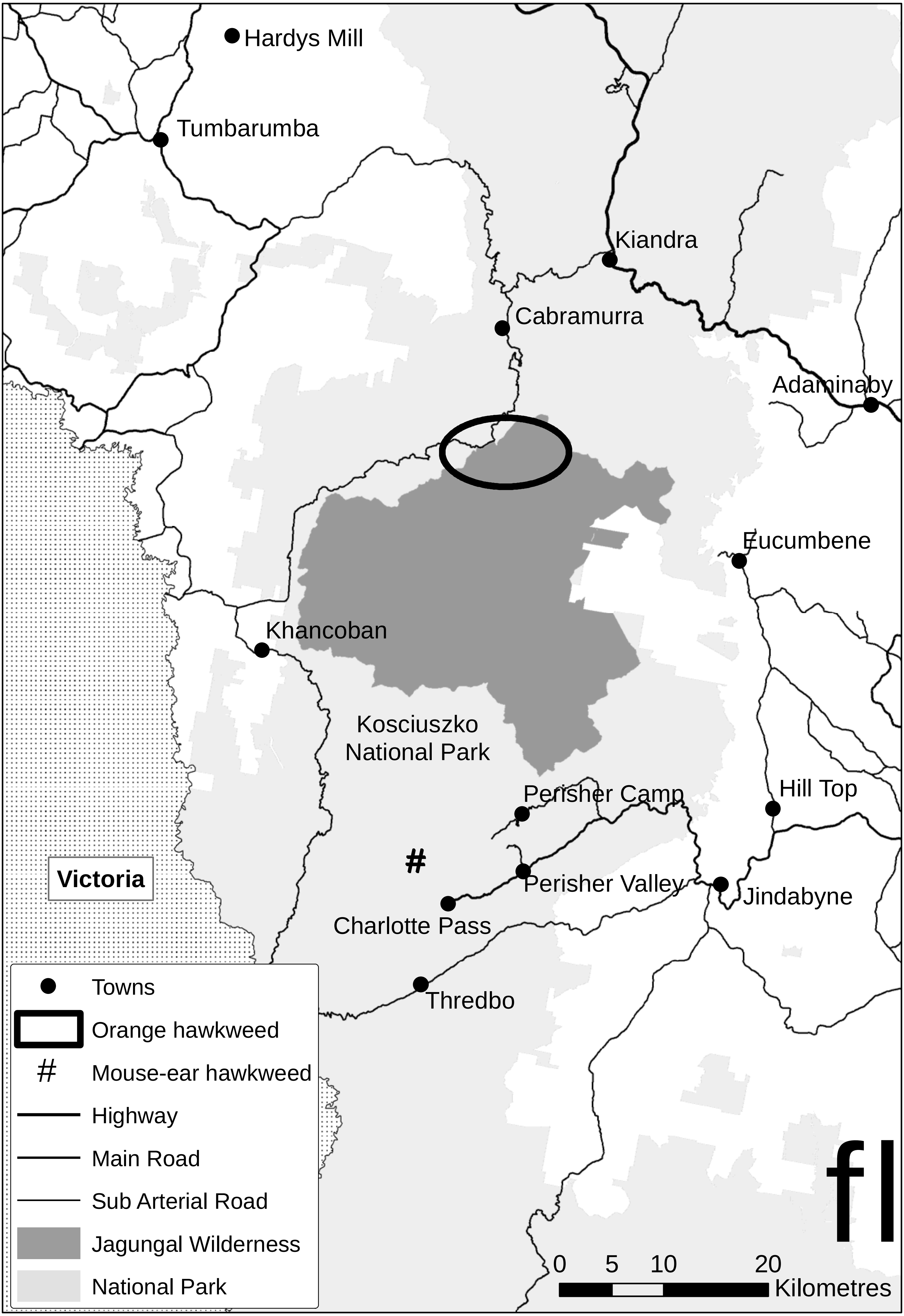


Hardys Mill
Tumbarumba
Kiandra
Cabramurra
Adaminaby
Eucumbene
Khancoban
Kosciuszko
National Park
Perisher Camp
Hill Top
Victoria
#
Perisher Valley
Jindabyne
Charlotte Pass
Thredbo
Towns
Orange hawkweed
#
Mouse-ear hawkweed
Highway
Main Road
Sub Arterial Road
Jagungal Wilderness
National Park
0
5
10
20
Kilometres

| Row Labels | Sum of Patch Size (m²) | Count of Patch Size (m²) |
|---|---|---|
| 2003/2004 | 903.01 | 5 |
| 2004/2005 | 60 | 1 |
| 2005/2006 | 21680 | 4 |
| 2007/2008 | 37585.01 | 10 |
| 2008/2009 | 7 | 5 |
| 2009/2010 | 445.35 | 47 |
| 2010/2011 | 13631.51 | 62 |
| 2011/2012 | 6844.9535 | 166 |
| 2012/2013 | 310.96 | 75 |
| 2013/2014 | 464.718 | 72 |
| **Grand Total** | **81932.5115** | **447** |

| **Season** | New infestation area (m²) | Cumulative infestation area | Cumulative area | New infestation area | Count of sites |
|---|---|---|---|---|---|
| 2003/2004 | 903.01 | 903.01 | 0.090301 | 0.090301 | 5 |
| 2004/2005 | 60 | 963.01 | 0.096301 | 0.006 | 1 |
| 2005/2006 | 21680 | 22643.01 | 2.264301 | 2.168 | 4 |
| 2007/2008 | 37585.01 | 60228.02 | 6.022802 | 3.758501 | 10 |
| 2008/2009 | 7 | 60235.02 | 6.023502 | 0.0007 | 5 |
| 2009/2010 | 445.35 | 60680.37 | 6.068037 | 0.044535 | 47 |
| 2010/2011 | 13631.51 | 74311.88 | 7.431188 | 1.363151 | 62 |
| 2011/2012 | 6844.9535 | 81156.8335 | 8.11568335 | 0.68449535 | 166 |
| 2012/2013 | 310.96 | 81467.7935 | 8.14677935 | 0.031096 | 75 |
| 2013/2014 | 464.718 | 81932.5115 | 8.19325115 | 0.0464718 | 72 |
| 2014/2015 | 166.5275 | 82099.039 | 8.2099039 | 0.01665275 | 28 |
| **Grand Total** | **82099.039** | | | | **475** |

A measure of search effort would be good context for this graph

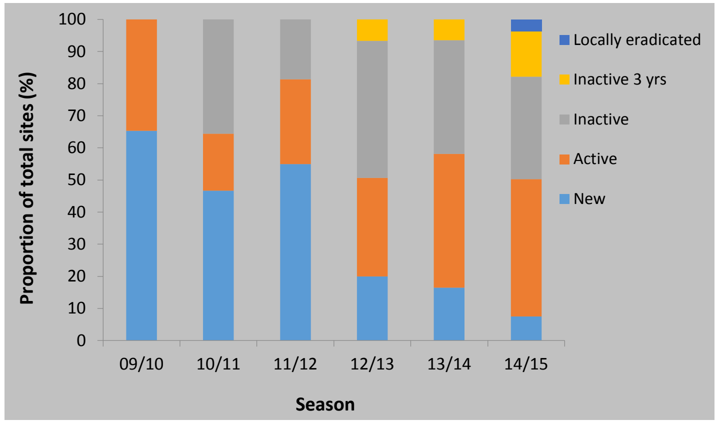
| **Season** | Active infestation ($m^2$) | Active infestation (ha) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003/2004 | 903.01 | 0.090301 | | | | | | | | | |
| 2004/2005 | | | | | | | | | | | |
| 2005/2006 | | | | | | | | | | | |
| 2007/2008 | | | | | | | | | | | |
| 2008/2009 | | | | | | | | | | | |
| 2009/2010 | | | multiply by 100 (sq cm) | | | | | | | | total |
| 2010/2011 | 10094.43 | 1.009443 | 153 | 599 | 400 | 754 | 1005029 | 1812 | 696 | | 1009443 |
| 2011/2012 | 8272.2325 | 0.82722325 | **1615.605** | **22.56** | **31.51** | **5113** | **408.52** | **884** | **196** | | 8272.233 |
| 2012/2013 | 2900.55 | 0.290055 | 11.21 | 21.46 | 136.22 | 10.6 | 2564.01 | 129 | 28 | | |
| 2013/2014 | 4294.86 | 0.429486 | 61.58 | 17.99 | 184.77 | 3795 | 176.63 | 6.05 | 41 | 12 | |
| 2014/2015 | 216.39 | 0.021639 | | | | | | | | | |

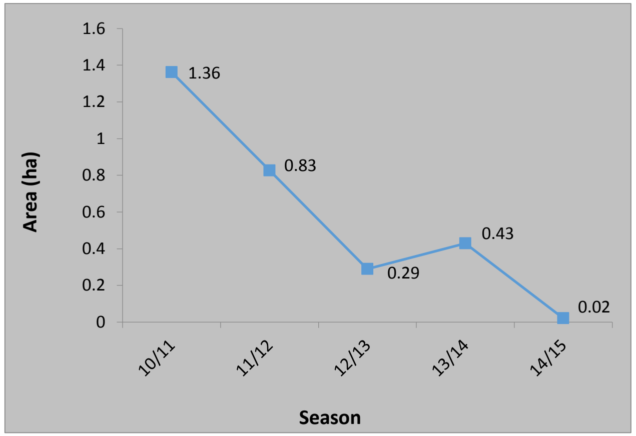
**For revised graphs**

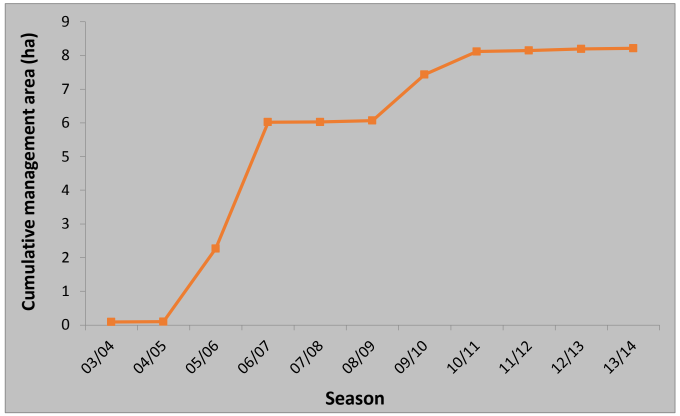
| **Season** | **Active infestation (ha)** | Proportion of active sites | Proportion of active sites (excl new sites) |
|---|---|---|---|
| 2009/2010 | | 100 | 100 |
| 2010/2011 | 1.363151 | 0.64 | 33 |
| 2011/2012 | 0.82722325 | 0.81 | 59 |
| 2012/2013 | 0.290055 | 0.51 | 38 |
| 2013/2014 | 0.429486 | 0.58 | 50 |
| 2014/2015 | 0.021639 | 0.52 | 49 |

| | **Site status** | | | | Inactive 5 yrs | |
|---|---|---|---|---|---|---|
| **Season** | New | Active | Inactive | Inactive 3 yrs | Locally eradicatec | Total |
| 2009/2010 | 47 | 25 | 0 | 0 | 0 | 72 |
| 2010/2011 | 63 | 24 | 48 | 0 | 0 | 135 |
| 2011/2012 | 165 | 79 | 56 | 0 | 0 | 300 |
| 2012/2013 | 75 | 115 | 160 | 25 | 0 | 375 |
| 2013/2014 | 74 | 187 | 159 | 29 | 0 | 449 |
| 2014/2015 | 36 | 207 | 154 | 68 | 18 | 483 |

| | **Proportion of total sites** | | | | Inactive 5 yrs | |
|---|---|---|---|---|---|---|
| **Season** | New | Active | Inactive | Inactive 3 yrs | Locally eradicatec | Total |
| 2009/2010 | 65.27777778 | 34.72222222 | 0 | 0 | 0 | |
| 2010/2011 | 46.66666667 | 17.77777778 | 35.55555556 | 0 | 0 | |
| 2011/2012 | 55 | 26.33333333 | 18.66666667 | 0 | 0 | |
| 2012/2013 | 20 | 30.66666667 | 42.66666667 | 6.666666667 | 0 | |
| 2013/2014 | 16.48106904 | 41.6481069 | 35.41202673 | 6.458797327 | 0 | |
| 2014/2015 | 7.453416149 | 42.85714286 | 31.88405797 | 14.07867495 | 3.726708074 | |



**10:10am Morning Tea and Trade Display**
**Hawkweed Eradication Detector Dog Demonstration**

**Mid-Morning Sessions**

| | Weed Control & Case Studies | Weed Eradication & Management |
|---|---|---|
| CHAIR | Winston Phillips | Michael Michelmore |
| 10:45am | Rocks, Dirt & Weeds : What's the connection? Lis Arundell – MV/ LVWAC & Stephen Johnson – NSW DPI | Could an innovative collaborative funding model aid weed biocon-trol RD&E in Australia? - Andrew McConnachie – NSW DPI |
| 11:05am | African Lovegrass Fire Man-agement and Control Measures – NSW Rural Fire Service – Gary Cooper Rural Fire Service | Key to achieving long term weed control – Sarah Rogers – University of NSW |
| 11:25am | Two steps back five steps forward : Improving Community Participation in Weed Management – Birgitte Verbeek – NSW DPI | |
| 11:45am | **Keynote Speaker –** Nicholas Gill – University of Wollongong<br>Living with weeds, learning about weeds : weed management, values and attitudes among lifestyle-oriented rural landholders | |
| 12:15pm | **Keynote Speaker –** Sandie Jones – NSW EPA<br>Pesticide Regulation – weed related perspectives on use, storage and disposal in South-Eastern NSW | |
| 12:45pm | **Keynote Speaker –** Peter Dougherty and Peter Brenton – CSIRO<br>-The Atlas of Living Australia – Tools to assist weed managers in data capture, management, discovery, visualisation and analysis | |

**1:15pm Lunch and Weed Spotter Demonstration**
**Anna Van Dugteren ACT Government**

## 2:15pm
## Conference Close

# ROCKS, DIRT AND WEEDS: WHAT'S THE CONNECTION?

Elisabeth Arundell[1*] and Stephen Johnson[2]

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Geology has strong ties with biodiversity. The nature of the substrate, being soil and the underlying rock from which it derives, is a key factor in determining the composition, structure and distribution of vegetation communities. Species and habitats are influenced by many factors including soil, climate, topography – relief in particular, biota, and human influence, but the way these natural elements are expressed is primarily influenced by the nature of the parent material, the rock below. New South Wales' geology is dominated by granite, basalt, sandstone and limestone. Weathering of these rocks produces different soil types and plant species often prefer soils derived from one over another. Numerous Australian studies have found that certain native plant species and communities favour particular soil types and that geology is a key controlling factor. Examples include Kurrajong trees (*Brachychiton populneus*) on limestone; Bangalow palms (*Archontophoenix cunninghamiana*) on the Narrabeen Sandstone; native pines *Callitris* sp. on sandstone or sandy granite soils; and numerous distinct eucalypt forest and scrub assemblages. An inequality is recognized in the conservation of native species and communities that prefer deep, fertile soil of a narrow range of geological substrates. These areas have been extensively cleared for agriculture and are underrepresented in the public reserve. This inequality heightens the value of remnant communities, weed control and revegetation programs.

We ask are some weed species also more likely to occur on certain rock types, preferring the soil derived from the underlying rocks? Initial research of statewide vegetation surveys suggests that a number of exotic weed species do have a strong affiliation with particular soil and rock types. Such a connection has implications for the management of noxious and environmental weeds, especially when prioritising areas for weed inspections. A better understanding of local geology may prove to be an advantage in conservation and weed management in New South Wales. The purpose of this paper is to open discussion on the topic.

## INTRODUCTION

The biogeography, or composition and distribution of plant communities, is determined by a number of factors. Notably topography, relief in particular, climate and soil (Beadle 1948). Topography and soil in turn are strongly influenced by a region's geology. The purpose of this paper is to explore the link between geology and biogeography in New South Wales (NSW), and to determine what influence rock type has on plant life. It is hoped that a better understanding of geology will assist in better conservation of native vegetation and weed management in NSW.

Topography and climate have been well documented as major influences on the structure and species composition of floristic assemblages in NSW, as shown in Figure 1 (RBGS, www.rbgsyd.nsw.gov.au). Five NE-NNE trending botanical divisions have been outlined, roughly paralleling the coast and reflecting the topography, and with it, corresponding rainfall and temperature of the state: coastal vegetation east of the Great Dividing Range; tableland communities along the divide; transitioning westward as the land extends out across the western slopes; the western plains; and finally far western plains communities. But are topography and climate the only factors influencing where plants grow?

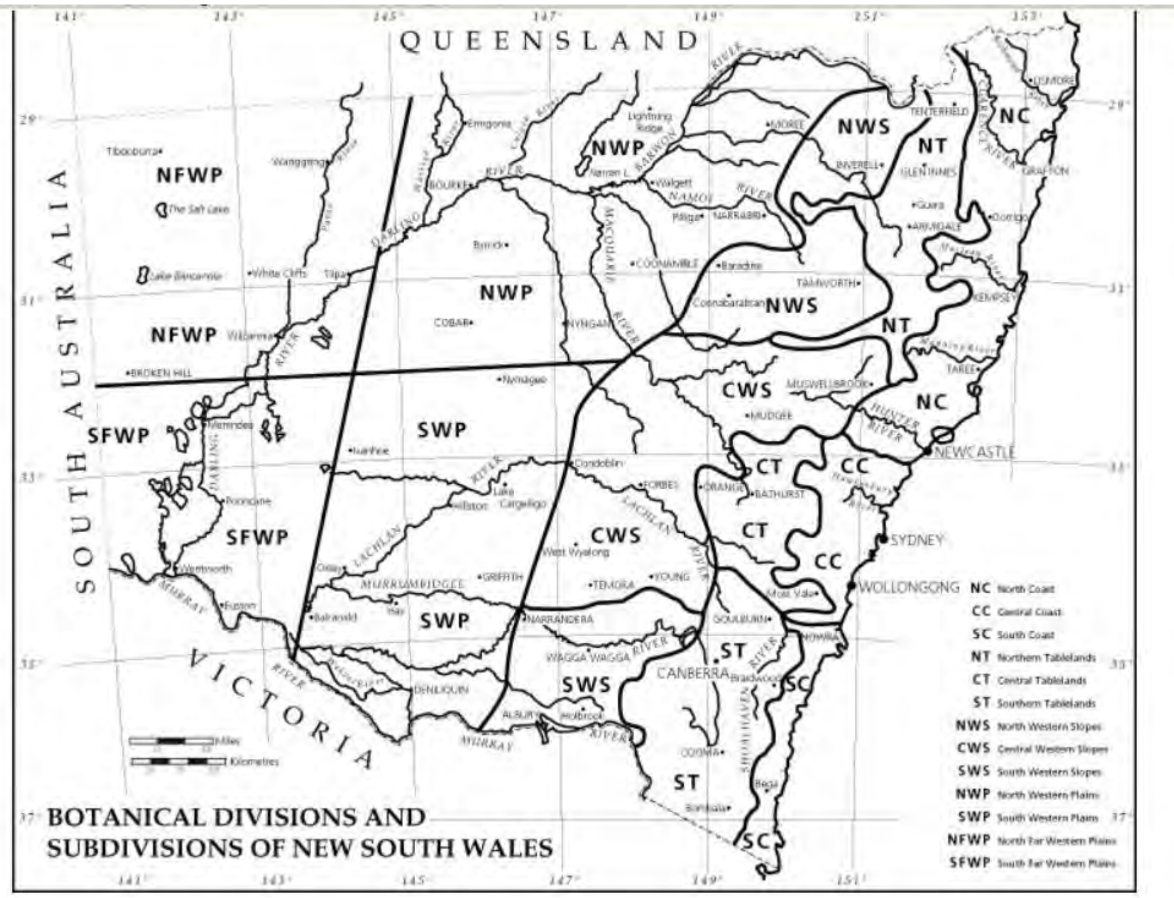


Figure 1. Botanical divisions and subdivisions of New South Wales (Royal Botanical Gardens Sydney, http://www.rbgsyd.nsw.gov.au)

The Interim Biogeographic Regionalisation for Australia (IBRA7, Environment Australia 2012) classifies NSW' landscapes into 18 geographically distinct bioregions based on common climate, geology, landform, native vegetation and species information (Figure 2). The bioregions reflect the varying dominant influences of geological substrate and climate that apply at a continental scale (Gellie 2005). For example, the Australian Alps (AUA), the Mulga Lands (MUL) and the North Coast (NNC) are distinct bioregions. The IBRA7 bioregions broadly follow the botanical subdivisions shown in Figure 1 but their boundaries more closely reflect local geomorphological features, for example the Darling River and its subsidiaries (Darling Riverine Plains, DRP), the Channel Country (CHC) and desert dunefields (Simpson Strzelecki Dunefields, SSD).

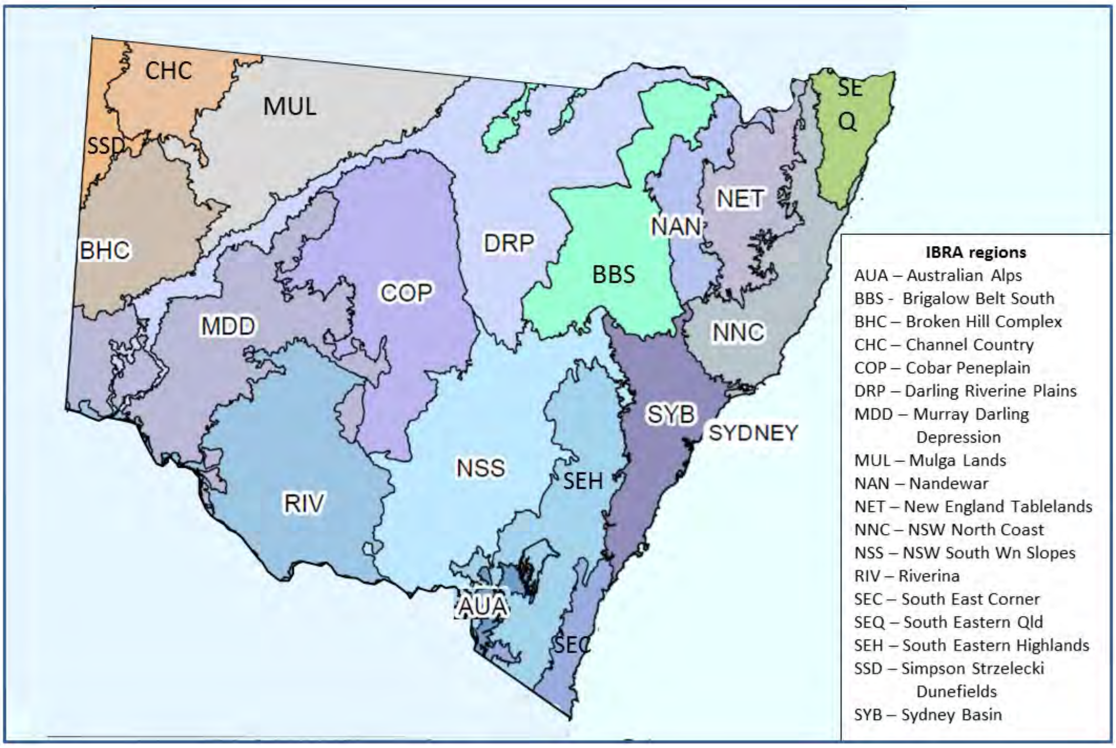


Figure 2. Bioregions of New South Wales
Modified from Environment Australia (2012)

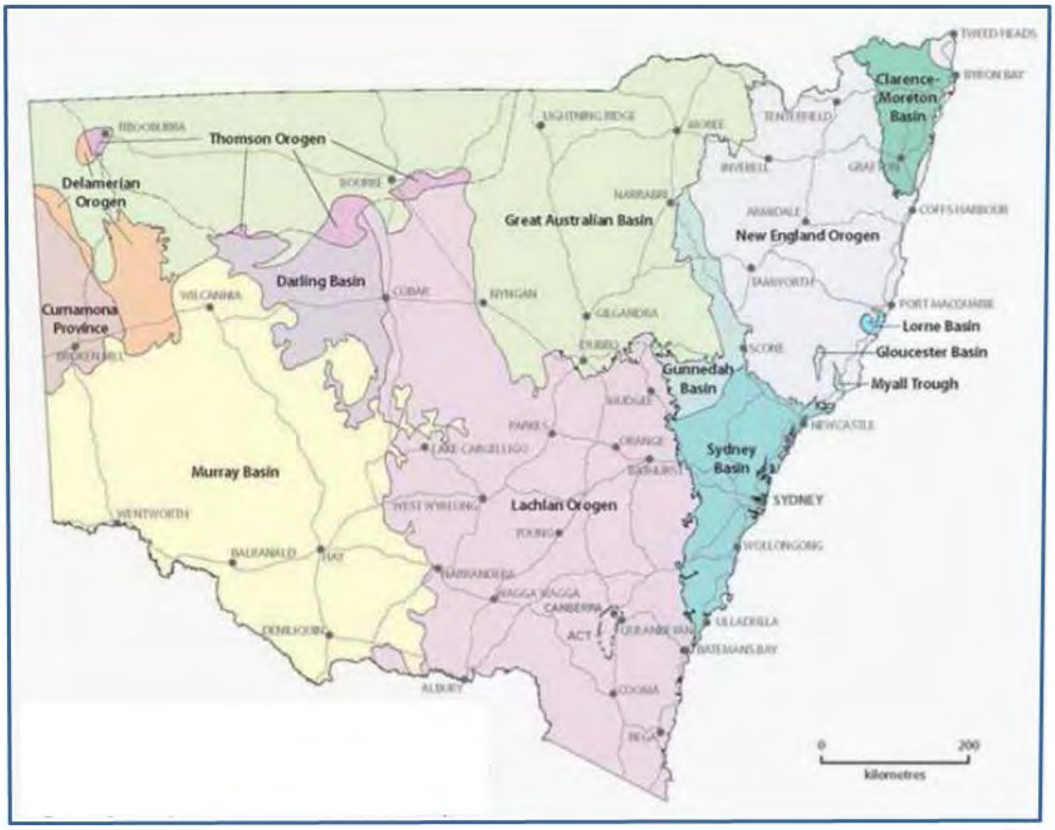


Figure 3. Major geological provinces of NSW (GSNSW 2009)

Comparison of the IBRA map with that of the geological map of NSW (GSNSW 2009, Figure 3) reveals the bioregions closely follow major geological provinces of the state. The Sydney Basin, Broken Hill Complex, Nandewar/New England Tablelands/North Coast and South Eastern Queensland bioregions correlate with the geological provinces of the same areas – the Sydney Basin, Curnamona Province/Delamerian Orogen, New England Orogen and Clarence Moreton Basin. One could even argue the north-south trending structures of the Lachlan and New England orogens have influenced the topography of the state at a regional level and that this structure is also reflected in the north-south trend of the botanical subdivisions and bioregions.

Keith (2011) completed an excellent comparison of geodiversity and vegetation in NSW, the term 'geodiversity' being used to include geology, geomorphology and soil. He analysed spatial data sets synthesised from extensive vegetation and geological surveys from across the state. Existing vegetation survey data was simplified and re-classified into 16 broad vegetation formations and 100 vegetation classes, following those described in Keith (2004), with the information merged into a state-wide vegetation map. Spatial geological data of Stewart *et al*. (2006 in Keith 2011, based primarily on mapping by the Geological Survey of New South Wales (http://www.resourcesandenergy.nsw.gov.au/miners-and-explorers/geoscience-information/products-and-data/maps/geological-maps)) was simplified and units reclassified into 16 substrate types based on features considered important to plant growth including mineral composition, derived soil type etc. Vegetation/geology occurrences were then compared. The influence of climatic factors on the biogeography of vegetation was also analysed. The study found that at a state-wide scale, native vegetation in NSW exhibited strong relationships with geodiversity at both class- and formation-level with almost one-fifth of floristic variation attributable to rock type, independent of climatic variables. Each vegetation formation and class showed strong associations to a small range of geological substrates, with some classes restricted to a single rock type (Keith 2011).

We speculate that with further study, a link will also be found between geology and the composition and distribution of introduced plant species, in particular those listed as noxious weeds in NSW. This information could then assist in future weed management in our state.

## FACTORS INFLUENCING THE RELATIONSHIP BETWEEN GEOLOGY AND BIOGEOGRAPHY

Geology has strong ties with the biogeography of vegetation. The nature of the substrate, being soil, and the underlying rock from which it has derived, is a key factor in determining species composition, vegetation structure and environmental habitat. Vegetation patterns are also influenced by climate, topography, and disturbance history (Beadle 1948, Whittaker 1967); but the way these elements are expressed in nature is primarily influenced by the nature of the rock below.

**Soil** is the mixture of rock particles, minerals, organic matter, air, water and organisms found above fresh bedrock that together support plant life. It is often formed in layers known as soil horizons. Soil properties most influencing plant growth include mineral content, texture, organic content, moisture holding capacity and depth. These properties are largely controlled by the nature of the parent material from which the soil derives, but other factors including climate – rainfall and temperature, biota – activity of organisms including humans, relief – especially its influence on drainage, and time, are also important. Working together, these factors control the various soil forming processes such as weathering of parent rock and the leaching, movement and accumulation of clays, soluble cations such as Calcium, Magnesium, Potassium and Sodium, and other soil materials that lead to the development of particular soil types (Gray and Murphy 1999).

The length of time that a soil has been forming is significant because as time proceeds and soil weathering and leaching, together with biological processes, continue, the composition of the soil will diverge from that of the original parent material (Grey and Murphy 1999). A strongly developed soil profile with distinct, texture-differentiated soil horizons may take 30,000 years to form, and most soils in eastern Australia are probably no more than 200,000 years old, as Gray and Murphy (1999) comment, relatively young. These soils are still considerably influenced by their parent material, while soils in more ancient landscapes such as central and Western Australia, which may be millions of years old, have lost the influence of the original parent rock (Gray and Murphy 1999). These ancient, impoverished soils are characteristic of Hopper's (2009) 'old climactically buffered infertile landscapes' (OCBILs), having experienced prolonged weathering, leaching and non-deposition. Landscapes that have experienced more (geologically) recent disturbance for example orogenic, glacial, fluvial, marine or mass movement events are termed 'young often disturbed fertile landscapes' (YODFELs); these areas are characterised by relatively fertile soils whose nutrient's have not been greatly depleted by leaching (Hopper 2009). YODFELs dominate eastern Australia but as commented by Hopper (2009, and others therein), OCBILs may occur locally for example where younger landscapes have been removed by erosion, revealing the underlying older landscapes. This could be the case in parts of central and western New South Wales where old landscapes developed on Paleozoic and Proterozoic basement have been exhumed following erosion of Mesozoic and Cenozoic cover (E. Arundell personal observation).

The **climate** of NSW largely reflects topography and geographic position, in particular latitude and distance from the coast. The north-south trending Great Dividing Range acts as a major climactic barrier, with humid temperate to subtropical conditions to the east of the range and dryer, temperate to arid conditions to the west. Average temperatures gradually increase while rainfall decreases with distance west and north west of the divide. On the coast, warm, moist conditions in the north give way to cool, moist conditions southwards to the Victorian border. Mean average rainfall varies from over 1500 mm along parts of the coast to less than 200 mm in the northwest corner of the state (BOM 2013). The tablelands receive the coolest temperatures with average maximum summer temperatures of 18$^{o}$C on the southern Alps, while the highest average summer temperatures (36$^{o}$C) occur in the far northwest of the state. Frost occurs on the central west and western slopes and plains, and together with snow, is common on the tablelands, while coastal areas are generally frost free (BOM 2013). Climate has a significant influence on the ecology of NSW, for example vegetation and fauna in alpine regions differ vastly from those in more arid, semi-desert regions. Small variations in topography can also influence local climatic conditions and hence vegetation patterns, for example hills producing local rain shadows, frost hollows, and at higher altitudes, alpine microclimates.

The **topography** of NSW largely reflects the geology and geological history of the state. The relative resistance of different rock types to erosion plays a significant role in determining relief at a local level, while major topographic structures such as the Great Dividing Range and the Warrumbungles, are the result of regional scale earth movements and/or volcanism. Individual rock types have differing levels of resistance to erosion. Factors such as hardness, permeability and internal structures including jointing and bedding planes will influence how quickly a particular lithology will erode. The length of time over which erosion has acted is also significant. In general, softer rocks such as shale and siltstone are less resistant to erosion than sandstone, coarse grained igneous rocks such as granite are less resistant to erosion than finer grained volcanic rocks such as basalt, while sedimentary rocks are less resistant to erosion than igneous rocks. A classic example of this is found in the Blue Mountains where sedimentary rocks of the Sydney Basin are exposed. Here softer siltstone and shale have eroded faster than the overlying, more resistant sandstone, resulting in undercutting of the overlying rocks. Joints in the sandstone give way under gravity leading to collapse and formation of steep vertical sandstone cliffs and 'U' shaped valleys. Remnant basalt lava flows locally 'cap' the tops of hills in the area, for example on Mount Tomah. The basalt flows represent an ancient land surface: the surrounding sedimentary rocks, being less resistant to erosion than the basalt, having been eroded away (van der Beek *et al.* 2001). The Blue Mountains contain vegetation communities quite distinct from those of adjacent plains, a reflection of the differing topography, climate, and as discussed in a later section, geology.

**Disturbance history** of land plays a small but significant role in influencing the biogeography of NSW through the physical removal of native vegetation, local extinctions and the introduction of alien plant species (eg. Keith and Bedward 1999). Natural vegetation patterns have been altered by land clearing, selective logging, overgrazing, nutrient enrichment from pasture improvement and/or stock manure, drought and fire. European occupation of NSW has focussed on areas with higher soil fertility and gentle topography, and the vegetation of these areas has especially been modified. Remnant grasslands, forests, woodlands, riparian habitats and wetlands in and around pastoral and urban areas are impacted by fertiliser run-off, weed infestation, domestic and feral animals, dumping of refuse, firewood collection and so on. Heavy grazing may also exacerbate rates of soil erosion. The role that climate, topography and disturbance history play in determining where plants grow in NSW can not be separated from the influence of the underlying geology; a simple description of the main rock types of NSW is presented in the following section.

## GEOLOGY OF NEW SOUTH WALES

The geology of New South Wales is dominated by granite, basalt, sandstone and limestone, and their metamorphosed equivalents. A simplified 'Geology of NSW' is presented below to explain how these different lithologies can be identified in the field and how they were formed. The relative ages of different rock units in NSW are presented in the geological time scale (Table 1); similar to a historical record, this outlines the sequence in which rocks were formed. Rock units in NSW range from the Proterozoic to the Cenozoic - from approximately 1700 million years (ma) to the present. The age of rock units reflects the geological formation of the east coast of Australia (Schiebner 1999, GSNSW 2009), with units becoming progressively younger moving eastwards. The oldest rocks occur on the western margin of NSW and form part of the Proterozoic Australian Craton (Curnamona Province, Figure 3). The central and eastern parts of NSW are built on orogenic, or fold, belts of late Proterozoic to Mesozoic age (Delamerian, Lachlan and New England orogens). These 'basement' rocks are overlain by the youngest rocks in NSW, late Carboniferous to Cenozoic sedimentary cover (Sydney, Gunnedah, Great Australian/Artesian, Clarence Moreton and Murray basins) and volcanic rocks associated with extinct volcanoes (Mount Warning, the Nandewar Range, the Warrumbungles, Gerringong and Mount Canobolas).

| Era | Period | Age (Ma) | NSW Geology |
|---|---|---|---|
| Cenozoic | Quaternary | 2.6 - present | |
| | Neogene (Tertiary) | 23 | Volcanism - Canobolas, Warrumbungles |
| | Paleogene | 66 | Murray Basin |
| Mesozoic | Cretaceous | 105 | Great Australian |
| | Jurassic | 201 | Basin |
| | Triassic | 252 | Sydney Basin |
| Paleozoic | Permian | 298 | New / NSW coal measures |
| | Carboniferous | 359 | England |
| | Devonian | 419 | Orogen |
| | Silurian | 444 | Lachlan |
| | Ordovician | 485 | Orogen |
| | Cambrian | 541 | |
| Proterozoic | | 2500 | Curnamona Province |
| Archean | | 4560 | |

Table 1: The Geological Timescale of New South Wales
(modified from Scheibner 1999, GSNSW 2009, Gradstein *et al.* 2012,)

Rocks can be differentiated into three main groups based on grain size, texture and mineralogical composition - features related to their formation: igneous, sedimentary or metamorphic. **Igneous rocks** form from magma either at depth (intrusive) or on the earth's surface as lava (extrusive). Mineralogy varies from quartz- and feldspar-rich assemblages found in light coloured, felsic/silicic igneous rocks such as granite (course grained intrusive) and its finer grained extrusive equivalent rhyolite; and dark coloured, olivine and pyroxene rich mafic/basic rocks which contain no quartz such as basalt (fine grained extrusive) and its coarser grained intrusive equivalents gabbro and dolerite. Andesite is an intermediate extrusive igneous rock with mineralogy between felsic and mafic. Granitic rocks are pale grey to white to pink in colour due to their high quartz and feldspar content, they commonly form large rounded 'tors' in the field such as those seen around Cooma and Bathurst. They weather slowly to yellow/pale brown/white coloured soil with crumbly, friable sandy texture. Basaltic rocks are dark grey to black in colour due to their high mafic mineral content. Remnant basalt lava flows 'cap' hill tops like Mount Tomah in the Blue Mountains and around Orange. Basaltic rocks also occurs as distinct columns at Dorrigo and the Kiama blowhole. Basaltic soils are highly fertile, rich dark red to brown in colour and heavy in texture due to their high clay content, for example those of the Liverpool Plains.

**Sedimentary rocks** are those derived from particles of other rocks, or in the case of limestone and coal, animal and plant remains. Eroded by water or wind, pebbles, sand and mud form bedded deposits in rivers, desert dunes and on the sea floor, which subsequently become cemented into rock. They vary in grainsize from conglomerates, to sandstones to mud and siltstones. Original bedding planes can often be seen in outcrop for example in the steep sandstone cliffs of the Blue Mountains and headlands around Sydney, coal measures (coal bearing sedimentary strata) in the Hunter Valley and many coastal exposures and road cuttings. Limestone is a carbonate deposit formed in marine environments from the precipitation of calcite within a coral reef or consolidation of marine animal remains (coral fragments, shells etc). They occur as prominent outcrops distinguished by their grey colour and smooth weathered surface; they are commonly associated with cave development (eg Jenolan Caves). Fossils may also be visible.

**Metamorphic rocks** form from pre-existing rocks that have undergone change through heat or pressure deep in the earth's crust. With increasing metamorphic grade, i.e. progressively greater pressure and/or temperature, siltstone and shale become slate, schist or gneiss, limestone changes to marble, and sandstone to quartzite. Rocks of the New England and Lachlan orogens display varying degrees of metamorphism, while schist and gneiss in the Broken Hill region are highly deformed. The metamorphosed rock is texturally and/or mineralogically distinct from the parent rock, but is not chemically different. Textural and structural features of metamorphic rocks are commonly aligned parallel, a feature known as foliation. Strongly foliated rocks, including slate, split easily along flat parallel planes.

## GEOLOGY, SOILS AND THEIR CONNECTION TO PLANT GROWTH

The traditional geological classification scheme described above divides rocks into three broad groups based on how they were formed. In the study of soil, particularly in relation to the influence of soil on plant growth, the most important feature of parent material is its mineralogical and chemical composition, with physical features such as grain size and mode of origin less significant. Gray and Murphy (1999) have outlined a more useful classification scheme for soil-parent material relationships. The scheme ranks different substrate types, including rock and unconsolidated material, according to their chemistry, in particular silica ($SiO_2$) and base content (calcium (Ca), iron (Fe) and magnesium (Mg) oxides). The ranking system correlates with the relative fertility of the derived soil. Seven of the ten broad categories outlined in the scheme are presented in Table 2.

According to the classification scheme, rocks that are highly silicious (>72% $SiO_2$) but with low base content (<7%) such as quartz sandstone, granite and rhyolite are grouped together. These rocks typically give rise to relatively shallow soils with high sand content and low clay content. They have high levels of aluminium (Al), potassium (K) and sodium (Na), but are somewhat deficient in phosphorus (P) and magnesium (Keith 2011), leading to low fertility. In contrast, mafic rocks which include basalt, gabbro, dolerite and mafic-dominated sedimentary rocks are lower in silica (<52% $SiO_2$) but have a high base content (>20%). These rocks give rise to deep soils with a high clay content but little or no quartz sand. The soils are highly fertile with relatively high phosphorus, magnesium and iron (Keith 2011). Ultramafic rocks such as serpentinite have a very high base content with a deep soil profile but they also contain high levels of heavy metals, for example chromium (Cr), cobalt (Co) and nickel (Ni). Soils derived from these rocks are more-or-less ‘toxic' for plant growth and not suitable for agriculture. Soils derived from limestone are thin, often with a high proportion of exposed rock, and are distinguished by their high calcium carbonate content ($CaCO_3$). Most lithic sandstone, siltstone and shale, as well as metamorphic rocks such as slate, phyllite and schist, have an intermediate silica content, with moderate to high levels of phosphorus and exchangeable cations (Keith 2011), and have moderate fertility (Gray and Murphy 1999).

Table 2: (*on separate page)* Substrate types and their corresponding soils, highlighting properties most influencing plant growth (modified from Gray and Murpy 1999 and Keith 2011

The range in mineral nutrient levels, texture and depth of soils produced by weathering of different substrates influences vegetation. Plant species vary in their ability to extract resources from the soil and particularly to tolerate extreme nutrient/water availability levels. Numerous Australian studies have found that certain native plant species and communities favour particular soil types (see Keith 2011 for a review) and that geology is a key controlling factor. For example Beadle (1953, 1966) related the distribution of major vegetation formations to levels of soil phosphorus; from rainforest vegetation associated with high soil phosphorus to sclerophyll heath and woodland associated with very low levels.

## CORRELATION BETWEEN NATIVE VEGETATION AND GEOLOGY IN NEW SOUTH WALES

Extensive surveys have been completed on the biogeography of native vegetation in New South Wales. Considerable bias is evident in the state-wide data set due to the greater number of these surveys having been completed on land under public tenure including State Forests, Crown Land, National Parks and other conservation reserves. In addition, areas retaining intact native vegetation are more likely to be on steep infertile terrain with shallow soils since these areas were often the last to be cleared by early European settlers. Vegetation mapping on private land is also biased due to extensive land clearing and the fact that private agricultural land is often concentrated on fertile flats and valleys. Surveys are more often limited to extant communities; the absence and or scarcity of substantial patches of unmodified, remnant vegetation can be a major limitation in sampling flora sites evenly across study areas (Gellie 2005). These biases need to be taken into account when considering what factors are controlling the distribution of vegetation communities.

Vegetation studies in south east NSW have tried to overcome these limitations by carrying out surveys on both public and private land, and using environmental spatial data including remote imagery to estimate/map communities present prior to clearing. This broad region incorporates the Sydney Basin, South Eastern Highlands, South Western Slopes and South East Corner bioregions (Benson and Keith 1990; Fisher *et al.* 1995, Keith and Bedward 1999; Gellie 2005, Benson 2008; Tozer *et al.* 2010, Figure 2). Vegetation types include rainforests, eucalypt forests and woodlands, heathlands, shrublands, grasslands and wetlands with over 190 identified floristic assemblages. Vegetation mapping has consistently found that the distribution of plant communities strongly reflects the lithology and soil fertility, combined with set rainfall and altitude limits.

The south east region of NSW straddles two very different geological provinces, with contrasting lithology, landforms and soil properties. To the east/northeast lies the Permo-Triassic Sydney Basin (Figure 3), a major sedimentary structural basin consisting of coal measures and siltstone, overlain by quartz sandstone that form the prominent cliffs, plateaus and deep gorges of the Blue Mountains. This province is characterised by well drained, sandy textured soils with low nutrient value. To the west and south, underlying the basin, lie older, basement rocks that form part of the Palaeozoic Lachlan Orogen. The orogen is dominated by sedimentary and igneous rocks with varying degrees of metamorphism that form undulating terrain typical of farmland of the Central and Southern Tablelands and South Coast region. Soils of this region are generally deeper, have a higher clay content and are higher in fertility.

At a regional scale, there is a distinction between vegetation communities of the Sydney Basin and assemblages of the surrounding tablelands and south coast. For example, dry shrub forests dominate the Sydney Basin, where despite relatively high rainfall, the low fertility and water holding capacity of the shallow soils limit growth of more lush and taller plants. Outside the Sydney Basin, on basement rocks of mixed lithology and deep fertile soil, moist eucalypt forests are found (Gellie 2005). Similarly Keith (2011), in his state-wide study, noted that impoverished soils derived from high-quartz sandstone are strongly associated with sclerophyllous (small, hard leaved) shrubs while lithologies that produce more fertile soil, for example low-quartz sedimentary and igneous rocks are associated with mesophyllous (large, soft leaved) shrubs and/or grasses. Benson and Keith (1990) noted that of the main tree species on the western edge of the Sydney Basin, eleven eucalypt species were largely confined to quartz sandstone, while sixteen other eucalypt species were largely confined to older (low quartz) sedimentary strata. It is also significant that of these two eucalypt groupings, the majority of species on quartz-rich rocks belong to the eucalypt subgenus *Monocalyptus*, while the majority of species on older strata belong to the subgenus *Symphyomyrtus*. As suggested in Benson and Keith (1990), the predominance of a particular plant species or subgenus probably relates to differences in the texture and nutrient content of the soils.

At a local scale, a strong correlation exists between certain eucalypt forest and scrub assemblages of similar climate and topography, and particular parent materials. For example, in the area around Eden, Hinterland Wet Fern Forests are found primarily on granitoids and quartz sandstones, Hinterland Wet Shrub Forests on metasedimentary rocks and Rhyolite Rock Scrub on rhyolite substrate, while three other distinctive assemblages are restricted to basalt substrate (Keith and Bedward 1999). Similarly, Fisher *et al.* (1995) recognised distinct plant communities associated with the Devonian felsic Bindook Volcanic Complex near Yerranderie north of Bowral. Benson (2008) also described a floristically and structurally distinct shrubland growing on serpentinite outcrops between Tumut and Coolac.

The occurrence of individual plant species can also be controlled by geology and soil type. Observations in the field made over many years suggest that a number of native species grow preferentially on the soil derived from certain rock types. In the Central West region of NSW and particularly in areas between Orange and Wellington, Kurrajong trees, *Brachychiton populneus* are often found on outcrops of limestone. Bangalow palms, *Archontophoenix cunninghamiana* are a common landscape feature below the escarpment south of Sydney and can be used as an indicator species for the Narrabeen Sandstone, a unit of the Sydney Basin. Native pines *Callitris* sp. are a common feature to sandy soils derived from sandstone and granite (Norris and Thomas 1991).

Recognition of the link between geology and vegetation communities has significant implications for conservation. As discussed above, vegetation assemblages common to areas of shallow, infertile soil derived from quartz-rich sandstone and granitoid lithologies are well represented in state conservation areas. Assemblages preferring fertile soil derived from low-quartz igneous and sedimentary lithologies are more likely to be found on private land and are under represented in the public reserve. These communities have suffered extensive clearing and remaining stands have been modified by grazing and selective logging. Exotic plant species dominate the ground cover. Keith and Bedward (1999) estimate that some assemblages on fertile, flat terrain are depleted by more than 90% while forests with shrubby understories in steep, infertile terrain retain close to their original extent. The inequality in conservation of different vegetation communities heightens the value of conservation for remaining stands, including Grassy White Box Woodlands and other Endangered Ecological Communities which once extended across large areas of the state but have been severely reduced for agriculture. The importance of weed control and revegetation programs in these areas is equally significant.

## CORRELATION BETWEEN WEED SPECIES AND GEOLOGY IN NEW SOUTH WALES

The strong relationship between native vegetation and soil type, and the parent rocks from which the soil derived raises the likelihood that a link also exists between geology and the composition and distribution of introduced plant species. Such a correlation has significant implications for the management of noxious and environmental weeds in NSW. Inspections for high priority weeds form a large part of the control work carried out by local councils and other control authorities. Can these inspections be prioritised to areas of certain rock types?

Limited work has been completed on this subject in Australia. Weed officers across central west NSW have reported the association of particular weed species with soil fertility. For example thistles, particularly Variegated Thistle are common on fertile soil; while St John's Wort, Spiny Burr Grass and Sifton Bush are often found on infertile soils derived from granite and sandstone. Our research, still in its early stages, has focused on statewide vegetation surveys. Results have been limited because most vegetation surveys in the state focus on native vegetation communities rather than introduced species. Where species lists are published, the data rarely compares species diversity with differing geological substrate, although differing soil types or landforms are often differentiated.

One notable exception is Norris and Thomas (1991, their Appendix 1). Although not the primary objective of their paper, those authors illustrate differences in weed species found on sandstone and granite outcrops in south western NSW. Members of the: daisy family (Asteraceae), for example the catsear/flatweeds (*Hypochaeris glabra* and *H. radicata*) and sowthistle/milk thistle (*Sonchus oleraceus*); members of the carnation family (Caryophyllaceae) such as the chickweeds (*Cerastium glomeratum* and *Stellaria media*); and some members of the grass family (Poaceae) such as the rat's tail fescues (*Vulpia myuros*) and the hairgrasses (the *Aira* spp.) are more common on sandstone outcrops.

In contrast, members of: the fumitory family (Fumariaceae) such as the fumitory species (*Fumaria* spp.); the geranium family (Geraniaceae) such as the geranium (*Geranium* spp.) and storksbill species (*Erodium* spp.); and the forget-me-not family (Boraginaceae) such as Paterson's curse (*Echium plantagineum*) and more common on granite outcrops.

Vegetation data collected in other studies and compared with contrasting geological substrates may reveal similar, or even more pronounced differences. This will be the subject of further research.

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## Could an innovative collaborative funding model aid weed biocontrol RD&E in Australia?

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The investment in weed biological control in Australia has been enormously beneficial; economically, environmentally and scientifically, yet the limited and sporadic funding of recent years has caused a sharp decline in national weed biocontrol research development and extension (RD&E) capacity. Hence, there is a critical need to establish a process to garner a broader funding base. This paper outlines a conceptually innovative collaborative model to monitor and maintain a functional and ongoing biocontrol agent delivery pipeline. The proposed model would coordinate funding, priorities and collection of monitoring data. Initially, the model would focus on NSW, with progressive expansion to other states. Through regular workshops between interested parties (government agencies, local government, regional weed committees, local land services and other industry and community bodies) and vehicles such as the NSW Biocontrol Taskforce, a partnership approach will be pursued. Based on the sustainable principle of 'beneficiary pays', such a model would require support from National and State governments and involve financial backing from NRM/Local Land Services, local governments and other stakeholders to form a centralised biocontrol RD&E node. Collectively, this node would bring together Australia's leading weed biocontrol RD&E agencies, and in so doing, would fast-track and maximise the on-ground delivery of biocontrol agents. This approach could also facilitate the collection and evaluation of monitoring data on a national level. This in turn would provide biocontrol services for the future, which would simultaneously catalyse the regional benefits from weed biocontrol, while re-invigorating and sustaining Australian biocontrol capability and capacity.

**We would like this abstract/paper to be considered for the:** Weed Management for Conservation symposium

**In particular in the topic area of:** Collaboration and innovation in weed management for conservation

**Presenters name, organisation and details:** Andrew McConnachie, NSW DPI, Orange:
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**Presentation length:** 15 minutes.

Presenter's name and organisation: Sonia Graham, The University of New South Wales

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- Name of presentation: The keys to achieving long-term collective weed control

- Duration: 20 minutes

- **Abstract:** Weeds present collective action problems—they are best controlled when public and private land managers work together, yet land managers have different levels of interest and motivation in controlling weeds. To date, much weeds research and policy development focuses on the actions of individuals, rather than groups. This study sought to understand how three land management groups—Towamba, McLaughlins, and Upper Lachlan/Jerrawa Creek—have come to be known for their cooperative, effective and ongoing approaches to weed control. An overview is provided of the history of each of the three groups: how they evolved, what they achieved, and the challenges they have faced and overcome. The similarities and differences across the groups provides insights that other groups and regions can adopt to establish their own community-oriented, collective approach to weeds.

# TWO STEPS BACK FIVE STEPS FORWARD

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## INTRODUCTION

For decades, scientific literature has shown that information intensive programs (those that improve knowledge and awareness about environmental issues) fail to change community behaviours. Despite numerous scientific findings to this effect (from the 1970s through to the present), state and local governments, in NSW and elsewhere, continue to invest millions of dollars annually in information-intensive campaigns to engage and motivate communities to manage weeds.

At both the state and local level the imperative now is to become more objective, strategic and sophisticated in investment choices for effective community engagement. To this end, here in NSW we are deploying Community-Based Social Marketing (CBSM), a field-tested and extensively peer reviewed series of engagement processes, to leverage best practices from the fields of communications, behavioural science and environmental psychology.

By merging knowledge from the social sciences and health-based social marketing, CBSM entails five clearly defined steps: (1) selecting target behaviours for change (2) identifying barriers to those behaviours and motivators for engaging in them (3) developing best-practice strategies to change the behaviours (4) piloting those strategies to measure effectiveness before (5) broad-scale implementation.

To date in NSW, and elsewhere in the public sector, we typically design strategies (CBSM step 3) before clearly defining the behaviours we are targeting (step 1) or researching the barriers and motivators to the adoption of the selected behaviours (step 2).

In essence, we need to move two steps backward before progressing forward in the design of new strategies.

This paper reports on the progress of a state-wide project “CBSM Biosecurity – Weeds Initiative” which commenced in January 2015. The project aimed to build a database to enable the first critical step of the CBSM process: the collation, selection and ranking of weed management behaviours.

Built in consultation with weeds professionals across NSW, the database provides a decision-support matrix to help with CBSM implementation, offering an empirically driven and strategically sound method for targeting behaviours, and funding and designing effective behaviour change strategies.

## WHERE DID WE START?

### The first steps

In March 2014, 37 weeds professionals representing 11 Regional Weeds Advisory Groups, Local Land Service regions, and other weed management stakeholders in NSW attended an introductory CBSM workshop. Conducted by Dr Doug McKenzie-Mohr, the founder of CBSM, and hosted and funded by NSW Department of Primary Industries (DPI), the workshop included an additional consultation day where an existing program was analysed by retrospectively applying the CBSM steps to it. The exercise encouraged participants to envisage the future use of CBSM across the state.

Senior executives from NSW DPI also attended an hour-long briefing session with Dr. McKenzie-Mohr, where he made five recommendations about how CBSM could improve weed management outcomes in NSW. The recommendations were:

1. Coordinating activities at a state level and through all stages drilling down to a local level to apply CBSM
2. Compiling and grouping end-state behaviours (an end-state behaviour is the precise targeted behaviour that creates the desired weed management outcome)
3. Tying funding to piloting strategies – then funding proven strategies
4. Developing and promoting proven strategies that can be applied in multiple locations
5. Employing in-house social marketers to help build capacity within the organisation.

### The way forward

During the CBSM workshop, attendees discussed how they would like to see CBSM adopted across the state, focusing on Dr McKenzie-Mohr's recommendations (see above).

Workshop participants agreed on a state-led approach to building capacity, and volunteers agreed to form a working group.

The CBSM working group met in May 2014 to begin compiling and grouping end-state behaviours for weeds, and defining categories of behaviours that could be populated by the rest of the workshop attendees and their regions. The group nominated DPI to coordinate the project across the state.

Behaviour change programs must be driven at a local level. Barriers to adopting desired behaviours can vary significantly between localities, weeds and segments of the community (such as urban or rural residents). For this reason, at every stage of the state-led approach, consultation will drill down to the local level, facilitated by the regional representative that attended the workshop.

Staff at Palerang Shire made a significant commitment documenting and tiering weed management behaviours for a specific weed (gorse) in their area, using an Excel spreadsheet. The working group decided to use this spreadsheet as a basis for further development. It was soon apparent that because of the number of behaviours, the complexities of locations and control options, etc. this was a difficult task in relation to weed management. The prospect of incorporating many different weeds promised additional complication and challenge. Further consultation with Dr McKenzie-Mohr ensured the CBSM working group was on the right path.

In addition to the efforts of Palerang Shire, involvement from other regional staff was needed. The network of Regional Weed Advisory Groups and their collective experiences and expertise was considered conducive to achieving state-wide outcomes. At the very least, their involvement in designing a database to collect and tier behaviours would be a valuable learning process.

Lacking sufficient expertise in this area DPI engaged a consultant to build a system to compile and tier weed management behaviours across the state, in collaboration with regional weed management groups (the “Biosecurity CBSM – Weeds Initiative” project).

## Advanced training

Spurred on by considerable interest from weeds professionals around the state, in April 2015 DPI organised an Advanced CBSM workshop with Dr McKenzie-Mohr for participants of the Introductory Workshop. During the workshop, the developmental CBSM database was shown to participants and feedback was sought from Dr McKenzie-Mohr.

## Feedback from workshops

Participants provided positive feedback about the workshops. Most attendees had little or no knowledge of CBSM prior to attending the introductory workshop and participants reported learning a great deal at both events (Figure 1).

There were no negative comments about the content of the workshops. However comments were made about the lack of relevant examples of CBSM applying to weed management. Not surprisingly many participants found it challenging to fully absorb how to apply this new knowledge to their current programs.

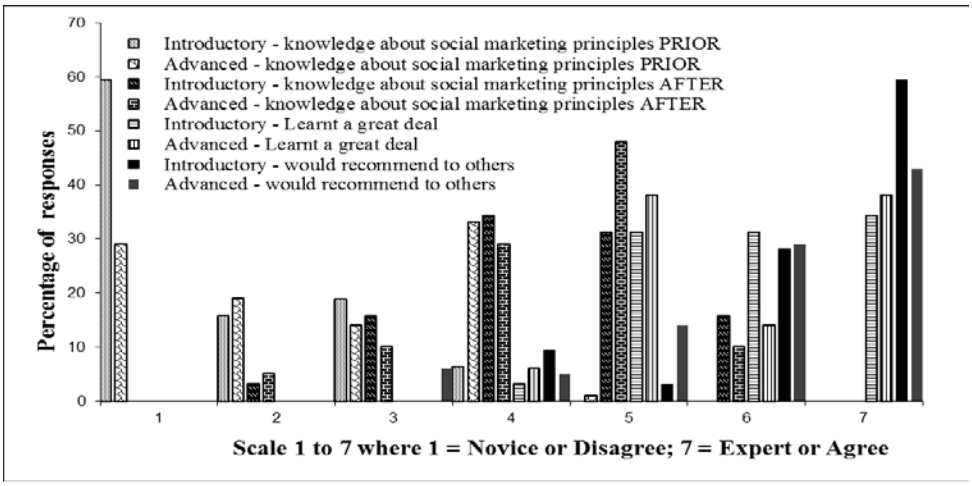



**Figure 1.** Summary of responses from participants when asked about their knowledge of social marketing principles and what they learnt at the CBSM workshops.

## CBSM DATADASE DEVELOPMENT

### The software development process

The building out of the database to meet the initial requirements of any CBSM or behaviour change program has involved four key stages:

1. Collating the entire 'universe' of possible behaviours for weed management in NSW. This list of behaviours is currently well over 100 and is growing, thanks to continued input from the regions.
2. Developing a schema of 'sectors' and 'categories' that affect behaviour selection in any given instance. For example, one sector is 'site constraint' with subsequent categories including waterway, native vegetation, steep or highly erodible land, and public health – all factors that affect what behaviours can or cannot be selected in a given situation.
3. Populating the database with 15 weeds (and related behaviours) that fall into different declaration classes in different regions around the state. Essentially test cases, these weeds are:
    a. lantana
    b. tropical soda apple
    c. gorse
    d. hawkweed
    e. bitou bush
    f. water hyacinth
    g. salvinia
    h. asparagus weeds
    i. serrated tussock
    j. alligator weed
    k. Coolatai grass
    l. privet
    m. mesquite
    n. blackberry
    o. St John's wort
4. Enabling the regions to jump into the tool by creating 'instances' in the database where a weed is selected (based on a real-world challenge), possible remediating behaviours are filtered by sector and category, and then the final list of chosen behaviours is ranked with input from peers and experts, from within NSW and outside of the state.

### Where to from here?

Behaviour selection is just the first step in the CBSM process. This database has been built to accommodate future behaviour change projects, in addition to providing empirical rigour for community engagement, funding and capacity building.

We see the database providing numerous benefits going forward, including but not limited to:

1. **Commonalities**: Managers and planners at a regional and state level will be able to identify, in real time, common behaviours being selected and ranked for various weeds across the state. With hundreds of weeds in thousands of unique situations interacting with hundreds of possible behaviours, finding commonalities from the millions of permutations can only be achieved algorithmically; and the database is currently generating the data required for this algorithmic filtering and analysis. The end game is to provide data on what behaviours are achieving maximum effect across *multiple* weeds in widely varied situations. These commonalities offers the promise of large

costs savings and efficiencies over time by promoting behaviours that generate maximum 'bang for our buck'.

2. **Smarter capacity building**: If 'behaviour x and its associated strategies' is shown to be highly effective in a large variety of situations, then the regions and the state can proceed with capacity building for that behaviour, reassured that their time, funding and other resources are being directed by empirical data, not hunches and gut calls.
3. **More effective community engagement**: The database will ultimately enable unprecedented access to the experience, expertise and data accumulated by peers across the state. A regional coordinator or weeds officer looking to engage the community around a set of target behaviours will use the tool to find barriers research conducted elsewhere in the state for those same behaviours, along with any strategies developed and the results of any piloting. Armed with relevant research about their audience behaviours and best practice strategies for engaging with the audience, community engagement practitioners will become increasingly focused on outcomes (actual behaviour change) as opposed to outputs (numbers of brochures printed, television advertisements aired, etc.).
4. **Institutional memory:** The database and various tools associated with it will capture and grow institutional expertise over time, benefiting new and experienced staff alike.

## National and international interest in the tool

No state or national weeds organisation anywhere in the world has attempted to build a CBSM / behaviour change framework of this scale and complexity. As a result, our work has attracted considerable interest nationally and internationally.

As part of our ongoing dialogue with stakeholders, we have presented on and discussed the database with numerous organisations including the New Zealand Ministry for Primary Industries, the Queensland Department of Agriculture and Fisheries and the South Australian Department of Environment, Water and Natural Resources.

## A work in progress

Although the database is evolving rapidly, the following screenshots provide a snapshot of the tool at a certain point in time.

Image 1: Selecting target behaviours to address a blackberry infestation

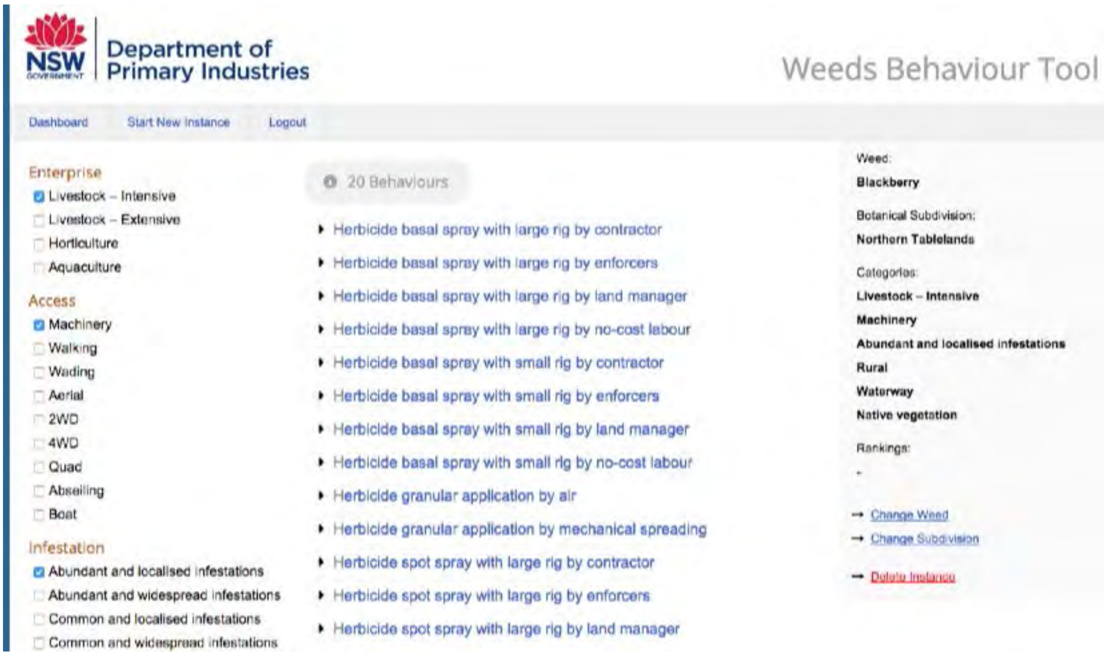



Image 2: Analysing and ranking behaviours according to CBSM metrics

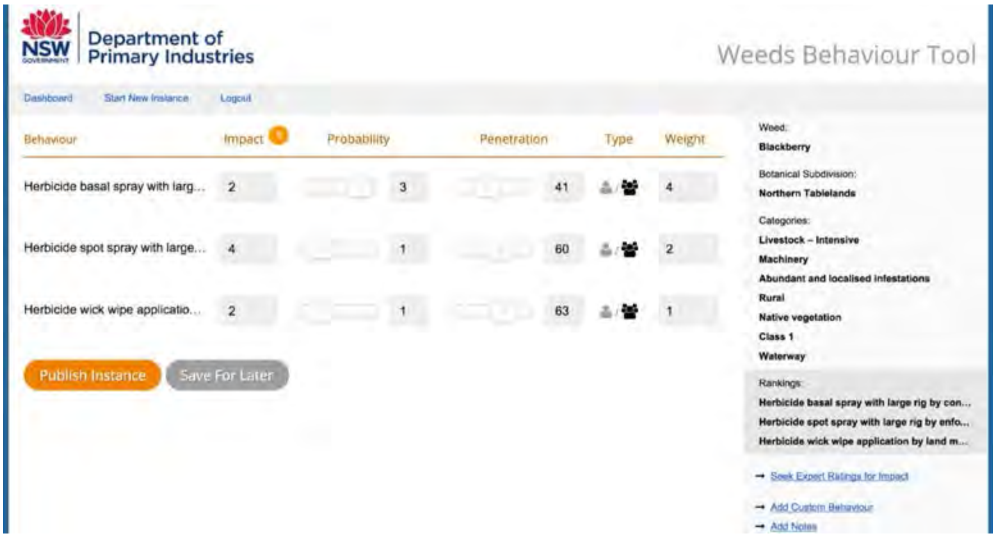



Image 3: The user dashboard, where 'instances' can be created and re-edited

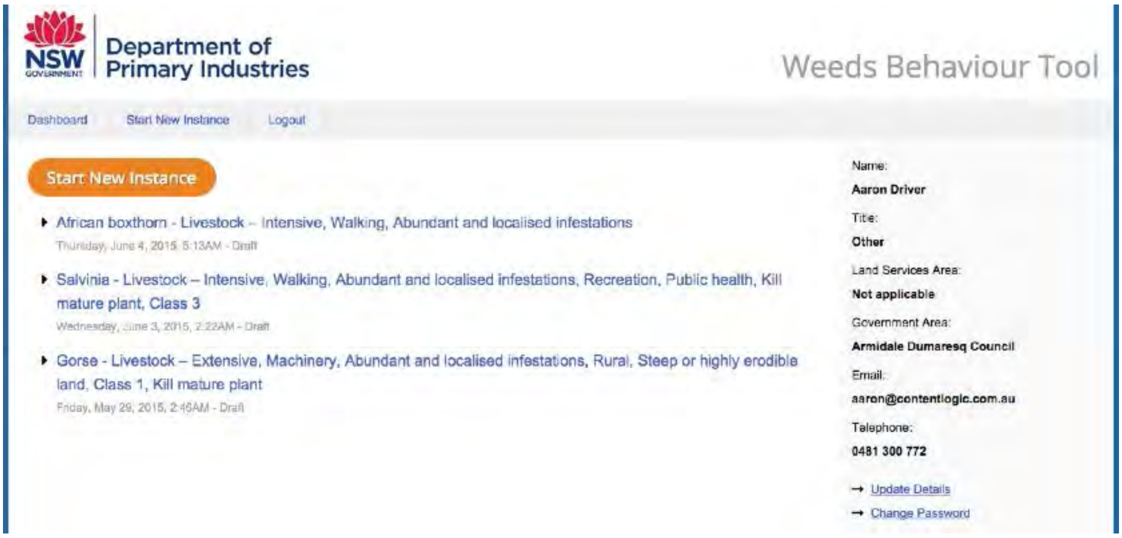
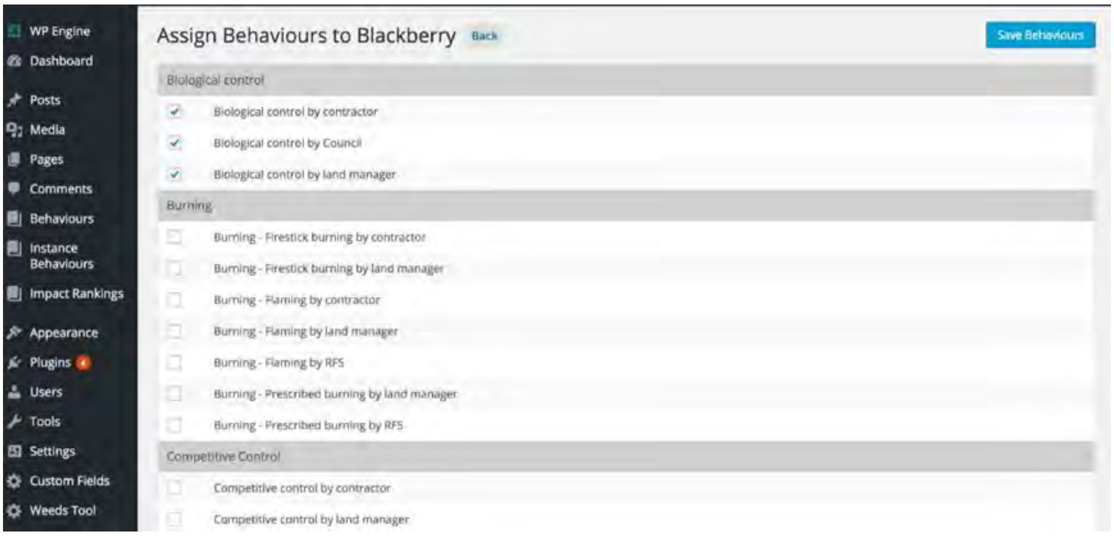



Image 4: Assigning behaviours in the backend of the database




ACKNOWLEDGEMENTS

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NEW SOUTH WALES WEEDS ACTION PROGRAM

Activities supported by funds from the NSW Weeds Action Program.

Living with weeds, learning about weeds: Weed management, values, and attitudes among lifestyle-oriented rural landholders

Weeds are a something of a hot topic in social science. In part this arises from debates, largely within ecological sciences, about how we are to live on a planet dominated by human activity and where the environmental 'baselines' that have for so long underpinned environmental thinking and policy can, arguably, no longer be taken for granted. Such debates pit concepts such as 'novel ecosystems' and acceptance of irreversible environmental change against long standing ideas of environmental 'purity' and a strong impulse to roll back change and restore ecosystems to a favoured past state. These debates resonate in perhaps contradictory ways within weed management policy and practice. Relatedly, the strong social science interest in weeds also arises from the way in which weeds provide a window into environmental attitudes and values and into the forms of 'nature' that people prioritise and wish to see evident in the landscapes around them; reproduced or nurtured through the work and activities of themselves or others. What is clear, however, that, with notable exceptions, there has been remarkably little social science research into weeds policy and management. Ecological and agronomic research abounds, and even socio-ecological research that examines weeds abundance with respect to parameters such as distance to roads, is not entirely uncommon. But the questions implicit above – how, and on what terms, do we live weeds – are largely open, at least in terms of systematic investigation.

In this paper, I present results from recent research with rural landholders in south-eastern NSW. The aim of the research was to investigate weed management in areas with high proportions of life-style oriented landholders, aka 'tree changers'. Such areas and the significant proportions of lifestylers are of interest as the ideals and activities of such landholders are reshaping landscapes with potential environmental benefits. I will draw on both survey and interview data with the aim of providing insights into how landholders, with a focus on lifestylers, are 'living with weeds' – the choices about weed management that they make, the compromises they accept, their sources of advice and means of learning about weeds, their motivations, and what keeps them going, or slows them down. If results from ongoing botanical surveys are available, I will also discuss the outcomes of environmental weed management by lifestylers and any associations of such outcomes with landholder characteristics. From more limited data, I also aim to compare lifestylers to farmers on selected weed management issues.

What ideals about future landscapes are embodied in weed management decisions? How are decisions about weeds made?

For weeds, the question then, is how do we live with weeds? Do we seek to eradicate them? Do we merely seek to keep them under some kind of control?

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**Pesticide Regulation –weed-related perspectives on use, storage and disposal in South-eastern NSW**

The use of pesticides within NSW is subject to a range of NSW and Commonwealth Government controls. The Australian Pesticides and Veterinary Medicines Authority (APVMA) is the Australian Government authority which regulates the import, manufacture, registration, packaging, labelling, distribution and retail sale of pesticides in Australia. The APVMA regulates pesticides up to and including the point of retail sale. After the point of sale, the NSW Environment Protection Authority (EPA) regulates the use of all pesticides, including pesticides used on public lands, in agriculture and on domestic and commercial premises through the provisions of the *Pesticides Act 1999* (the Act) and *Pesticides Regulation 2009* (the Regulation) in NSW. Regulation traditionally focuses on investigation of complaints regarding the misuse of or impact from the use of pesticides and campaigns to check compliance with certification, record keeping and storage requirements. The most common investigations involve allegations of over-spray or spray-drift, often in relation to weather conditions and subsequent environmental or property damage. Determining and achieving compliance with label requirements is a problem that is commonly encountered during investigations. Education is still required on the appropriate storage of pesticides and disposal options for out of date and non-registered products. The paper uses case examples to highlight some common regulatory themes and discusses some challenges of pesticide regulation.