20th

Weeds

NSW CONFERENCE

city country coast

*putting the **we** in **we**eds*

PROCEEDINGS

Editors: Kim Hignell, Hanwen Wu, Michael Walsh

26 - 29 August 2019

Newcastle, NSW

The Weed Society of New South Wales

Enquiries should be addressed to the secretary of The Weed Society of New South Wales Inc.

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The Weed Society of New South Wales

CONFERENCE HOST CITY

City of Newcastle

The City of Newcastle was the proud host city of the 20th NSW Biennial Weeds Conference in 2019. The City of Newcastle invited delegates and presenters to participate in the theme of the conference 'City Country Coast – putting the WE in weeds' and for them to enjoy the surroundings, while visiting this beautiful city.

This conference aimed to provide delegates from around NSW with opportunities to build or strengthen networks, partnerships, and to raise awareness of challenges and opportunities for those working in the field of weeds.

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CONFERENCE PROGRAM

MONDAY 26TH AUGUST 2019

CONFERENCE PROGRAM

3:00	**Conference Registrations Open** Upstairs Foyer at Newcastle Exhibition & Convention Centre (NEX) 309 King Street Newcastle West
3:00	**Intro to Newcastle Walking Tour** – Departing from NEX
3:30	**Rapidmap Users Meeting** – Vivid Room, NEX
5:30 - 7:30	**Welcome Reception** The Avenue – 1st Floor, NEX

TUESDAY 27TH AUGUST 2019

8:30	**Opening Session**		
Chair	Brett Miners – LLS & State Weeds Committee		
8:35	Welcome to Country		
8:40	Welcome to the Conference - **Cr Declan Clausen,** Deputy Lord Mayor, City of Newcastle		
8:45	Opening of the Conference – **Mr Michael Johnsen MP,** Parliamentary Secretary for Agriculture		
9:00	**Keynote Speaker – Dr Kristine French** – University of Wollongong		
9:30	Plenary Speaker – **Dr Andrew McConnachie** – DPI Orange		
10:00	**Morning Tea and Trade Display**		
10:25	**Mid-Morning Session**		
	Concurrent Sessions		
Room	The Extra	The Arena	The Vivid
Theme	**Biocontrol**	**We In Weeds**	**Risk Management**
Chair	Terry Bignell	Ian Turnbull	Wendy Bushell
10:30	**Dr Louise Morin** Major biological control initiative for environmental weeds in NSW: update and future investments	**Doug Campbell & Maria Edmonds** Hunter - Putting the We in Weeds	**Rod Ensbey** Managing Cross Border Priority Weeds
10:50	**Troy Brown** NSW Weed Biological Control Taskforce – collaborating to maintain a functional biocontrol agent delivery pipeline	**Stuart Henry** Sydney Flower Markets: A Unique Weed in a Sea of Beauty	**Sam Porter** Operationalising the NSW Weed Risk Management system – A resource prioritisation & allocation model
11:10	**Jenny Schabel** Investigating *Opuntia aurantiaca* (tiger pear) infestations in Greater Sydney and observa-tions following cochineal biocontrol release	**Garry Herbert** Illegal Release of Weeds	**Dr Matt Sheehan** Weed Risk Management – what it can do for you
11:30	**Dr Daniella Egli** Update on native range studies in South Africa for the biological control of fireweed	**Dr Rajendra Shilpakar** Sydney WeedAPP - an example of web GIS to enhance regional scale collaborative weed management	**Philip Blackmore** Successes and Pitfalls a review of four historical weed incursions with lessons for the future
11:50	**Dr Ben Gooden** Wandering trad (*Tradescantia fluminensis*): impacts on native vegetation and prospects for fungal biocontrol	**Dr Matt Sheehan** Making the most of mandatory documents	**Michael Michelmore** Weed risk management for district & property programs and to determine biosecurity duty
12:15	Lunch and Trade Display		
12:55	**Mid-Afternoon Session**		
Chair	Jordan Skinner		
1:00	Plenary Speaker – **Paul Fong** - Australian Centre for Financial and Environmental Compliance		
1:30	Plenary Speaker – **Dr Carmen Castor** - **CSER** - University of Newcastle		
1:50	Gold Sponsor – **Brett Miner** - Hunter Local Land Services		
1:55	Hunter Regional Weeds – **Lorna Adlem** - Stop Weeds at the Gate		
2:10	Afternoon Tea and Trade Display		

CONFERENCE PROGRAM cont.

12:55	**Mid-Afternoon Session**	
Chair	Jordan Skinner	
1:00	Plenary Speaker – **Paul Fong** - Australian Centre for Financial and Environmental Compliance	
1:30	Plenary Speaker – **Dr Carmen Castor** - **CSER** - University of Newcastle	
1:50	Gold Sponsor – **Brett Miner** - Hunter Local Land Services	
1:55	Hunter Regional Weeds – **Lorna Adlem** - Stop Weeds at the Gate	
2:10	Afternoon Tea and Trade Display	
2:35	**Afternoon Session**	
	Concurrent Sessions	
Room	The Extra	The Vivid
Theme	**Weed Management**	**Innovative Weed Control**
Chair	Maria Edmonds	Dean Semit
2:40	**Dr Nicholas Gill** Track users' weed hygiene practices and attitudes in Kosciuszko National Park	**Jyri Kaapro** Indaziflam, a new herbicide for industrial vegetation management
3:00	**Matthew McGrath** Weed Hygiene Station	**Jeremy Winer** Holistic weed control practice for urban storm water catchments.Global trends, methods, limitations and cost benefits
3:20	**Craig Perring** The Nursery & Garden Industry	**Tony Cook** Preventing Woody Weed Spread by Stopping Seed Set
3:40	**Julia Rayment** Invasion of Exotic Perennial Grasses into Threatened Ecological Communities in NSW	**Amali Welgama** How to Control Herbicide Resistant Weeds with Innovative Herbicide Strategies?
4:00	Sessions End - **Additional Activities Commence**	
	Innovation Workshop	**Meeting**
4:10 - 5:00	**DNA Diagnostics – LAMP lighting the way** Learn about the portable tool kit, that has the power to identify the DNA of invasive weeds when they first appear in the landscape.	**Weed Officers Association** Annual General Meeting All members welcome
6:30	**Social Networking Night** Honeysuckle Hotel, Lot 31 Lee Wharf C, Honeysuckle Drive, Newcastle	

WEDNESDAY 28TH AUGUST 2019

8:25	**Morning Session in The Arena**		
Chair	Kim Hignell		
8:30	**Keynote Speaker – Sarah Richmond** – Griffith University		
9:00	**Plenary Speaker – Dr Elissa van Oosterhout** – DPI Grafton		
9:30	**Concurrent Sessions**		
Room	The Extra	The Arena	The Vivid
Theme	**Weed Management**	**Alternative Weed Management**	**Peri Urban**
Chair	Rod Ensby	Lorna Adlem	Eric Pasenow
9:30	**Mathew Warren** Invasive Pests Control Scheme: a new approach to managing pests at the local government level	**Den Barber** Yellomundee Firesticks - Aboriginal Cultural Burning of weeds in Shaws Creek Aboriginal Place	**Philip Hansen** Town vs Country - the Biosecurity Act 2015 in conflict
9:50	**Charles Mifsud & Terry Inkson** Frogbit (*Limnobium laevigatum*) detection and eradication in New South Wales	**Dr John Van Der Kallen** Novel Technique for Weed Management: Ecopigs	**Lynette McLeod** Weed management activities by peri-urban landholders: A statewide perspective
10:10	**Matt Bell** A model for effective tenure-blind aquatic weed control	**Hillary Cherry** Adaptative management and accelerated commitment facilitate NSW Hawkweed Eradication	**Claire Lock** A Century of Centaurea: using historic herbarium and archival records to trace the origin and movement of black knapweed in New South Wales
10:30	Morning Tea and Trade Display		

Staggered start from 10:50 in Foyer	Field Trip	Field Trip	Field Trip	Field Trip
	Hunter Tour **Hunter Valley** Boarding 10:50	**Coast Tour** **Port Stephens** Boarding 10:55	**Country Tour** **Maitland** Boarding 11:00	**City Tour** **Newcastle & Lake Mac** Boarding 11:05
4:00	Field Trips Return			
6:00 - 11:00	**Conference Dinner** The Arena – NEX			

CONFERENCE PROGRAM cont.

THURSDAY 29TH AUGUST 2019

8:00 – 9:30	Breakfast BBQ The Station – Cnr Scott & Watt Sts Newcastle	
10:00	Morning Tea and Trade Display	
10:15	**Mid-Morning Session**	
Room	The Arena	The Extra
Theme	We in Weeds - Community Engagement	Innovations & Technology
Chair	Terry Inkson	Doug Campbell
10:20	**Jodie Bartlett-Taylor** Soft skills doing the hard work	**Victor Galea and Peter Riikonen** An environmentally sustainable way to control trees and shrubs with encapsulated dry herbicides.
10:40	**Wendy Gibney** Increasing community engagement in green cestrum control on rural and urban properties in Maitland LGA	**Philip Milling** UAVs - Another tool for the urban and rural weed controller
11:00	**Kerrie Guppy** Working collaboratively with community groups opposed to herbicides	**Dr David Gopurenko** Portable DNA diagnostics for onsite identification of Chilean needle grass and serrated tussock
11:20	**Jo-anna Skewes** Community Approach to Cactus Control	**Lynette Terrett** We in Weeds: Using Smart technologies for NSW BIS
11:40	**Mathew Savage** Hudson Pear (*Cylindropuntia pallida*) management: An integrated approach underpinned by the community	**Daniel Firth** Advanced Remote Rewind Hose Reel interfaces can reduce chemical waste, improve operator safety and efficiency
12:00	LUNCH and Trade Display	
12:55	**Mid-Afternoon Session**	
Room	The Arena	The Extra
Theme	Weed Management	Innovative Weed Control
Chair	Brad Shultz	Leigh Ernst
1:00	**Pauline Sykes** Martindale Creek Catchment Landcare	**Wendy Bushell** Control of *Gleditsia triacanthos* in the Wallamba River
1:20	**Bob Doyle** Gresford District Landcare – Riparian Weeds	**Paul Wynn** Turning Weeds Brown with Green Science
1:40	**Sita Tiwari** Abundance and distribution of weeds in seed banks of vegetable fields of Australia	**Warren Braybon** Aquatic Surfactant for Addition to Products approved for use in Aquatic Situations
2:00	**Carol Harris** Management of *Nassella neesiana* using essential oil products	**Tony Cook** Blue Heliotrope herbicide research summary
2:20	**Kim Hignell** Stopping the invasion of Chinese Knotweed - A herbicide solution	**Alana Trott** Investigating the efficacy of Pine oil on natural area weeds
2:40	Afternoon Tea and Trade Display	
3:00	**Afternoon Session**	
Chair	Birgitte Verbeek	
3:00	**The Great Debate Topic: Tenure neutral control successfully puts the We in Weeds - Adjudicator Pete Turner** Team A: The Affirmative	Team B: The Negative
4:00	Conference Summary – **Sid Lyle**	
4:15	Closing of Conference – **Dean Semit**	
4:20	Conference Closes	

Hunter
No Space for
Weeeeeds

KEYNOTE SPEAKERS

DR KRISTINE FRENCH

Professor with School of Biological Sciences, University of Wollongong, NSW

Kris has worked on environmental weeds for over 25 years, investigating the mechanisms and effects of invasion on natural communities. While there has been an initial focus on coastal weeds, the work is expanding to include a range of species in both agricultural and natural landscapes.

SARAH RICHMOND

Project Manager, Biodiversity and Climate Change Virtual Laboratory,
Griffith University Queensland

Sarah currently coordinates the development and delivery of the Ecoscience DEVL/RDC Project (ecocloud Platform), as well as the Biodiversity and Climate Change Virtual Laboratory (BCCVL). With a research background in ecology, Sarah has a special interest in enhancing environmental research through digital solutions by building integrated, user-friendly and supported cloud platforms for accessing data and analysis workflows

CONTENTS

OPERATIONALISING THE NSW WEED RISK MANAGEMENT SYSTEM – A RESOURCE PRIORITISATION & ALLOCATION MODEL

Jordan Skinner[1] and Samuel Porter[2]

[1]Natural Resource Team Leader, Port Stephens Council, Raymond Terrace, New South Wales 2324, Australia. Email: jordan.skinner@portstephens.nsw.gov.au

[2]Invasive Species Planner, Port Stephens Council, Raymond Terrace, New South Wales 2324, Australia. Email: samuel.porter@portstephens.nsw.gov.au

ABSTRACT

With over 2700 naturalised plants in Australia, there are always going to be more weeds to manage than resources available to do so. Organisations the world over have worked to develop assessment and prioritisation processes to manage this. In Australia, weed risk assessment and management systems have been a focus for the last 20 years, from pre-border risk and quarantine work designed to protect the country from new incursions, to post-border management post-arrival. The NSW Weed Risk Management (WRM) System was developed by the NSW Department of Primary Industry to prioritise weed management objectives and actions, particularly through legislation. The NSW WRM system is consistent with the Australian Standard for National Post-Border Weed Risk Management Protocol in that it considers a series of questions on the biology and control of a species, categorising the species and assigning a management goal based on weed risk and feasibility of control. We have used the NSW WRM system to produce a prioritised program of works, essentially operationalising or implementing the NSW WRM goals on-ground. The model works equally well when applied to resource allocation at organisational, regional, or state scale control programs, or as a decision support tool for the allocation of grant funding. Our model produces a prioritised list of weeds, considers the available resources and the management goals, allocates expenditure, and most importantly, limits management time before moving on to the next species, ensuring goals are met for the highest priority weeds, and time is not wasted on lower priority species.

Keywords: Resource Prioritisation, Weed Risk Management

INTRODUCTION

Assessments of weed impact and weed risk are common where weeds are regulated (Auld *et al.*, 2012). The NSW Weed Risk Management (WRM) system has been developed by the NSW Department of Primary Industry (DPI) to prioritise weed management objectives and actions, particularly through legislation (Johnson 2009). The NSW WRM system is consistent with the Australian Standard for National Post-Border Weed Risk Management Protocol (Anon. 2006) in that it considers a series of questions on the biology and control of a species, categorising the species and assigning a management goal based on scores for weed risk and feasibility of control. Along with the NSW WRM system, other Australian state, industry, and some international systems (Weiss & McLaren, 2002; Stone *et al.*, 2008; Setterfield *et al.*, 2010; Auld 2012), have been modelled on the South Australian system developed by Virtue (2010). The outcome of these risk management systems is to provide a management goal or category for each species via the 5 x 5 strategic weed management matrix, e.g. eradicate, destroy infestations or contain spread, to name just a few from NSW WRM. But when do we stop "destroying an infestation" or "containing spread"? What about that weed that you've been treating for 30 years; how much time *should* you be spending on it? Deciding how to allocate limited funding to deal with weed problems is an increasingly important challenge (Wainger & King, 2001).

Many organisations and landholders commit significant resources towards weed management across a diverse array of weed species (Downey et al., 2010a; Sinden et al., 2004). A key principle to efficient and effective weed management is early intervention (NRM, 2007; Davis, 2009; Dodd, 2016). In NSW, the NSW DPI encourages the management of weeds in this manner by funding Local Government through its Weed Action Program (WAP); the goals of which relate to prevention and early intervention as per the NSW Biosecurity Strategy 2013-21 (DPI, 2013). Under the NSW Biosecurity Act 2015, a shared responsibility for risk mitigation is legislated, where by all land holders and any person dealing with biosecurity matter must do what is reasonably practical to prevent, eliminate or minimise biosecurity risks. With the State funded WAP focusing on prevention and early intervention, weed managers are left to comply with the legislation in minimising biosecurity risk by controlling priority weeds on land in their care and control. After considering individual species weed risk management assessment performed at a state scale, risk-based investment in biosecurity programs have generally been implemented at a regional scale through Regional Strategic Weed Management Plans (LLS, 2017). These plans identify priority weeds and assign management goals, but with state funding going towards prevention and early detection of new weeds, landholders are left to their own devices to control more widespread weeds if they wish to comply with the legislation. Considering the benefits of a risk-based approach to managing wide spread weeds (Skinner et al., 2000; Downey et al., 2010b; Forsyth et al., 2012), and with risk assessments already completed regionally, we produce a model that determines resource allocation based on these assessments. Our model bridges the gap between the weed risk management category assigned by the NSW WRM and an on-ground operational program, to produce a true resource allocation prioritisation tool, or Weed Risk Assessment Program Prioritisation System (WRAPPS). WRAPPS can be used at a variety of scales: state; regional; local; or for site scale programs; can be used to allocate time or money; works equally as well when implementing inspection or treatment programs, or allocating time to both in a combined program; and can be used as a decision support tool for the allocation grant funds. The mathematical model described below has been designed as an add-on to the NSW WRM system and requires the completion of only two additional questions to produce a full operational plan for weed managers, essentially outlining the investment required to discharge Biosecurity Duty under the Biosecurity Act 2015.

Method

We use the NSW WRM system, via a series of questions relating to distribution, biology and control, to establish a score for weed risk (*WRS*) and feasibility of control (*CFS*) for all land uses potentially affected by a given weed species. *WRS* and *CFS* are then placed in a matrix to give the assessor a management goal (the goal).

Building on these existing NSW WRM assessments we included a question to estimate the time required to achieve the management goal for each individual species (t), and another on the total available program resources (time) (T). The total available program resources T may include the proportion of staff time available to manage the weed (amongst other duties) and/or time that can be purchased from contractors and/or donated by volunteers.

The scores for the *WRS* and *CFS* are counterintuitive to each other (figure 1); the higher the *WRS*, the higher the weed risk, whilst the higher the *CFS*, the easier the weed is to control. By adapting this logic we sub-tracted from *CFS* *WRS* to pro-duce a total score used to rank (*R*) all weeds. This rank was used to order weeds with the high-est *R* being the first priori-ty.

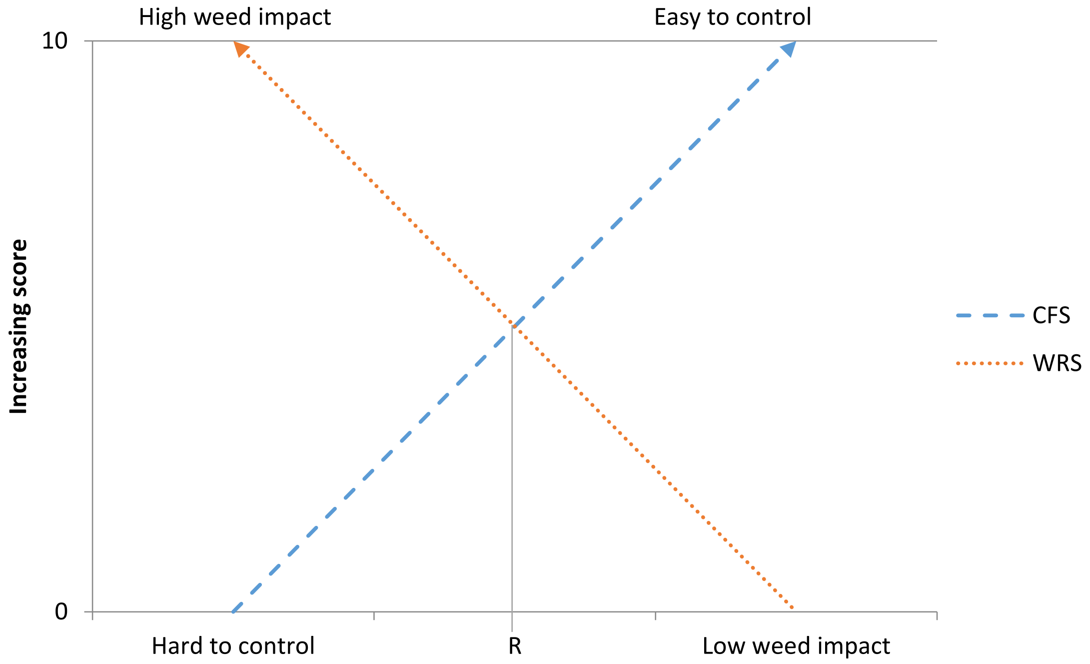

Figure 1. Counter intuitive score of *WRS-CFS* to determine *R*

$$WRS - CFS = R$$

Then by dividing each species *R* by the sum of all species, *R* we produced a prioritised resource proportion for each species (*P*);

$$R / (\Sigma R) = P$$

It is possible that the score for *CFS>WFS* results in a negative *R* (rank). If carried through to the prioritised resource proportion *P*, this would result in a negative score (the equivalent to adding more weeds at (*a*) resource level input stage). To overcome this, any negative rank (*R*) was corrected to a zero and the result was to "do nothing" about these weeds.

The (*P*) value of (*T*) is presented as (*p*) and is simply;

$$p = P \times T$$

The sum of all *T* (times required to achieve a management goal) will generally exceed the total available program time (*T*). This is because there are generally more weeds to treat than time available, hence the need to ensure time is spent on all top priority weeds first. Given that all WRM goals are not often achievable in the given *T*, a limiting factor (*a*) is used to allocate resources appropriately. This ensures that the top priority weeds are treated first but only to a point whereby the remainder of the weeds also receive an allocation according to *P* (the total resource proportion). The value of *a* is calculated by using either the lesser of the total resource proportion of that weed (*p*), or an estimate of the time to achieve the WRM management goal (*t*);

$$\text{If } p < t$$

$$a = p$$

$$\textit{or alternatively}$$

$$a = t$$

The model works such that if the WRM or management goal for the highest priority weed is achieved and the proportion of the program time available (*T*) is not fully allocated, the result will be surplus time available (*S*). We calculate (*S*) by subtracting the sum of all resource allocation (*a*) from the total time resource available (*T*).

$$(S = T - \Sigma a)$$

To ensure that the highest priority weeds are managed first, any surplus is reallocated to the model as allocation surplus (s). To calculate (s) and prevent a circular reference of (S) a formatting step is used to determine the original change of surplus (c_0) of the first priority weed and the following change of surplus for the remaining weeds (c_0+1). This then returns the amount of surplus available to be used by each weed species

$$\text{If } a < t$$

$$c_o = S - (t - a)$$

$$\text{or alternatively}$$

$$c_0 = S$$

$$\text{and}$$

$$c_1 = c_0 - (t - a)$$

$$\text{or alternatively}$$

$$c_1 = 0$$

(s) is then determined by adding any available (S) to (a) to the maximum amount of (t) to the next highest priority weed, to provide the best chance to achieve the WRM or management goal for that species. The process follows:

If $S \leq 0$

(i.e. there is no surplus time)

then

$s = a$

Alternatively,

$s_1 = a + S$ to the maximum of t

unless $a > t$

then

$s = a$ and

$s_{1+1} = a + c_1$ to the maximum of t

If the estimated time to achieve the WRM or management goal is met, the reallocation is then added to the next priority weed species to achieve its WRM or management goal. This re-investment of time continues down the list of species until it is exhausted. This means that the highest priority weeds have a better chance of being managed fully to the goals set by the WRM system.

If an Invasive Species Manager is fortunate enough to have either only a small scale infestation/s or the land manager is resource (time) rich, there may be more time available than weeds to be managed. To ensure the extra time available stays within the parameters of the model and is allocated accordingly, the remaining balance (*B*) left after the surplus is then redistributed into an allocation plus balance (*A*) as per the original priority proportions, as:

$$A = s + (B \text{ x } P)$$

where *A* is the final amount of time allocation that is needed to achieve each species WRM or management goal. An example is provided below to demonstrate the workings of the model.

RESULTS

T= 500 B= 0.00 S= 245.52

Weed Name	WRS	CFS	Outcome	t	R [WRS-CFS]	P [R/ΣR] {note; if RS<0= 0})	p [P*T]	a [=P x t if P x T>t or else a=t]	c [if a<t =S-(t-a) else =a]	s [if a<t =a+S to meet t if S is available else =a]	A [=s+(BxP)]
Dolichandra unguis-cati	140.35	1.03	Destroy infestations	20.00	139.32	0.40	198.71	20.00	245.52	20.00	20.00
Bryophyllum spp.	98.25	8.84	Contain spread	120.00	89.41	0.26	127.52	120.00	245.52	120.00	120.00
Rubus spp.	124.91	67.55	Manage weed	32.00	57.36	0.16	81.82	32.00	245.52	32.00	32.00
Cestrum parqui	68.16	22.25	Protect priority sites	56.00	45.90	0.13	65.47	56.00	245.52	56.00	56.00
Ludwigia longifolia	109.47	90.91	Manage weed	430.00	18.56	0.05	26.48	26.48	0.00	272.00	272.00

A hypothetical example where an organisation has 500 hrs to commit towards its weed management program (*T* = 500) is shown (Table 1). There are 5 weeds from this area's Regional Strategic Weed Management Plan that have known infestations in the area (column 1). The Invasive Species Manager and their team have risk assessed the 5 weeds using the NSW WRM system, and the WRS and CFS scores are shown (columns 2 and 3), as is the NSW WRM management goal (column 4). Column 5 or t is the time the Invasive Species Manager and their team estimate it will take them to achieve the WRM goal. Column 6 or *R* is the rank score given to each species by the model and is the column used to order the rows from highest to lowest. Column 7 or *P* is the proportional allocation the model gives each weed. This is proportionate to the rank, while column 8 or *p* is the weeds proportionate rank of the total time available (*T*).

Column 9 or a takes the smaller value of either the proportion *P* of the total resource *T* (being *p*), or the time estimated to reach the goal *t.* For example, *Dolichandra unguis-cati* is this area's top priority weed after the WRM assessment process and the first calculation of the model ranked it at 139.32. As such it receives the highest portion *P* of the program at 0.40 or 40% (*T* = 500) so 40% of this time is 200 hours, if this is needed). However, this weed has a limited distribution and the team have estimated it will require just 20 hours of their time to achieve the goal.

The next calculation in column 10 (*c*) allows for formatting of column 11(*s*). This step essentially identifies where there is a need to use the surplus to meet the WRM goal and the availability of time usable as surplus. In Table 1 the first four weeds met the requirements of *t,* thus remain the same *S* for the highest priority weed or as the available surplus as that of the weed above. *Ludwigi longifolia* does however use all the surplus therefor depleting *c* to zero.

Column 11 is the addition of available *S* (or *c*) to *a*, to the amount of *t*. Again for the first four weeds where the objective time of *t* are met, nothing changes. However the last weed (*Ludwigi longifolia a* = 26.48h) does not meet t (430h), and so uses all available surplus to increase *a* to *t* being s (272h).

The last column (*A*) is used in conjunction with (*B*) for when there is the scenario that there is more time available then weeds to be treated ($B = T > \Sigma\ a$). *B* is distributed back into the system for non-direct management (ie; education, broader inspection programs etc) at the same proportional rate as *P*.

Table 1. Hypothetical WRAPPS model example

DISCUSSION, ASSUMPTIONS, NOTES, AND LIMITATIONS

Failure to correctly allocate often scarce resources available to invasive species management results in compounding impacts of weed invasions (Davis, 2009). The WRAPPS model was originally conceived to address the common miss-allocation of resources towards long running programs on widespread weeds. There are many reasons for failures to correctly allocate resources, these include: long running programs that are engrained in an organisations makeup; organisational politics; misunderstandings of weed risk; or even inaccurate WRM assessments. The following are some discussion points arising out of WRAPPS modelling, some notes on its use, and some of models limitations.

WRM accuracy

The WRM assessments used to initiate the model need to be accurate. Upon reviewing the Hunter WRM assessments as updated for the Hunter Regional Strategic Weed Management Plan and entering them into WRAPPS, it was evident that some widespread or low impact weeds appeared higher in the model than they perhaps should have. We found that often the WRM question about potential distribution was misinterpreted. This question in particular has significant ramification for the overall weed risk rank as it has one of the highest weightings in the WRM model.

Land use scoring & averaging

Despite many weeds having an impact (often differing) on more than one land use, and WRAPPS being designed to accommodate this, completed NSW WRM's rarely take into consideration all land uses potentially affected by the relative weed. Instead, WRM assessments are almost always completed against the most impacted or at risk land use, and management of the weed then inferred to other land uses. This is not the intention of the NSW WRM system, but the reality of how it is most often used. It is understood that there are complexities around land use values in weed risk management and assessment systems as suggested by Johnson (2009), and Virtue (2010): not to mention earlier examinations, specifically Vranjiv et al. (2000) and Wainger and King (2001) and in more general texts, e.g. Sindel (2000) and Groves et al. (2001). We do not attempt to resolve these issues here, but in WRAPPS we assess each species against all land uses that it may affect, providing a complete assessment before averaging each weed score from all land uses, to provide a single allocation for each species. Averaging the scores gives the invasive species manager flexibility. For example, St. John's wort is a risk to agriculture; however it is not recorded on agricultural land in a certain shire. It is however found in adjoining intensive use areas. In this situation the impact to Intensive Use land is very low, but the potential to spread to adjoining land where the impact is greater is high. The Invasive Species Manager may fail to prioritise control of the weed in Intensive Use land because its impact is low creating a risk to Agriculture land uses. Averaging the scores allows an invasive species manager to manipulate resource allocation in the most appropriate way. Assessing weeds against all land uses they impact upon and then averaging the scores provides an indication of how much time to spend on the weed in total; without necessarily dictating which land use to spend it on. This allows a manager to target a weed that poses a risk to a certain land use despite its absences from that land use, based on the impact and distribution on surrounding land uses.

The alternative would be to allocate a certain proportion of the total resource pool to each land use. This would mean that all species that impact that specific land use were allocated a proportion of only that land uses resources in the WRAPPS. For example, if urban land uses were allocated 20% of the total resource pool *T* each weed impacting that land use could be allocated management resources only from that from urban land use resource pool (20% of *T*). Whilst implementing the system for each weed on each land use would solve the problem outlined in the paragraph above, it does provide further complexity to the system.

Water as a Land Use

Upon reviewing NSW WRM's as used for the Hunter Regional Strategic Weed Management Plan, we found water weeds to be on the lower side of the impact scoring. The trend appears to be occurring due to water weeds being undervalued by the distribution questions in the WRM assessments because of the smaller impacts and potential distribution areas of water weeds. We question the inclusion of water as a land use, and suggest the impacts and risks of water weeds are intrinsically linked to the other land uses in which that water exists. Water is a component of the other land uses, and the risk and impact of weeds therein could be included to the inherent land use. For example, the impact of water weeds in an agricultural land use might be access for human or livestock, whereas the impact to conservation land is loss of biodiversity. Water areas exists in nearly all other land uses included in NSW WRM, and making these a point of difference from the other land uses produces an impediment.

Ranking Equation

The equation we use to produce a Ranking Score by subtracting the WRM Feasibility of control score from Risk score ($WRS - CFS = R$) is the first equation in the model, and was conceived due to its logical nature. As seen in figure 1 the counter intuitive scores when subtracted produce seemingly correct results.

We acknowledge that a negative *R* (rank) and subsequent allocation to a “do nothing” management outcome can produce partially perverse management outcome for some weeds. Negative ranks would be expected for all weeds allocated to the following management outcomes from the 5 x 5 strategic weed management matrix in the NSW WRM system (Johnson 2009), that is: those with negligible weed risk scores ($WRS < 13$); many of those with low weed risk scores ($WRS = 13 - 38$); and even some with medium ($WRS > 38$) and high ($WRS > 100$) weed risk scores. Fortunately, the management matrix allocates almost all species with negligible and low *WRS* to “Limited Action” or “Monitor” management activities. Although a limited number of weeds with either a medium or high *WRS* also have a negative (*R*) rank ($CFS > WRS$), these weeds generally have lower order management outcomes and are managed as resources allow.

Estimating time to achieve goals

After completing each of the WRM's to be used in WRAPPS, the estimation of time required to meet WRM goals (*t*) needs to be carefully considered. This estimation improves with experience and knowledge of each infestation, and we found that it becomes refined over time in using WRAPPS.

CONCLUSION

When applied in NSW to WRM's undertaken by Regional Weeds Committees, and with the added input of the available resources, WRAPPS can provide a prioritised allocation of time required to control priority weeds according your Regional Strategic Weed Management Plan, operationalising Weed Risk Management. It fits perfectly in parallel to the WAP, and we consider it could be implemented as well to an entire Region or State as it has been at organisational level. Additionally, by substituting the time estimated to achieve the goal (*t)* with an estimated cost to achieve each goal, and substituting the total time resource (*T)* with a total budget, WRAPPS can easily aid in identifying the budget required to achieve weed management goals, facilitating factual and clear budget requirement communications to upper management, an aspect or use of the model that should not be underestimated.

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SUCCESSES AND PITFALLS – A REVIEW OF FOUR HISTORICAL WEED INCURSIONS IN NSW

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INTRODUCTION

This paper reviews four historical weed incursions to New South Wales (NSW), the short and long term responses to those incursions and the outcomes from those responses. The weeds are:

Fireweed (*Senecio madagascariensis*) Poir.

Serrated Tussock (*Nassella trichotoma*) (Nees) Hack. ex Arechav.

Parthenium weed (*Parthenium hysterophorus*) L., and

Water hyacinth (*Eichhornia crassipes*) (Mart.) Solms in the Gingham Watercourse.

The attitude to the incursion of each of these four weed species, by both landholders and officials, has been quite varied. The potential impact of each species, the identification of control methods relevant to the mechanism of weed spread and an understanding of the need for control of the incursion at an early stage have in most cases been wanting. The review will attempt to establish the reasons behind the successes and failures of responses to these incursions and to identify any commonalities between the approaches from which lessons can be learned.

FIREWEED

Fireweed (*Senecio madagascariensis*) Poir., a wind-spread, short-lived perennial herb, was first collected in NSW in 1918, from Raymond Terrace in the lower Hunter Valley (Australasian Virtual Herbarium, 2019a). It is thought to have been introduced in ship ballast, discharged from vessels that had earlier docked in South Africa and were waiting to load in Newcastle (Sindel, 1986). For many years fireweed was thought to be an invasive form of the native plant known as "variable groundsel" (*Senecio pinnatifolius* syn. *S. lautus*) (Whittet, 1958; Martin and Coleman, 1977; Sindel, 1986). It was not until 1980 that fireweed was confirmed as an exotic invader (Michael, 1981). Following introduction, fireweed spread throughout the lower Hunter Valley. It was introduced to the north coast of NSW in about 1940 in crop seed (Green, 1953). Spread of fireweed continued largely unchecked and it was introduced to the south coast of NSW during the 1979-1983 drought, probably in hay from the Hunter valley (I. Borrowdale, pers. comm.).

Although fireweed was declared a noxious weed in 1946, there were no effective herbicides available to treat infestations. Green (1954) reported that intensive pasture and grazing management could destroy fireweed infestations and prevent reinvasion from neighbouring populations. Work in the late 1970's investigated control using combinations of herbicides, fertilizers and grazing strategies (Martin and Coleman, 1977). Launders (1979) identified bromoxynil as the most effective herbicide for fireweed control. However, no significant ecological studies of fireweed were completed until ten years later (Sindel, 1989).

Community concern about the spread and increase in density of fireweed on the NSW south coast during the Millennium drought (1997-2009) caused the Minister for Primary Industries to request advice on fireweed management from the Noxious Weeds Advisory Committee (NWAC, 2008). The response of NSW Department of Primary Industries to this review was to employ a project officer for two years to demonstrate the effectiveness of a range of herbicide treatments to landholders and producers.

Fireweed is now endemic to coastal NSW. It has spread onto coastal highland areas such as the Dorrigo plateau and Kangaroo Valley and is spreading onto the eastern edges of the northern and southern tablelands. As a Weed of National Significance, fireweed plants are prohibited from sale under the Biosecurity Regulation 2017. Fireweed is not listed as a priority weed in any coastal area under the Regional Strategic Weed Management Plans, although the General Biosecurity Duty applies to all landholders in relation to fireweed. The eradication of fireweed is required for land in the Central Tablelands, Central West, Riverina regions and the southern tablelands area of the South East region.

SERRATED TUSSOCK

Serrated tussock (*Nassella trichotoma*) (Nees) Hack. ex Arechav., a wind spread tussock forming perennial grass, is believed to have been introduced to Australia in the early 1900's (Parsons and Cuthbertson, 2001). It is not known whether serrated tussock was introduced directly from South America or indirectly from South Africa, possibly as stuffing in military saddles brought back to Australia after the Boer War (M. Michelmore, pers. comm.). It became established in the Yass River valley (Land, 1937b) and was commonly known as Yass River Tussock (Cross, 1937), although it was originally known locally as "Thompson's Curse" (Yass Tribune-Courier, 1936).

A sample of serrated tussock was submitted to the NSW Herbarium in 1935, which took more than two years to identify (Cross, 1937), in part, because the botanists had never seen a grass from the Nassella genus and because the sample did not include flowers or seeds. By 1937 more than eighty landholders in the Yass district were so alarmed by the spread and impact of serrated tussock that they presented a petition to the Goodradigbee Shire Council (the shire surrounding Yass) calling for the species to be declared noxious (Farmer and Settler, 1937). It was declared later that year (Land, 1937a) after the NSW Herbarium had formally identified the species (Cross, 1937).

In 1937, local and state officials agreed about the area of land in the Yass valley heavily infested with serrated tussock but disagreed about the area and potential impact of scattered infestations (Sydney Morning Herald, 1937; Land, 1937b), which may have occupied more than 20 000ha (Yass Tribune-Courier, 1936). The NSW Department of Agriculture (Land, 1937b) was aware of another infestation at Rockley, south of Bathurst, of about 40ha.

In the 1930s the only controls for serrated tussock were hand chipping scattered plants or to spray larger infestations with a sodium chlorate, a knockdown herbicide that was largely ineffective (Healy, 1945). Carn (Land, 1937b) was of the opinion that serrated tussock invaded overgrazed pastures and recommended cultivation of arable lands infested with serrated tussock, followed by the sowing of improved grass and legume pastures to suppress the growth of serrated tussock seedlings.

The manpower shortage on farms during World War 2 reduced the amount of serrated tussock control that could be carried out by hand chipping. Drought affected NSW during most of the war years (BoM, 1999). After the war better seasons prevailed from 1947 into the 1950's and during this period many new infestations of serrated tussock were reported on the southern and central tablelands of NSW (Australasian Virtual Herbarium, 2019b) where it has become widely established. Serrated tussock was introduced to the northern tablelands near Rockvale, north east of Armidale before 1955 (Australasian Virtual Herbarium, 2019b) and later, south of Armidale in hay brought from the southern tablelands during the 1965 drought

(B. Tombs, pers. comm.).

Commencing in 1958, M.H. Campbell, a research officer from the NSW Department of Agriculture, produced a series of papers over the following 30 years on the distribution, ecology and control of serrated tussock (Campbell and Vere, 1995). The introduction of flupropanate (tetrapion, Frenock®), a selective herbicide for the control of perennial grasses in 1978 was a leap forward in the control of serrated tussock, especially when integrated with improved pasture establishment (Campbell *et al*., 1979).

The declaration of serrated tussock as a noxious weed does not appear to have been an effective tool in containing the spread of this species. However, it has been reasonably effective at achieving the suppression of scattered populations of serrated tussock on the northern tablelands.

As a Weed of National Significance, serrated tussock plants are prohibited from sale under the Biosecurity Regulation 2017. Although serrated tussock is listed as a priority weed in all tablelands areas under Regional Strategic Weed Management Plans, the control requirement is no higher than "protect priority sites" except for the western edges of those areas, where high level suppression is required.

PARTHENIUM WEED

Parthenium weed (*Parthenium hysterophorus*) L., was introduced into Queensland as a contaminant of pasture seed in 1958 (Everist, 1976). It became naturalised in the central highlands region of that state, where spread was aided by land clearing operations during the Brigalow Development Scheme (Holman, 1981). The impact of Parthenium weed was not appreciated until a series of favourable seasons commencing in 1973 promoted an alarming increase in its spread and density (Haseler, 1976). It is now endemic throughout the central highlands area and regular isolated outbreaks occur in all surrounding areas.

The NSW Department of Agriculture became aware of the threat posed by Parthenium weed in 1976 (Mears, 1976). Work to develop a strategic response to Parthenium weed incursion commenced in 1978 (Brown, 1978), four years before the first discovery of an infestation in NSW. The response identified potential invasion pathways and methods to intercept those pathways using existing resources.

Parthenium weed was first discovered in NSW in 1982 (Blackmore, 1997). Almost 800 infestations have been discovered in NSW between 1982 and 2019, the greater majority being in Moree Plains Shire (Blackmore and Johnson, 2010; Blackmore, unpublished data). The number of new incursions peaked in 1989. Most infestations have occurred on roadsides and have consisted of less than 10 plants with the greatest proportion of roadside infestations occurring along the Newell Highway between Goondiwindi and Narrabri. All infestations have been eradicated or fully suppressed. Many of these infestations have been linked to deliveries of Queensland oilseeds, contaminated with Parthenium weed seed, to oilseed extraction works in Moree and Narrabri (Brown, 1986). The Narrabri works now only processes locally sourced cotton seed and the Moree works (Gwydir Valley Oilseeds) was closed in 2001. Since then, roadside infestations in Moree Plains and Narrabri Shires have fallen almost to zero (Blackmore and Johnson, 2010; Blackmore, unpublished data). Numerous incursions have been discovered on other roads entering NSW from Queensland.

A much smaller number of incursions have occurred on private property, with 67 infestations recorded between 1983 and 2019 (Blackmore, unpublished data). Most infestations have occurred in the north of the state, to the west of the Great Dividing Range but infestations have also occurred in the central western plains and the Riverina. All of these incursions have been linked to human activity and in particular, the movement of grain harvesting machinery (headers) from Queensland into NSW and the operation of that machinery in NSW.

Approximately 500 headers enter NSW from Queensland each year but this can vary between 100 and 850 depending on the size of the Queensland wheat crop. Unregulated movement of harvesting machinery entering NSW from Queensland caused several outbreaks on farming land before legislation was introduced in 1984 imposing hygiene standards for entry to NSW (Brown, 1986). Inspection of harvesting machinery was carried out by existing stock inspectors at the cattle tick inspection stations already in place. Three clean-down sites at the main border crossing points of Goondiwindi, Mungindi and Hebel have been established by NSW Department of Primary Industries, to encourage the cleaning of headers at three known locations, rather than at many unknown locations in southern Queensland.

Amendments to existing legislation covering the movement of harvesting machinery into NSW from Queensland were introduced in 1997 and new legislation was introduced in 2017 with the Biosecurity Act 2015. The inspection procedures were upgraded in accordance with each set of new statutory requirements. Since 1997, the number of new outbreaks of Parthenium weed linked to grain harvesters has declined significantly (Blackmore and Johnson, 2010). In turn, this has meant a decline in all outbreaks on private properties.

The natural mechanism for spread of Parthenium weed seed is along waterways in flood flows. As the core areas of Parthenium weed infestation in Queensland in the late 1970's were outside the Murray-Darling Basin (Haseler, 1976), there was limited threat of spread by natural forces into NSW. However, Parthenium weed is now established in the Maranoa River upstream from St George and is slowly spreading south towards NSW (C. Hunter, pers. comm.).

Other invasion pathways for Parthenium weed have been assessed, including; cotton harvesting machinery, hay and silage making machinery, earthmoving machinery, mining and mineral exploration machinery, livestock and livestock transports, cars and caravans, and hay, grain and seed (Blackmore and Johnson, 2010). Of these pathways, only mineral exploration machinery has been considered sufficiently high risk to be more actively regulated, despite no infestations being linked to that machinery to date.

Commencing in 1996, the NSW Parthenium Weed Taskforce became the coordinating group for the NSW Parthenium Weed Strategy, replacing an earlier committee. The Taskforce has enjoyed the continuity of a single convenor during its life. The goal of the Strategy since its inception has been to prevent the establishment of Parthenium weed in NSW. To date this has been achieved. There continues to be no self-sustaining populations of Parthenium weed in NSW. The NSW Government has remained committed to the Strategy from its inception and this support has been critical to its success. Parthenium weed is listed as Prohibited Matter under the *Biosecurity Act 2015*.

WATER HYACINTH – GINGHAM WATERCOURSE

Water hyacinth (*Eichhornia crassipes*) (Mart.) Solms, is an emergent free floating perennial aquatic plant. Water hyacinth was first found in the Gingham Watercourse (the Watercourse), an ephemeral flood channel north west of Moree, in 1955. It had probably escaped from a garden pond during a flood (Strang *et al.*, 1972). By 1976, 7000ha of the Watercourse were infested (Smith *et al.*, 1984). Strang *et al.* (1972) considered that water hyacinth from this infestation could have easily escaped into the Murray-Darling River system.

Flooding in the Watercourse caused by upstream rain events produced localised verdancy in stark contrast to the surrounding dry countryside. Land was selected for agriculture in the Watercourse because it was subject to regular inundation (Curran, 1969). Two significant floods in the Gwydir valley in 1956 assisted the establishment of the infestation (Strang *et al.*, 1972), which had become apparent by 1958. In 1964 the NSW Department of Agriculture and the Water Conservation and Irrigation Commission urged Boomi

Shire Council to enforce control of the emerging infestation in the Watercourse while it was still at a manageable level. However Boomi Shire Council took no action, even when drought in the following year offered a perfect opportunity (BLWA 1965; Strang *et al*., 1972). By 1970 the size of the infestation started to cause local concern (Moree Champion, 1970). Yet Boomi Shire Council continued to take no action and finally, when the situation had become critical, baulked at the huge potential cost of control works, seeing this as a responsibility for state and national governments (Northern Daily Leader, 1972).

Unpublished letters and meeting minutes held at the NSW Department of Primary Industries Armidale Office have revealed the following information: in 1972, a meeting between the NSW Department of Agriculture and Boomi Shire Council established that Boomi Shire had never served notices on landholders in the Watercourse for water hyacinth and according to the Shire Clerk, the shire was unlikely to do so.

In 1972 the Premier of South Australia was becoming concerned about the threat of the Gingham infestation to the whole of the Murray-Darling River system, which was considered to be imminent. By the end of the year the Australian Weeds Committee had formed a tristate working panel to consider approaches to control the infestation. The working panel (AAC84/SCA90/26) recommended that:

- herbicides should not be regarded as the sole answer to the problem and that a combination of drainage and local use of herbicides offered the best prospects for control,
- any drainage scheme should cause minimal disturbance to flooding patterns,
- the water hyacinth be contained by spraying the western fringe of the infestation,
- Boomi Shire appoint a competent weeds officer,
- the limits of the existing infestation be determined and that regular downstream surveillance take place, and
- the state government make a special allocation of funds to support the control work on private property.

The control program commenced soon after the creation of the inter-departmental project team in 1976 (Smith *et al*., 1984). The program was funded by equal grants from NSW, Victoria, South Australia and the Commonwealth and the total contributions were $550 000 (Smith *et al*., 1984). The program was carried out in accordance with the recommendations of the working panel and was conducted in three phases.

The first phase was to destroy the existing infestation. This was implemented by:

- building earth dams at the Gwydir Pool to prevent inflow into the Watercourse during times of normal flow in the Gwydir,
- clearing the main channel with a specialised bulldozer to drain the larger swamps,
- aerially spraying selected channels with herbicide,
- land based treatment of water hyacinth with herbicides initially from a specialised amphibious vehicle (the Tortoise) and later from four wheel drive trucks (SPCC, 1978),
- containing westward movement of floating water hyacinth plants by constructing a netting fence was at a narrow point above the Gingham Bridge.

The second phase of the program was to exhaust the seed bank by promoting the recruitment of seedlings and destroying those seedlings prior to flowering (Smith *et al*., 1984). This was attempted in 1980 and 1981 by a program of local flooding in the watercourse but was only partially successful due to limited water flows in the prevailing drought conditions and was finally abandoned in the severe drought of 1982 (Smith *et al*., 1984). The third phase of the program was to trial biological control. This was not successful.

The ecology of water hyacinth in a warm temperate environment was not well known at the time. The University of New England under the leadership of Dr John Duggin from the School of Rural Science and Natural Resources was commissioned to study aspects of the water hyacinth seedbank, including the longevity of seed in the seedbank and methods of reducing viability of that seed (Smith *et al*., 1984).

In 1983, the tristate project was concluded. Responsibility for implementing the project passed to the newly formed Moree Plains Shire Council. Water hyacinth in the Watercourse appears to have remained under control for the next 13 years. Irrigated cropping developed in the Gwydir valley in the 1980's after the completion of Copeton Dam, with the demand for water by the expanding cotton industry reducing flows into the Watercourse. During the series of dry years from 1978-1983, the Gingham Watercourse Association lobbied successfully for the construction of a stock and domestic water supply channel through the Watercourse and a stock and domestic water allocation (S. Murphy, pers. comm.).

Flooding in the Gwydir valley in late 1995 and early 1996 re-established water hyacinth in the Watercourse from the existing seedbank. More floods during the remainder of the 1998 and the first half of the 2000's expanded the infestation (Albertson, 2008). Apart from periods of flooding, a combination of natural flows through the Watercourse and allocated flows for stock and domestic purposes and for environmental benefit assisted in maintaining the water hyacinth population (J. Duggin, pers. comm., Albertson, 2008). Although responsibility for control of water hyacinth in the Watercourse rests with individual landholders, the logistics of controlling plants in inundated country are challenging and not practicable for most landholders.

The following year, Moree Plains Shire Council convened a workshop that developed a new management plan for the Watercourse. The plan failed, for the want of a disinterested leader, with several interested parties making conflicting demands on the size and timing of water flows through the Watercourse.

Ad hoc control of water hyacinth continued until 2005 when it became apparent that water hyacinth was spreading westward along the stock and domestic channel and had spread beyond the limits of the 1970's infestation. Water hyacinth was spreading downstream at about one kilometre per annum and by 2009 was 15km further west than in 1996. Established populations of water hyacinth were less than 45km from the Barwon River which greatly increased the probability that water hyacinth may escape into the Murray-Darling System during a significant flood event (Albertson, 2008). A flood in 1998 had passed through the full length of the Watercourse and reached the Barwon River.

The problem was ultimately relieved by two water supply projects unassociated with water hyacinth control. The first was a project to decommission the existing free flowing artesian bores and to sink new capped bores supplying piped stock water to troughs. The second project was to install ground water bores to each homestead. Together, these projects eliminated the need for stock and domestic flows through the Watercourse. The stock and domestic channel was now redundant and was blocked at a number of points (Albertson, 2008). Moree Plains Shire Council has successfully controlled with herbicides all infestations of water hyacinth downstream from the Gingham Waterhole.

As a Weed of National Significance, water hyacinth plants are prohibited from sale under the Biosecurity Regulation 2017. All land west of the Great Dividing Range is subject to a Biosecurity Zone under the *Biosecurity Act 2015*, with the exception of Moree Plains Shire Council. However, water hyacinth is a containment target for the North West Regional Strategic Weed Management Plan, except for the core area of infestation in the Watercourse.

DISCUSSION

The incursions of fireweed and serrated tussock seem to have generated no sense of urgency by state or local government officials until these species had become so widespread that containment was impossible. The spread of water hyacinth in the Watercourse was due solely to the inaction of Boomi Shire Council, over which the NSW Department of Agriculture had no authority. There seemed to be reluctance at a local level to declare weeds "noxious" until they were well established. A "wait and see" attitude appeared to prevail.

Prior to the 1960's, the lack of effective controls for many weed species, beyond chipping by hand, required early detection and rapid response to new incursions to be paramount. This did not happen in the case of these three species. Poor or delayed identification was an issue with fireweed and serrated tussock. There also appears to be a lack of understanding of strategic weed management at a local level, with a strong focus on the core infestations (Sydney Morning Herald, 1937) at the expense of outliers. Cross (1937), urged immediate action to contain and eradicate new incursions of serrated tussock but this did not appear to have been implemented and was hampered by the manpower shortages of the Second World War. In all three cases, there appears to have been a "this plant won't grow here" attitude, a belief that particular areas were outside the optimal range for these species, particularly, serrated tussock on the northern tablelands (M. Duncan, pers. comm.), fireweed on the south coast (W. Johnston, pers. comm.) and water hyacinth west of the Great Dividing Range (Strang *et al*., 1972).

The lack of response to fireweed, serrated tussock and water hyacinth may be contrasted with the response to Parthenium weed, albeit with the benefit of foreknowledge and in dealing with a weed that was spread by long distance human dispersal rather than by natural forces. Plans to deal with this species were in place before the first incursion was discovered, a major invasion pathway was intercepted at early stage and the response to incursions was immediate and effective. The large number of incursions on the Newell Highway might have been prevented if the powers to deal with carriers, enacted by the *Biosecurity Act 2015*, had been available in 1985.

From the above examples, it is apparent that the essence of successful official programs to deal with incursions of new weed invaders will be:

- Active and passive inspection programs to ensure early detection of new invaders and to establish the extent of any new incursion,
- Rapid and correct identification of new invaders,
- Knowledge of the invaders ecology, including mechanisms for spread,
- Rapid response to the incursion in a planned and strategic approach, controlling outliers as a priority,
- Availability of effective and economic control methods,
- Identification of invasion pathways and interception of those pathways where possible,
- Willingness to fully implement the biosecurity legislation and to lead and coordinate the program, and
- Commitment to implementing and resourcing the program.

Panetta and Scanlan (1995) considered early detection to be the key factor.

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HOLISTIC WEED CONTROL PRACTICES FOR URBAN STORM WATER CATCHMENTS
Global trends – re-thinking the way weeds are managed

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SUMMARY

This paper evaluates the effectiveness and deficiencies of weed management practices to protect the ecosystems, that Water Sensitive Urban Design (WSUD) intends to facilitate. There is an increasing range of non-chemical control methods, from around the globe, that are being used and trialled to mitigate herbicide residues in storm water. These have been evaluated and compared with glyphosate. There are growing public concerns of the use of herbicides and their effects. Planning to implement sustainable, holistic weed management is a way that policy makers, financial and operational managers can limit the risks of herbicide toxin exposure to workers, volunteers, endangered species and waterways.

Keywords: saturated steam, invasive, non-toxic, chemical-free, weed control

INTRODUCTION

Weed control is necessary in urban storm water catchments as weeds cause several problems, including, damage to public assets, such as footpaths, paved areas and road surfaces by breaking up asphalt and opening up cracks (Holgersen, 1994; Schroedr, 1994). Weeds and moss contribute to slip hazards on footpaths. Weeds accumulate debris, particulate, vegetation & sediment at their base and create an environment for harbouring weed seed, perpetuating further weed establishment. This accumulation of residues can impede storm water run-off or be trans-located by storm events into the storm water system and contribute to sedimentation and weed establishment downstream. Established weeds can impede vision of traffic when in the proximity of kerbs, channels and traffic islands. (Rask & Kristoffersen, 2007). There is a general view that weeds in footpaths and the streetscape creates a perception of a city in decline (Popay et al., 1992; Benvenuti, 2004).

'Conventional' weed control in the urban areas since the late 1970's has been carried out with herbicides, dominantly glyphosate products. (Ramwell, 2006). Glyphosate (the active constituent in Roundup) is the world most used herbicide at 650,000 tonnes in 2011; (Friends of the Earth Europe) more than 850 kilo tons in 2015 and is slated to grow at a compound annual growth rate (CAGR) of 5.3% by 2024 (Verma V, 2017).

Glyphosate, once claimed to be safe enough to drink, is increasingly being found to have bio-accumulative effects in mammals, has been found in 60 – 100% of urine samples taken in populations across Europe (Sewell, 2013) found in mothers breast milk in the US (Honeycutt et al., 2014). Roundup has been shown to be 125 times more toxic to humans than its glyphosate active principle (Mesnage et al, 2014).
Urban areas are designed to facilitate surface runoff, rapid infiltration and flood mitigation. Public assets within urban storm water catchments which are regularly treated with herbicide, mainly glyphosate; include kerbs, gutters, footpaths, streets & WSUD installations. Glyphosate moves easily from asphalt and concrete. Ramwell (2006) demonstrated 35% loss of applied glyphosate to storm water in two studies. 80% of loss occurred in first few mm of rainfall leading to contamination of storm water, sewage systems and

groundwater (e.g. Allender 1991; Ramwell et al 2002; Skark et al 2004). A study of glyphosate and aminomethyl phosphonic acid (AMPA) transfer in the Orge watershed (France) (Botta et al 2009) showed annual glyphosate estimated load was 1.9 kg/year downstream from agricultural zone and 179.5 kg/year at the catchment outlet from the urban zone. This result suggested that the contamination of this basin by glyphosate was essentially from urban origin and contributed 94 times as much as the agriculture area upstream.

The benefits of WSUD, as indicated by Sydney Water (2018): reducing the quantity of stormwater runoff; improving the quality of stormwater runoff; protecting and restoring creeks and rivers; improving wildlife habitat; improving the appearance of streets and parks; cooling our local environment by retaining water. Contamination of stormwater with glyphosate is counter-intuitive to the aims of WSUD.

This paper provides a brief overview of the non-chemical weed management apparatus which have become available in the last 5 years. The results of desktop research into the current available studies, web-based information, as well as the authors own experience with 'on the ground' weed management have been collated into a table which starts to compare management considerations such as efficacy, carbon footprint, cost and environmental impact of the nominated methods. An extract of this table is presented.

THERMAL AND MECHANICAL WEED MANAGEMENT ALTERNATIVES

Mechanical

Mechanical methods of weed control for paved surfaces include brushing, whipper-snipping (weed whacking/ brush cutting), hand weeding. Thermal weed control methods include flaming, hot air, radiant heat, hot water, hot foam and saturated steam. Weed brushes are a specialist piece of equipment mounted to mobile plant produced by companies that specialize in cleaning apparatus such as Karcher, Nilfisk, Koti, Kersten, Ecobrush, Weedbrush. Whipper Snippers are manually operated hand held units which are readily available from grounds and garden care outlets. Mechanical weed control has the disadvantage of removing the above ground parts of weed only. Weeds by their nature are adapted to grazing and regenerate quickly from the meristematic cells at the plants crown or from the apical cells of leaves and shoots. Mechanical weed control also has been shown to damage assets, brushes causing additional wear and tear on paved surfaces (Lefevre et al., 2001; Wood, 2004) and potentially damage tree assets eg whipper snipper girdling of trunks.

Thermal

Thermal weed control utilises the processes of lethal heat or thermal shock to explode cells with the plant material, plasmolysis. Lethal heat occurs at temperatures above 60C. The higher the heat the faster plasmolysis occurs. At 100C the rate rapid expansion of cells due to thermal shock is more destructive than the slow cooking using lethal heat at lower temperatures.

Earliest documented patents for thermal weed control date back to the 1920's when steam trains in Australia were fitted with pipes to divert locomotive steam to distribution pipes directing hot water to vegetation growing on the rock ballast under the tracks. The advent of herbicides in the 1940's saw this technology almost disappear until the early 1990's when a mobile method and apparatus for controlling vegetation using hot water was patented (Newson R J, PCT/NZ93/00035). In the last 10 years there has been significant development of a number of varieties of thermal weed control. Thermal weed control options can be broadly classed into two categories; Hot Dry and Hot Wet.

Despite not being widely used, there are a few more thermal methods of weed control, such as freezing, electric currents, irradiation, microwave radiation, and ultraviolet light (PAN Europe 2017).

Hot Dry

Hot dry includes flame, hot air and radiant heat. Flame and radiant heat tend to be more portable, use LPG / propane but do not penetrate into the crown of the plants efficiently, often requiring more frequent interventions. Exposed flame weeders pose significant fire risk in dry conditions and on mulches, and cannot be used on rubber soft fall, rubber paving, near litter, debris or irrigation lines and fittings.

Hot air weed control extracts hot air from a flame source directing it onto vegetation such as the Zacho: Turbo Weed Blaster. Hot air has very high energy consumption. Radiant Flame units direct flame heat, under the protection of a shroud, onto a ceramic or metal surface in close to proximity of vegetation. Units can be hand held, trolley or vehicle mounted available from HOAF NL, Sunburst OR, USA. Hand held LPG/ propane flame burners are an often used alternative, mainly for small or difficult to access areas.

Hot Wet

Hot wet weed control apparatus are mainly hot water, hot foam and saturated steam embodiments. Wet steam, such as the Canadian Greensteam ® (no longer in production) and HOAF 'greensteam' overcome some of the fire risk of open flame but produce too little volume of wet stream to provide commercial viability (Authors personal experience). The superior control of weeds by hot wet methods over hot dry is due to moisture enabling more rapid transfer of lethal heat into cell structure than dry heat. Deeper penetration into meristematic cells is experienced and residual heat in the surface soil is enough to provide some control of seed bank. (Hansson & Ascard 2004; Kristoffersen et al., 2007).

There have been improved methods of heating water by a number of manufacturers in Europe, USA and Australia. Development of hydraulic controlled machine mounted applicator heads by Heat Weed (formerly Wave) in NL, Empas Gmbh and Weedtechnics Aus, increases speed and area of application in accessible open paved areas such as parks, footpaths, streets and lanes. Use of infra-red weed detection by Heat Weed NL reduces water and energy consumption. Heated foam, formed by mixing a heated aqueous solution of water, surfactant and hot air, first patented in 1995 (Rajamannan A.H.J US5,575,111 Filed 28 Sept,1995) has been further developed by Weeding Technologies Ltd, UK. Heated foam has been demonstrated to expose plant tissue to heat for a longer period increasing efficacy when compared to hot water. Saturated steam, created by increasing the boiling point of heated water under pressure to approximately 115 - 120°C and then depressurising in a depressurising nozzle assembly in close proximity to vegetation delivers a mixture of saturated steam and hot water at 100°C to the weeds. (Aus Patent 2004320467 P.Musten, D.Parkin, J.Winer). Saturated Steam delivered at 100°C is the only method that utilises the process of thermal shock.

Weed management considerations

There is a requirement upon managers responsible for vegetation management to consider environmental and economic targets. In states and regions where, regulatory authorities have not banned the use of herbicides; managers work within municipal or organisational policies to decide on the weed methodologies to employ. Increasingly in Australia, municipalities are adopting policies which include commitments to the risk associated with locations deemed 'sensitive' such as pre-schools, schools and playgrounds; and high traffic pedestrian areas, where cordoning off an area while herbicide dries is not an option.

The management considerations include, carbon emissions (CE), whole of life cycle analysis (LCA), water consumption, health and safety for operators, health and safety for community, ecological/ environmental impacts and cost .

A determinant in the frequency of weed control interventions is the presentation standard required of the asset. For example, a footpath in a pedestrian shopping precinct may have a requirement to have < 2% weed cover at any time, whereas a suburban footpath in a residential area may be permitted to have <10% weed cover with no weeds more than 50mm in height.

		Capacity (m2/h)	Energy kW h h^{-1}	working width cm	Treatment per annum[5]	mean dose kg gas ha	Mean dose per year	CE/kg a.i[1]
Flames	HOAF	320-350	61.4-67.2	50	8	150	1200	94.5
Hot air	Zacho	350-400	150.1 - 171.5	65	8	335	2680	211.1
Steam	Danstream	250-300	52.2 -62.6	50	8	163	1304	102.7
Hot Water	Waipuna	200	79.9	20	4	312	1240	196.6
Brushes	DUKS FM-BS			50	4			0.0
Saturated steam[4]	Steamwand SW900	350-520		50	4	105	419	65.9
Glyphosate [2]					3			>75.6[3]

CARBON EMISSIONS – 7 WEED MANAGEMENT TOOLS

Carbon emissions (CE) are a measure of the CO and CO2 emitted in the course of a product's life cycle. Barber, 2009 estimated the total CE of glyphosate to be 28 kg/ Litre in its production, formulation and packaging. Kristoffersen & Rask et al 2007 determined the relative energy consumption of 5 various non-chemical weed treatments used on traffic islands over a number of treatments. R. Lal in his paper Carbon emissions from farm operations 2004 cites 0.63 as the emission coefficient for LPG/kg. The author has documented production rates and fuel consumption for saturated steam weed control.

Table 1. Carbon emissions (CE) of some non-chemical alternatives and glyphosate

All fields shaded in grey are from Kristoffersen (2007)

[1]CE coefficient of 0.63/kg propane (R.Lal 2004)

Table 2. Urban Weed Management Methodologies Matrix

		Chemical Spray	Mechanical	Thermal					
		Glyphosate based	Weed brush	Flame	Saturated Steam & hot water	Hot Water Foam	Hot Water	Radiant	Hot air
Application	Contact	Y	Y	Y	Y	Y	y	Y	Y
	Systemic	Y							
	Pre-emergent				Potentially	Potentially			
Effect	Above ground	Y	Y	Y	Y	Y	y	Y	Y
	Meristematic crown	Y			Y	Y	y		Y

- for full table see https://www.weedtechnics.com/wsud-research-report/

[2]Barber 2009 calculated glyphosate CE 28kg/L

[3]Nufarm Roundup Biactive label states Active Constituent of glyphosate 360g/L. Rate per ha of Roundup Biactive is 2-3L. Average 2.5L/ha x 360g = 0.9kg with a CE of 28 kg/L = CE 25.2 kg/ha (3 x p.a = 75.6). This does not include CE of applicator pump or the carrying vehicle. Barber also does not include transport of the Roundup from point of manufacture (China) to the end user or the post consumed disposal of the toxin drum. CE does not include calculation for the surfactant and other non-disclosed additives which make up the Roundup formulation.

[4]Data for saturated steam is supplied by the author whilst undertaking weed control for a municipal council on terrain that the author considers comparable to segmental paving areas of the Kristoffersen study.

[5]Treatment frequencies are for Danish growing season of Kristoffersen study.

Table 2 is an extract of a more detailed urban weed management methodologies matrix developed by the author. Much of the classification and rudimentary values are the author's subjective assessment based on knowledge and experience in the field. The intention of the table is to create a platform for discussion and be a handy reference point for managers to refer when evaluating the options. The table may also generate questions and hypothesis for further research projects, for instance, does thermal weed control germinate seed banks thereby reducing future weed control activity after regular first year treatment.

It is not possible to determine meaningful comparative dollar value costs for the various methods of control for a general publication. There are too many variable factors which play a role in the frequency of application required.

CONCLUDING REMARKS

There is a growing body of evidence concluding that herbicides and specifically glyphosate are not safe for our environment and pose significant risk to aquatic ecosystems, potable water supplies and human health. Samsell and Sanef (2013) found that 'Glyphosate, contrary to being essentially nontoxic, may in fact be the most biologically disruptive chemical in our environment'. There is a global trend emerging of decision makers and regulators opting for chemical reduction and alternative technologies. This has been a catalyst for development of a new generation of thermal, mechanical and 'organic'/non-synthetic weed control technologies that have improved upon predecessors.

The majority of municipalities in Australia take a low cost, weed management with herbicide option, therefore passing on the consequential costs of the translocation of their herbicides onto other agencies such as the water authorities, NPWS, and the State government..

It is suggested that to manage weeds sustainably the following principles should be applied. If applied using a range of alternative modes of action they will provide weed management to a presentation standard of < 2% weed coverage:

- Design to reduce weeds through pavement selection and competitive planting.
- Design for and specify presentation standards, therefore the level of tolerance for weeds dictates the level of intervention, which allows budgets to be allocated on a presentation requirement. Be aware of biosecurity threats and pesticide resistance.
- Identify 'no chemical spray' areas which have runoff potential within potable water catchments.
- Identify socially and environmentally sensitive 'no chemical spray' areas within urban communities i.e schools, playgrounds, shopping centres, parks. For WSUD, Melbourne Water (2013) states 'remove weeds (avoid use of herbicides)'.
- Adopt a variety of modes of action such as brushing/ sweeping away of debris & sediment that creates seed banks before spring, followed up with thermal weed control. Over time some species may persist which can be treated with an alternative mode of action such as an 'organic approved' vinegar, pelargonic acid or pine oil.
- Keep records of weed management practices, what worked, what didn't, duration between treatments, weather records and the changes in weed populations over time.

- Budget for the new paradigm. Weed management without chemicals or utilising alternatives may have higher per sq.m costs initially, which should be budgeted for, however with repeated applications the weeds species present reduce, the number of weeds and their vigour also reduce. The seed bank will be depleted when hydro-thermal weed control is used. Therefore, application costs will decrease over time and the hidden costs associated with chemical weed control will be avoided.

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FROGBIT (*LIMNOBIUM LAEVIGATUM)* DETECTION AND ERADICATION IN

NEW SOUTH WALES

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SUMMARY

Frogbit (Limnobium laevigatum) is a state priority aquatic weed in New South Wales (NSW) listed as Prohibited Matter under the NSW Biosecurity Act 2015. In July 2017 Mid-Coast Council received a report from a member of the public who had seen a suspicious plant growing on a pond while walking in bushland near Green Point south of Forster. Mid-Coast Council staff inspected the site and suspected the plant to be frogbit. They submitted a sample to the NSW Herbarium and the plant was confirmed as frogbit. This was the first known naturalised infestation in NSW and posed an environmental threat to waterways within the adjoining national park. A rapid response was implemented over the following three months involving staff from Mid-Coast Council, NSW Department of Primary Industries (DPI) and National Parks. This response involved:

- immediate treatment of the known infestation and surveillance of all 312 residential properties in Green Point.
- identification of and surveillance of high-risk sites within 10 kilometres of the known infestation.
- a communication plan involving advertising to alert the public.

The probable source of the infestation was located on a neighbouring residential property in Green Point where frogbit and other aquatic weeds were discovered in fish ponds. An eradication plan was initiated for this property and a trace-back was done on the source of the frogbit but the original supplier was no longer in business.

No other infestations of frogbit were found during the surveillance. Other sources of frogbit were located for sale on the online sites Ebay and Gumtree. These sellers were contacted, their properties inspected and the plants confiscated.

Keywords: frogbit, prohibited matter, rapid response

INTRODUCTION

Frogbit (Limnobium laevigatum), also known as Amazonian frogbit or West Indian spongeplant, is native to Central and South America. It is a perennial floating aquatic herb that spreads by seeds and stem fragments. Floating rosettes produce runners which can produce juvenile plants at the ends (Csurhes 2011). Plants produce multiple seed pods with each pod containing 20 – 30 seeds (Sercul 2013). Seeds are covered with small spinules and surrounded by a gelatinous mass enabling them to readily attach to animals and watercraft (Hrusa 2012). Seeds germinate in water or mud and then float to the surface (Cook & Urmi-Konig 1983). The plant has a large seedbank and seed is thought to be viable for at least 3 years (Akers unpublished).

The species is adaptive and has a broad climatic tolerance including temperate, sub-tropical and tropical environments (Cook & Urmi-Konig 1983; Csurhes 2011).

Its invasiveness is characterised by its ability to rapidly spread and out-compete other water plants, dominating a waterbody. Frogbit can form dense mats of up to 2,500 plants per square metre (Sercul 20013). Infestations impact aquatic life by reducing oxygen levels, sunlight penetration, access to waterways for recreational purposes, and aesthetic values. Up until 2014 frogbit was widely traded in the aquarium industry in NSW. In February 2014 frogbit was declared a Class 1 weed in NSW under the Noxious Weeds Act 1993 and in 2017 frogbit was identified as a significant biosecurity risk in NSW and listed as prohibited matter in Schedule 2 under Part 4 of the Biosecurity Act 2015. It has also become naturalised in and is considered a weed in parts of Asia, Southern Africa and North America.

The previous trade in NSW has resulted in numerous populations of frogbit being present in aquariums and fish ponds within the State. There is continued online trade in NSW from sellers who are unaware of the plant's biosecurity risks. Frogbit is not a declared weed in Victoria, Queensland or the Australian Capital Territory and is often sold online in these states and to customers in NSW.

RAPID RESPONSE

The discovery of the frogbit infestation at Green Point was due to a member of the public informing Mid-Coast Council on 11 July 2017 of a suspicious plant growing on a pond in bushland adjacent to a residential area.

An inspection of the pond by Mid Coast Council weeds officers on 12 July 2017 resulted in the discovery of several aquatic weeds including suspected frogbit. A sample sent to the NSW herbarium returned a positive identification for frogbit on 18 July 2017.

This discovery of frogbit at Green Point was the first naturalised infestation of this weed in NSW and the first infestation of a Prohibited Matter weed since the NSW Biosecurity Act 2015 was implemented.

The infestation initiated a rapid response from State and Local Government agencies involved in weed management in NSW. This response involved surveillance, treatment and a communication plan.

Surveillance was initiated to locate the source of the infestation and any other infestations nearby. This involved:

- initial inspection of all properties near the infestation
- inspection of all 312 residential properties in Green Point
- inspection of significant waterbodies within a 10 km radius of the infestation.

The inspection of residential properties in close proximity to the infestation was undertaken two days after the report on 13 July 2017. The residential property closest to the infestation had several fish ponds containing frogbit and other aquatic weeds.

Seven days after issuing a notice of entry, surveillance was undertaken on all 312 residential properties in Green Point on 8-9 August 2017. Eight staff from NSW DPI and Mid-Coast Council conducted the door to door inspections. No frogbit was found but two other state priority aquatic weeds - water lettuce and salvinia were detected.

The surveillance of high risk sites identified within 10 kilometres of the known infestation occurred between August – October 2017 by ground and air searches. No further infestations of frogbit were found.

The inspections were recorded in DPI's Biosecurity Information System – Weeds in the Weeds Information Database.

The treatment of the infestation was undertaken on 17 July with Glyphosate at the rate of 1 litre to 100 litres of water. Retreatment of germinating plants has occurred at times when the pond has water in it. The pond is shallow and has dried up on occasions since discovery of the infestation.

Aquatic weeds on the source property were removed and composted on site in an area surrounded by a bund. The water was then drained from the ponds and the sediment was also removed and stored in the same area. The property owners were issued with a Biosecurity Direction to remove any weeds that re-appeared in the ponds. Regular follow up inspections are undertaken by Mid-Coast Council weeds staff.

The communication plan involved the following:

- press releases by NSW DPI and Mid-Coast Council
- a media tile to be displayed in printed media and online
- a DL brochure that was mail dropped to local residents
- a letter sent to local residents prior to inspection. This included a list of frequently asked questions.
- a radio advertisement by Mid-Coast Council
- a television interview by Mid-Coast Council weeds officers
- information on Mid-Coast Councils and NSW DPI's Facebook pages.

Once the source of the infestation was found at the residential property a trace back process was initiated to locate the source of the original plants, which were purchased from an aquarium business some years previously. This business had ceased trading and an inspection of the site found no frogbit plants.

During this investigation several other sources of frogbit were reported and these properties were inspected and the plants seized and destroyed.

Continued sale of frogbit on online websites has resulted in development of an online sales procedure to give guidance on how to deal with the online sale of plants under the NSW Biosecurity Act 2015. Online sellers of frogbit in NSW are contacted to remove their advertisements, surrender their plants and supply the details of people they have purchased the plants from and of anyone they have sold them to.

There have been many successful seizures of plants from either people that online sellers had originally purchased the plants from or customers they had sold them to. In one case an online seller had their plants seized and also supplied the details of 5 customers they had sold plants to. All the sold plants were also seized.

DISCUSSION AND CONCLUSION

The frogbit infestation at Green point in 2017 is an example of a rapid response to a state priority weed incursion and a cooperative effort between the community, multiple organisations and staff. The infestation is well on the path to eradication.

Between the time of discovery of the Green Point infestation and June 2019 there have been seven more frogbit infestations located in NSW. Many of these are suspected to be sites where plants have been

dumped or escaped from ponds in rainfall events. At least one is suspected to have been spread by waterbirds and two sites have a direct link to plants bought online and then released into dams. The rapid responses to all of these infestations have been modelled on the Green Point response.

SOFT SKILLS DOING THE HARD WORK

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SUMMARY

When someone is described as 'soft' it often implies that they are a pushover, weak or may have less rigour in their work. However, a person with 'soft skills' is highly sought after in the invasive workplace. They are a strategic thinker, someone who seeks an understanding of particular situations to achieve change, they have ability to effectively engage and collaborate with the community and all stakeholders.

Having stakeholders on your side is one thing, however getting them motivated to act is another matter and not always easy to achieve. This is where soft skills work the hardest; they are central to effective invasive species management.

A two-day course, 'Community Engagement (CE) - moving people towards action' is nationally accredited course mapped to the competency unit BSBPMG418 *Apply project stakeholder engagement techniques*. The CE course has been developed to strengthen the soft skills for invasive species professionals through a hands-on approach. It steps participants through the factors that influence people's decisions and provides job specific examples that can be applied to motivate ongoing action to address the management of invasive species.

This paper discusses delivery of a course for soft skills and covers how the course has influenced participants in their workplace.

Keywords: Training, community engagement, behaviourally effective communications

INTRODUCTION

The Australian Industry and Skills Committee (2018), and professional networks like LinkedIn (2019) consider soft skills to be highly desirable in the current Australian workplace. They list these skills as being;

- communication and teamwork skills
- active listening
- relationship management and
- social and cultural awareness.

Invasive weed management is a community problem and often poses complex challenges. An effective result often requires people to work together with a shared vision and commitment (Howard, 2017).

To move people towards action we first need to get them interested in the issue, develop relationships and build trust. Effective communication, listening, relationships and social awareness are key to this process.

A training course was developed to help invasive species professional enhance human relations in their work for long term success.

TRAINING DEVELOPMENT AND CONTENT

Community engagement – moving people towards action is a nationally accredited short course with a focus on the practical skills needed to engage the community and increase adoption of desired behaviours. During development, we worked closely with Bruce Howie, an experienced trainer, extension specialist and clear thinker. We also consulted with a technical reference group of community engagement specialists and practitioners associated with the Invasive Animal CRC representing most Australian States.

In weed management, legislation and associated infringements can be used as a threat to incentivise landholders to control weeds. Such threats lead to short-term behaviour change which will only be displayed while the threat is near. As Howard (2017) states, 'action must be sustained over time in order to address the persistent nature of invasive species'. To achieve longer term change in weed management, we need to use soft skills to develop positive connections with landholders. People get burnt out by repeated bad news stories, (Hine et al. 2014). If a landholder is already stressed about personal finance or drought, more negative emotions such as consequences of poor weed management will fail to engage them. Applying soft skills will help weeds professionals not only to find out more about their community but to understand issues from the community's perspective. Consequently, the philosophy of the CE course has been shaped by both science and practical application, that is; behaviourally effective communication techniques combined with basic tools that are really needed in the workplace.

The CE course describes a planned approach to community engagement.

- Getting to know the people you are working with - listening, asking, developing relationships and building trust.
- Identifying and categorising common types of barriers – help to lower the hurdle to address them.
- Knowledge and understanding of the community which leads to finding a solution that meets community needs.
- Targeting or tuning the message – so that not only rational decision-making processes (using facts and data) but also acknowledging our intuitive process based on values and emotions are incorporated.
- Seeking commitment and providing support to the community during and after engagement with a view to see the behaviour maintained in the community. (Howie, 2017).

During the two-day CE course, participants have the opportunity to learn and practice what is often a new pattern of behaviour to them. Through the incorporation of learning activities, small chunks of information are presented and tools and systems are demonstrated by the facilitator. This style of learning is more motivating for participants. Low motivation is often a side effect of problems associated with not knowing how to apply knowledge and skills (Moore, 2017). CE course participants can incorporate a new way of thinking directly into their work activities.

TRAINING DELIVERY AND EVALUATION

We have delivered 19 CE courses to 227 participants across Australia. Of the 13 courses in NSW, participants came from Local Government, Local Lands Services, National Parks and Wildlife Services, Landcare and NSW Department of Primary Industries (DPI). Since writing this paper, a further three training courses will have been delivered taking the total number of participants in NSW to just over 160.

Measuring soft skills is difficult. The benefits of improved soft skills are at times intangible and are often slow. However, when trying to evaluate the effectiveness of any training course, there are three indicators which we explore; satisfaction, learning and application.

On completion of the course work, participants are asked to complete a feedback sheet. It is the participants' own reactions that are the quickest measure of effectiveness and satisfaction. Of the 215 participants who provided feedback at the time of the course, it is clear that the training content is relevant to them; 99% of participants felt that the course had met their expectations; 50% at an 'excellent' level and 49% at a 'good' level (Table 1).

	Poor	**Fair**	**Good**	**Excellent**
The course met your aims and expectations.		1%	49%	50%
The course was presented at a level I could under-stand.		2%	32%	66%
The topics covered were useful.		5%	36%	59%

Table 1. Participant feedback collected at the time of training

Participants were asked to recall what they felt were the strong points of the course; 48% stated information on emotions and interests and how it effects people decisions; 24% of participants considered the strong point to be getting to know stakeholders through listening and open question techniques.

During the feedback process, participants were asked to gauge if their level of understanding of skills and knowledge in the topic area had changed from before the course to afterwards. 84% of participants felt that their level of skills and knowledge had increased. When asked if the topics covered at the course were useful, 95% of participants responded with good or excellent.

Practical and written assessment tasks were designed to gather evidence to satisfy the performance and knowledge requirements of the CE course accreditation. The majority of participants completed assessment tasks conducted during course time and 43% of participants choose to complete and submit the post-course assessment tasks. When participants were asked informally why they did not complete the assessment task

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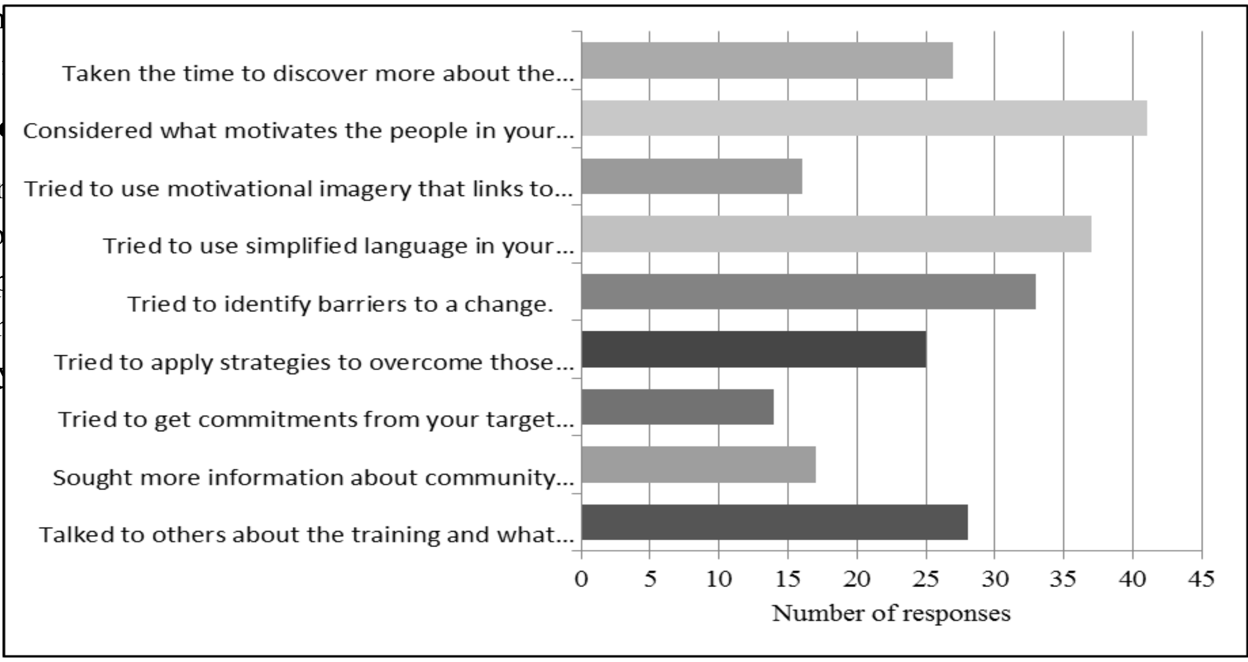

Figure 1. Number of people who are applying learnt techniques in their workplace.

From 128 participants, 61 responses were returned. Most responses included the following main areas:

- considering what motivates their target audience
- using simplified language in their communications
- finding out more about their community
- looking more closely at overcoming barriers.

EVIDENCE OF INDUSTRY APPLICATION

An important consideration in developing a training course is to ensure that the course is more than just competence and knowledge. Trainers and facilitators of the CE course provide a learning experience that goes beyond just putting information in peoples' heads. Tools and examples are provided so that people can apply new skills directly in their work. As a result of the CE course, NSW DPI invasive species team are evolving approaches to community engagement. The team are trying to model the change we want to see and hope to motivate other participants of the CE course to change what people do – not just what they know (Moore, 2017).

We have seen a change in how the invasive species team delivers information, taking a different direction to the typical governmental narrative with scientific detail and legalistic language. The CE course has influenced the team in its key weed publications such as:

- NSW Weed Control Handbook – front and back covers
- look of NSW weeds awareness campaign
- tropical soda apple control cards.

These examples validate the importance of modelling desired behaviours learnt from the CE course. By linking messages to values and interests through emotional images, shared stories and streamlined information we can better trigger a connection with our community.

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WORKING COLLABORATIVELY WITH COMMUNITY GROUPS OPPOSED TO HERBICIDES

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SUMMARY

Sections of communities across Australia are becoming increasingly intolerant of the use of herbicides in public spaces. This can vary from individuals voicing their concerns via complaints to Councils to active formal groups who provide voluntary labour without the use of herbicides.

This paper shares the results of survey responses from four respondents, three email responses, and two phone interviews and outlines their concerns and motivations for their stance on herbicide usage. The validity of these concerns is explored citing scientific research from around the globe. Organisations represented included three friends of reserves groups, one contractor, three lobby groups, and one Council.

Case studies explore approaches and challenges for Council interactions in dealing with the following groups:

Friends of Mrs York's Garden in Port Macquarie (including saturated steam contractors)

Byron Shire Chemical-Free Landcare

Friends of Success Hill Reserve in Western Australia (chemical free site)

Byron Bay Council Chemical Sensitive Register

This paper concludes with a summary of key points based on the results of the surveys and case studies for working collaboratively with community groups opposed to herbicides.

Keywords: Chemical Free, Organic, Herbicide Opposition, Holistic Weed Control, Integrated Weed Management.

INTRODUCTION

Councils use a range of herbicides in public spaces to control weeds to suit the particular weed species and as part of integrated weed management approaches (Inkson, 2019). As the author prepared this paper in June 2019, the commonly used herbicide glyphosate was featuring regularly in the media.

This paper focused on groups opposed to herbicide usage and acknowledges the recent focus on glyphosate. There is an opportunity to harness this outrage into constructive collaboration "to put the we in weeds". This is the objective of this paper.

METHODS

The information presented in this paper was collated from survey results from four respondees, three email responses, Facebook pages, websites and two phone call interviews representing the following organisations:

- Mrs York's Garden, Port Macquarie (survey response personal interview)
- Bushtekniq Pty Ltd, Brisbane (survey response & phone interview)
- National Toxics Network (survey response)
- Coastal Warriors Midnorth Coast (survey response)
- Byron Shire Chemical-Free Landcare (email correspondence)
- Pesticide Action Group, Western Australia (email correspondence)
- Friends of Success Hill Reserve, Western Australia (email correspondence)
- Midcoast Council Weed Officer, Terry Inkson (phone interview)

A simple survey with the following ten questions was sent to selected groups to gather data on concerns and motivations for their stance on herbicide usage:

1. What is the name of your community group / organisation?
2. What year was your organisation established?
3. How many members in your organisation?
4. What is the purpose of your organisation?
5. What is the stance of your organisation on the use of herbicides?
6. Why has your organisation taken this stance?
7. Please give examples of challenges your organisation has faced in relation to the use of herbicides.
8. Please give examples of projects where herbicides have not been used
9. What would you like to see improved in relation to weed control within your community?
10. Please add any other comments you would like to make in relation to working collaboratively with community groups opposed to herbicides (optional)

Scientific papers available via the internet have also been referenced where they relate to the discussion in point.

RESULTS

Table 1 summarises the responses received from the eight groups aligned with survey questions 1 to 5. The stance of each of the groups varied from strong opposition to use of herbicides to those supporting integrated weed management (IWM) which includes the use of herbicides where deemed to be the most efficient and economical method.

The Australian Government (2019) definition of IWM "is the control of weeds through a long-term management approach, using several weed management techniques such as physical, chemical, biological, and cultural controls". Cultural controls include plantings to outcompete weeds.

Table 1. Summary of Responses to Survey Questions 1 to 5

Organisation Name	Year Est.	No.	Purpose	Stance to Herbicide Use
National Toxics Network	1993	52	Creating a toxic-free future for all	Support IWM based on ecology, prefer non-chem methods used
Coastal Warriors Mid North Coast	2017	50+	Ocean conservation and clean up group	Strongly oppose
Bushtekniq Pty Ltd	2015	3	to relearn, regenerate and reconnect	100% herbicide free
Friends of Mrs	2015	29	To return the area to a place of natural	No policy
Byron Shire Chemical-Free Landcare *	2010	-	To promote a chemical-free ecological restoration approach towards conservation	100% herbicide free
Pesticide Action Group, Western	2013	-	To bring a balance to earth's ecological systems and wellness in our communi-	Strongly oppose
Friends of Success Hill Reserve, WA *	2013	-	Pro-active management for the long term health and sustainability of the reserve through non chemical weed management	100% herbicide free
Midcoast Council *	-	-	Deliver benefits for our community in a way that adds value and builds trust	IWM including herbicides

[* indicates survey not completed; data collated from emails, websites, phone calls; IWM = integrated weed management]

The common theme of those groups opposing the use of herbicides did so based on the published scientific literature of the ecological and health hazards of pesticides (including herbicides). The National Toxics Network (NTN) survey response also highlighted the concern “that the chemical approach is a 'treadmill' and doesn't ever ultimately solve problems.”

Two of the groups raised the challenge they face of the entrenched and passive acceptance of herbicide usage. The National Toxics Network survey response also stated that their “greatest challenge is the power agrochemical corporations have over the Government and the Australian Pesticides and Veterinary Medicines Authority (APVMA) and state regulators.”

There are a number of bush regenerators and volunteer groups across Australia using no herbicides, including contractor bushtekniq Pty Ltd in Brisbane. The aim of bushtekniq is to “enlighten clients and the community to the efficacy of chemical-free methods”. Bushtekniq’s survey response also stated that there has been “increasing engagement with Brisbane City Council's Habitat Brisbane/ Community Conservation Partnerships Program. Responding to bushcare volunteers' enquiry, interest and sometimes stipulation for chemical-free worksites, the Council has recently augmented bushtekniq's specialised workshops and presentations around 'Volunteer Training in Chemical-Free Bush Regeneration Methods’. Saturated steam weeding is a part of bushtekniq's practice that is also gaining the public's attention and traction on these Habitat Brisbane bushland sites.

Case Studies

The following section outlines three case studies where predominantly no herbicides are used. The case studies explore weed control approaches and challenges for Council interactions in dealing with the groups. The final case study outlines the approach taken in Byron Shire Council for their Chemical Sensitive Register.

Friends of Mrs York’s Garden in Port Macquarie (including saturated steam contractors)

“Mrs York's Garden is a beautiful headland Garden overlooking the river mouth, recreated since 2015 by the volunteers of the Friends of Mrs York's Garden.

The area has been transformed into a place of natural beauty using native littoral rainforest and coastal headland species, as well as providing safe and attractive facilities for the local community and visitors to enjoy. It’s a place for admiring your native species, for exercise, recreation and solace.” (GPMVIC 2019)

More than 15 volunteers meet each Wednesday for a few hours to maintain the garden. Mrs York’s granddaughter, Glenys Pearson, is one of the volunteers and the only one who was willing and qualified to use herbicides to control weeds which were getting beyond the capacity of the group. Some of the group members would prefer that less herbicides were used on the site. The Hastings Port Macquarie Council bush regeneration team also taught the group weed control techniques.

In April 2019, Aus Eco Solutions offered to volunteer to use their saturated steam unit to keep on top of the weeds so Glenys did not have to use herbicides on the site. Three visits have been undertaken to date, and have been focusing on the thick blanket of coastal plain pennywort *Hydrocotyle bonariensis* Lam. and paspalum Paspalum dilatatum Poir. (RBG&DT 2019). The pennywort has proved challenging to control with multiple techniques tested to determine the best approach. Treatments three weeks apart appear to have been successful using both 300mm steam head followed by the spike, with the root systems showing signs of wilting as well as the foliage.

Saturated steam is most effective on plants in their initial growth stages and many species perish after their first treatment. For species requiring multiple treatments, keeping the treatments closer together allows the treatments to target the species when most vulnerable.

The volunteers have indicated that they are pleased to be able to work alongside the saturated steam unit. Glenys would usually control the weeds with herbicides on days when the other volunteers were not there but that could not exclude exposure to other park users.

Byron Shire Chemical-Free Landcare

Botanist Ellen White established Byron Shire Chemical-free Landcare (BSCFL) along with community members Hilary Bain and Asa Marks in response to the intention of Crown Lands and NPWS to aerial spray bitou bush along the coastline in the Shire (White 2019). BSCFL is sponsored by the Mullumbimby Centre for Sustainable Living and Environmental Education Inc.

Ellen had previously coordinated the regeneration of over 48ha of 50ha of bitou bush dominated coastline in the Dirrawong Reserve, Evans Head. This had given her the chance to develop not just the techniques but, as importantly, the timing and strategies for successful removal of bitou bush, coastal tea tree *Leptospermum laevigatum* and glory lily. *Gloriosa superba* (RBG&DT 2019), all abundant on the Reserve. Opposition to Ellen and her ecological philosophies saw her removal from the Dirrawong Reserve Trust and from project coordination. Funding was then provided to a non-volunteer group (White 2019).

In general the chemical-free approach was continued. However, bitou bush control was achieved by “a specialist abseiling bush regeneration team to spot spray or cut and paint Bitou Bush in difficult locations such as cliff faces” (Jarman B 2012). White (2019) reports that a recent visit to the Dirrawong Reserve noted that herbicides were now being used on less than 2ha of Bitou Bush that had remained from the original project over 10 years ago and that glory lily had again become rampant. This illustrates the value of project management remaining, where it is available, with dedicated and knowledgeable community volunteers (White 2019).

In May 2010 Byron Shire Chemical-Free Landcare volunteers began work on a 5ha parcel of Crown Land at Brunswick Heads with a small grant provided under the Caring for Country Program (de Souza Pietramale 2019). No further funding was provided as it was considered that chemical-free techniques were not ‘best practice’ (White 2019).

After nine years, the primary work was complete. Follow-up work on bitou bush seedlings has also nearly been completed. This site was once densely covered in bitou bush up to three metres high with large areas where coastal tree was dominant. The coast banksia *Banksia integrifolia* (RBG&DT 2019) woodland has returned, along with spinifex grassland on the frontal dune (de Souza Pietramale 2019). Two threatened species have been found on site (White 2019).

There have been challenges at the Brunswick site including the illegal spraying of herbicides. In May 2018, towards the end of the time-line for the North Coast National Bitou Containment Zone, the small remaining area the group was due to work on was sprayed, as well as scattered bitou bush seedlings throughout the site, leaving dead banksia saplings and dead native ground covers. Considerable time has also been spent dealing with the illegal campers, their fires, and their rubbish who moved in as bitou bush was removed (de Souza Pietramale 2019).

The group has since had new sites allocated to them including Saltwater Creek, adjacent to the Mullumbimby Community Gardens where workshops are held on "how to convert a Camphor Forest into rain forest with zero herbicides". There are also plans to create “an open classroom on how to implement sustainable land management in different ecosystems” (de Souza Pietramale 2019).

Friend of Success Hill Reserve in WA (FoSHR)

"Success Hill Reserve is a registered Class A bushland reserve and is increasingly under threat from the spread of invasive weeds and destruction of biodiversity, by trespass trail bike riders, loss of fauna from domestic cats, soil erosion, pollution of the groundwater and river ecosystems and most importantly threats to the Indigenous Heritage of this site.

Friends of Success Hill Reserve (FoSHR) commits to -

- Recognition and protection of the Indigenous Heritage of the Success Hill Reserve.
- Recognition and protection of the unique ecological biodiversity of the reserve.
- Pro-active management for the long term health and sustainability of the reserve through non chemical weed management.
- Ensure equitable and representative community engagement with state and local government."

(Town of Bassendean, 2019)

The FoSHR Facebook page shares posts about the successes and challenges managing weeds and other issues within the reserve. The techniques used for their non-chemical weed management approach are often shared i.e. Town of Bassendean cutting and mulching weeds (Facebook post on 6 December 2018) and a video of David White demonstrating removal of veldt grass Ehrharta calycina (DPI WA 2019) by chipping with a hoe (Facebook post on 23 January 2019).

Challenges have included timing of Council mowing being while weeds are in seed further spreading weed seeds (Facebook post on 6 December 2018 and Figure 1).

Figure 1. Examples of hand weeding compared with herbicide usage on adjoining riverbank at Success Hill Reserve (FoSHR Facebook page posts on 27 May 2019)

Byron Bay Council Chemical Sensitive Register

Byron Bay Council maintains a register for Chemical Sensitive Residents and Organic Growers. This approach is taken by Councils across NSW, where residents sensitive to chemical herbicide and certified organic or biodynamic growers can apply to Councils in writing to be placed on the Register using an official application form (Byron Shire Council 2019).

Details are kept confidential and only given to authorised spraying contractors for the purposes of notifying applicants of proposed spraying operations (Byron Shire Council 2019).

The difference with Byron Bay Council is that they allow residents to maintain their road frontage to alleviate the need for spraying. This policy is communicated to residents as part of their Pesticide Notification Plan on their website (Byron Shire Council 2019).

Byron Bay Council has updated their Pesticide Notification Plan and released a new version in April 2018 which now includes reference to the use of temporary signage for spot and direct application of pesticides, and acknowledges areas that have been nominated as pesticide free (Byron Shire Council 2019).

DISCUSSIONS

The common ground for all groups contacted in relation to this paper is the need to control weeds. There may be other groups or individuals that may dispute the need to control weeds but that has not been explored in this paper. As highlighted in the introduction, the media is increasingly reporting on communities opposed to the use of the herbicide glyphosate. Herbicide opposition is not new, with groups like the National Toxics Network (NTN) being established 25 years ago.

Those that support the use of herbicides see them as an efficient way to control weeds as part of an IWM program. At the other extreme those that oppose the use of herbicides see them as a toxicology risk and prefer the precautionary approach to be taken.

Those that support the use of herbicides do not necessarily dispute that there are hazards associated with the use of herbicides, but accept that residual risk when compared to the biosecurity risks posed by weeds.

The Toxicology Foundation Education website (2019) states that it “is important for understanding the role of toxicology in assessing risks. A hazard is anything that can cause harm, whereas risk is the potential for a hazard to cause harm. In virtually every situation, whether the hazard is chemical, biological, or physical, you can usually decrease your exposure such that the hazard does not pose any significant risk.”

So the contentious issue in this debate is how much exposure to the hazard (i.e. herbicide) does not pose any significant risk. Both cases can be backed by peer reviewed science to support each stance.

The author explored some of the science surrounding toxicology risks of the herbicide glyphosate in a paper presented at the 18th NSW Weeds Conference in Cooma (Guppy et al., 2015 and Winer 2014) and since this time further studies have been released on impacts of glyphosate on human health (Zhang et al. 2019), waterways (Dabney and Patinob 2018), soil (Herbert et al. 2018) and bees (Motta et al. 2018).

In Australia, herbicides must be registered with the Australian Pesticides and Veterinary Medicines Authority (APVMA). The APVMA use a weight-of-assessment approach which considers both the number of studies reporting a particular conclusion as well as the quality of the study design and data analysis. Regulators do not use strength-of-evidence assessments which can be based on a single study (APVMA 2019).

The National Toxics Network challenges the scope of the testing guidelines that the APVMA uses as developmental neurotoxicity or endocrine (hormone) disruption are not evaluated nor exposure to multiple pesticides and other ingredients. NTN also highlights that foetuses, babies and children are more vulnerable to pesticide exposure impacts and less able to detoxify chemicals (NTN, 2009). The NTN also highlights that Australia does not have a systematic review program for pesticides which are in place in the United States, Canada and European Union. (NTN, 2017).

So we have a situation with both sides stance backed by science, and the crux of the debate is how much exposure is acceptable? The theme of the 20th NSW Weed Conference is “putting the we in weeds”, so how do we move forward with communities in conflict over the use of herbicides?

The NTN website page (2019) states that community engagement in chemical management is a right that the Australian Government signed in the international Bahia Declaration on Chemical Safety 2000 that “communities have a right to participate meaningfully in decisions about chemical safety that affect them.”

There are many ways to engage with communities opposed to herbicides and learnings can be gleaned from previous experiences, particularly where there is community conflict. After analysing community engagement for a controversial wind energy proposal, Colvin et al. (2016) propose that a collaborative and participatory approach is expected to provide better outcomes than traditional approaches where there is no decision making powers for affected communities.

Points have been extracted below that could be applied to engaging with communities opposed to herbicides.

“Attributes of this higher-level of community involvement which differ from the traditional approach to community engagement include:

- genuinely incorporating community input into project planning and design (Hindmarsh, 2010; Hindmarsh and Matthews, 2008; Jami and Walsh, 2014);

- building and maintaining trust between proponent and community (Alberts, 2007; Hall et al. 2015);
- exceeding minimum (mandated or legislated) requirements (Anderson, 2013; Fast et al., 2016; Hall and Jeanneret, 2015; Howard, 2015; Soma and Haggett, 2015);
- establishing community consultative committees (Fast et al., 2016; Howard, 2015);
- forming a long-term commitment to and relationship with the community (Anderson, 2013; Fast et al., 2016; Hindmarsh and Matthews, 2008; Jami and Walsh, 2014; McLaren Loring, 2007);
- and avoiding incendiary settings, such as town-hall meetings which can descend into a "shouting match" (Hall et al. 2015, p. 306)"

(Colvin et al. 2016. p484)

Notifications of herbicide usage are another area that could be explored further with community input. Councils in NSW maintain a chemical sensitive register to enable those on the register to be notified of herbicide spraying activities. Reactions to these notifications within Midcoast Council vary from those with chemical sensitivity health issues who appreciate the notification so they can relocate from their home at that time, to a local beekeeper who claims it is inconvenient to him to have to move his bee hives (Inkson, 2019).

With the rise of environmental issues i.e. climate and biodiversity emergencies, increasing numbers of people are not only voicing their concerns but also wanting to take direct action. This is an opportunity to work collaboratively with communities to tackle weed problems, particularly where people are willing to volunteer to control weeds without herbicides and plant native vegetation to outcompete weeds.

Considering the case studies and information presented in this paper the following ideas provide a summary of key points for working collaboratively with community groups opposed to herbicides:

- Adopt a collaborative and participatory approach to community engagement
- Meet, listen and incorporate community input into herbicide usage reviews
- Build long term relationships with community groups and keep dialogue open
- Provide opportunities for people to volunteer to control weeds without herbicides and/or plant native vegetation to outcompete weeds
- Nominate herbicide free public areas i.e. parks or gardens
- Set targets to reduce herbicide usage - measure and report progress to the community
- Learn about the effectiveness of non-chemical weed control methods from local groups utilising these techniques, and at a State level capture in Weedwise website/app and Best Practice Weed Control Guides
- Further explore community expectations around herbicide notification processes
- Allow residents to maintain their road frontage to alleviate the need for spraying
- Ensure contractors and Council crews respect areas set aside as herbicide free, especially those maintained by the community

CONCLUSION

Greta Thunberg has been widely quoted as saying "Change is coming whether you like it or not" (Thunberg, 2019) and we can see this change with communities becoming increasingly vocal opposing the use of herbicides in public spaces both internationally and across Australia.

These changes are also presenting opportunities to "put the we in weeds" and adopt a collaborative and participatory approach when working with community groups opposed to herbicides.

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WEED SEED BANKS OF AUSTRALIAN VEGETABLE FIELDS

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SUMMARY

Soil seed banks form a key source of weed infestation in vegetable crops, since frequent disturbance favours the formation of large and persistent seed banks. To assess the abundance and species richness of weed seed banks in vegetable fields, a survey was carried out across seven States and Territories in Australia. Soil samples were collected from 36 vegetable farms to a depth of 20 cm. Weed seeds for each sample were counted using the seedling emergence method, and identified to species or genus level. A total of 43 dicotyledonous and 20 monocotyledonous species were recorded in soil seed banks. *Portulaca oleracea* L. was the most widely distributed and abundant species occurring in 20 of the 36 sites and had a mean seed bank density of 1,418 ± 752 seeds m-2. Northern Territory farms had the largest seed bank (12,762 ± 7,384 seeds m-2), while Victorian farms had the smallest (2,774 ± 932 seeds m-2). On average, seed of dicotyledonous species were slightly more abundant (4,105 ± 978 seeds m-2) than those of monocotyledonous species (3,629 ± 1,286 seeds m-2). Higher abundance of certain species may be a function of their dormancy, longevity and persistence in soil, prolific seeding, and tolerance to wide temperature ranges. Therefore, this study suggests that a site and agro-ecosystem specific study of the seed bank is needed to help farmers design effective weed management strategies.

Keywords: seed bank density, species richness, dicotyledonous, monocotyledonous, ecosystems.

INTRODUCTION

Weeds are a persistent and significant problem in Australia's vegetable industry, which was valued at approximately $3.45 billion in 2016-17 (AusVeg, n.d.) They are capable of out-competing crops, reducing crop yield and quality, and increasing farm management expenses (Kristiansen et al., 2014; Coleman et al., 2015).

Substantial advances have been made in the last 20 years in more sustainable Integrated Weed Management (IWM) in broadacre industries (Charles et al., 2013; Storrie, 2014) and many of these advances are applicable in the more diverse vegetable industry, which features a large variety of crops and therefore, diverse production systems.

The regular soil disturbance in vegetable farming (e.g. cultivation of soil) favours short-lived annual weeds, many of which produce seed early (they are precocious) and prolifically and create a large weed seed bank (Kristiansen et al., 2014). For vegetable farmers, depletion of weed seed banks in soil is an important strategy in controlling weeds, and can be supported through an in-depth understanding of the weed seed population. However, studying the weed seed banks in vegetable cropping has received little attention globally or more particularly in Australia. Soil seed banks have been quantified in rice fields in Australia (McIntyre, 1985) and China (Li et al., 2012) and continuous cropping of wheat and wheat included in crop rotation in Iran (Hosseini et al., 2014). In Australia, seed banks of forest and woodlands in north-west Victoria (Callister et al., 2018), grassy woodland in Western Australia (Graham et al., 2004), forest and pastures and grazing lands (Lunt, 1997; Kinloch and Friedel, 2005a; Kinloch and Friedel, 2005b), urban eucalyptus forest reserves (Odgers, 1994), alpine summits (Venn and Morgan, 2010) and rainforest in North Queensland (Graham and Hopkins, 1990) have also been recorded. These studies show a large variation in the size of the seed bank and its species composition. Further, weed seed banks in vegetable production may differ from these studies in other ecosystems.

The aim of this research was to conduct a baseline study of species richness and abundance of soil weed seed population across Australian vegetable fields. This work is being undertaken as part of a larger industry-funded project on strategic and integrated approaches to weed management for the Australian vegetable industry.

METHODS

Site descriptions

The study included 36 vegetable farm sites across a number of major vegetable growing regions in Australia: 5 sites in the Lockyer Valley (Queensland); 5 in the Sydney Basin (New South Wales); 5 in the Cranbourne and Gippsland regions (Victoria); 5 in the Devonport/La Trobe regions (Tasmania); 5 in the Adelaide Hills and Gawler regions (South Australia); 5 in the Darwin region (Northern Territory); and 6 in the Gingin and Myalup regions (Western Australia). The geography and climate differs between each region and at least one or two management practices differed between sites.

Soil sampling for the weed seed bank

At each farm, a paddock that was typical of the farmer's vegetable production system was selected for sampling. Seed banks were sampled from vegetable fields between March and December 2017. Adapting methods used by Forcella et al. (1992) and Hartley and Rahman (1995) we used a 50 mm diameter soil corer to systematically collect soil samples from each paddock. Sample points were at least 10 metres apart, and the sampling pattern followed a 'W' pattern across the sample paddock, where this was feasible. Paddock boundaries were excluded in order to avoid edge effects. This systematic approach sought to maximise the representativeness of the weed seed bank from each paddock within the soil samples.

Soil samples were collected at 0-5 cm, 5-10 cm and 10-20 cm depth increments to allow analysis of the weed seed bank at different depths within the soil profile. Ten soil cores were collected at each paddock site, and the soil was bulked by depth increment.

Weed seed bank assessment

The seedling emergence/germination method was adopted for this study as it ensured all germinable seed were counted. Three replicate subsamples of soil from each farm site/depth increment combination were used for seed germination. Following Hartley and Rahman (1995), 20 mm of vermiculite was placed in small plastic trays, with a water-permeable mesh placed on top. Approximately 300-400 g of moist soil (20 mm depth) was placed on top of the mesh layer, and the mass of the soil recorded for each tray. A 20 g subsample of soil for each depth was dried at 105°C to determine the dry weight of soil added to each tray.

Trays were placed in a glasshouse with a 15°C to 25°C daily temperature cycle, and watered regularly from below to provide moisture for germination. Given its warmer climate, the temperature cycle was modified for germination in soils from the Northern Territory to 22°C to 28°C. Weeds were counted and removed as soon as they had germinated and were large enough to identify. Weeds that we were unable to identify at the cotyledon stage were planted out in a separate pot and grown to maturity to allow identification to species, genus, family or type (e.g. monocot), where this was possible.

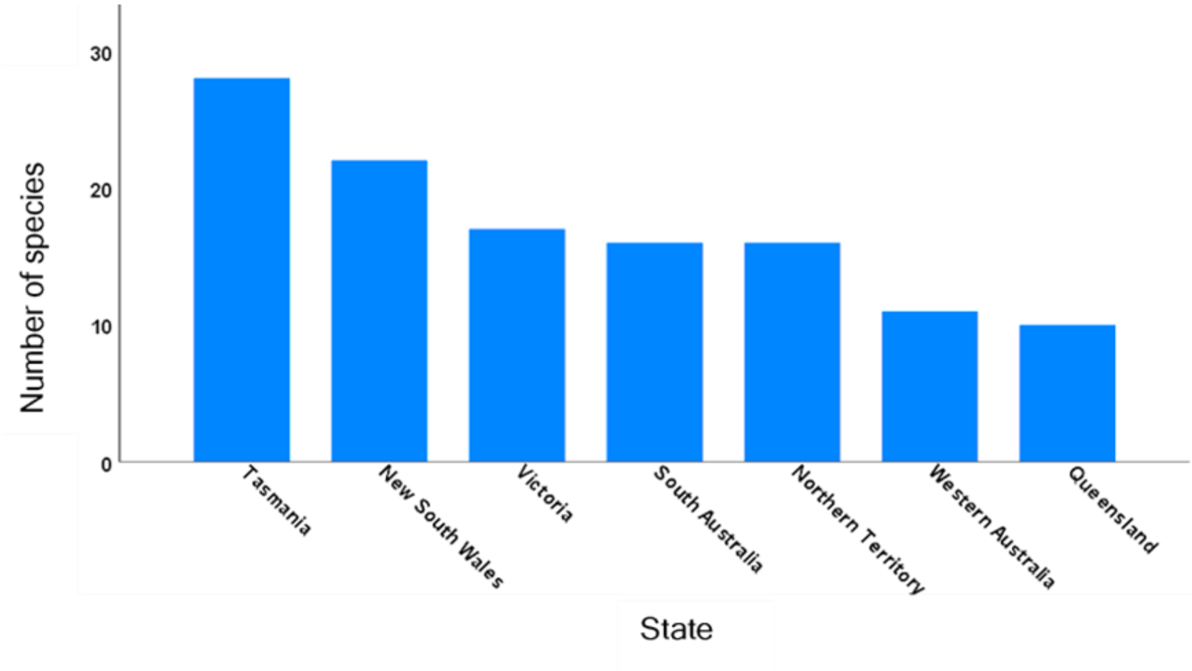
Once each flush of germination was complete (approximately one month), dormancy breaks (drying down, and/or two week refrigeration, and soil stirring) were used to stimulate additional cohorts of weeds. This process was repeated over several months until all apparently viable seed had been germinated.

Data analysis

For the analysis of data, total number of seeds to a depth of 20 cm for each paddock (site) was used. Species richness and their distribution (occurrence) were analysed using basic count functions in Microsoft Excel. Analysis of variance (ANOVA) was used to test whether the differences in seed bank density of monocotyledonous and dicotyledonous weeds were significant. The differences in mean seed bank density between the five most abundant species were also tested by ANOVA in SPSS (IBM Corp., 2017).

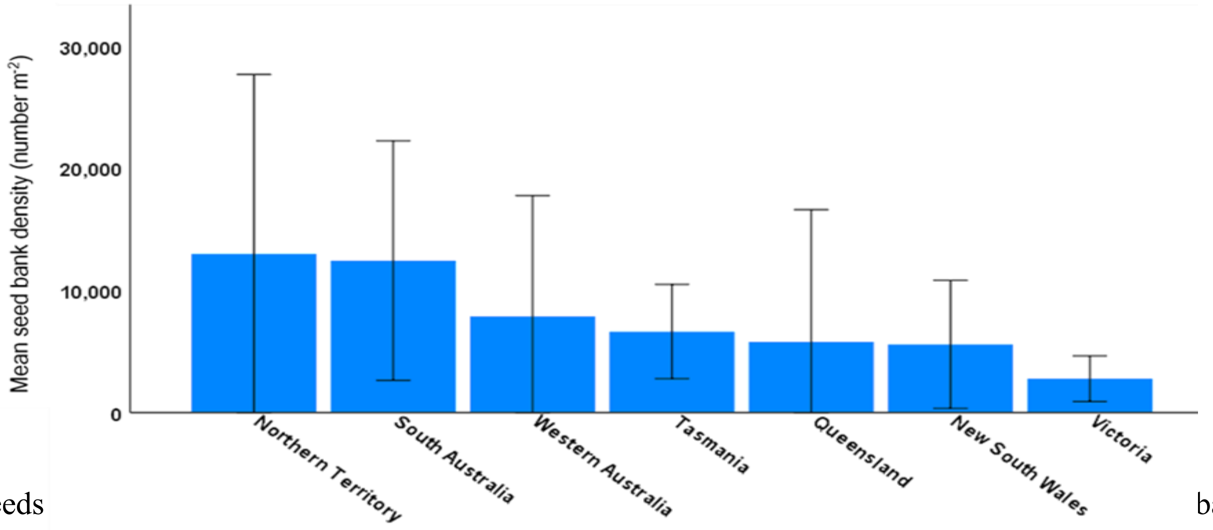
RESULTS

Dis-



tribution of weeds in seed banks on vegetables farms in Australia

A total of 63 species was recorded at the survey sites of which 43 were dicotyledonous and 20 monocotyledonous species. Out of the total species, the highest species richness was found in Tasmania (Tas) with 28 species of weed, and lowest in Queensland (Qld) with only 10 species (Figure 1). The highest species richness per site was 15, and was recorded at a site in Tasmania where all the sites had vegetables at the time of sampling while previous crops varied betweed sites ranging from vegetables to pastures. Survey sites feature a temperate climate, and relatively small seasonal variation (Tasmanian Government, n.d.).



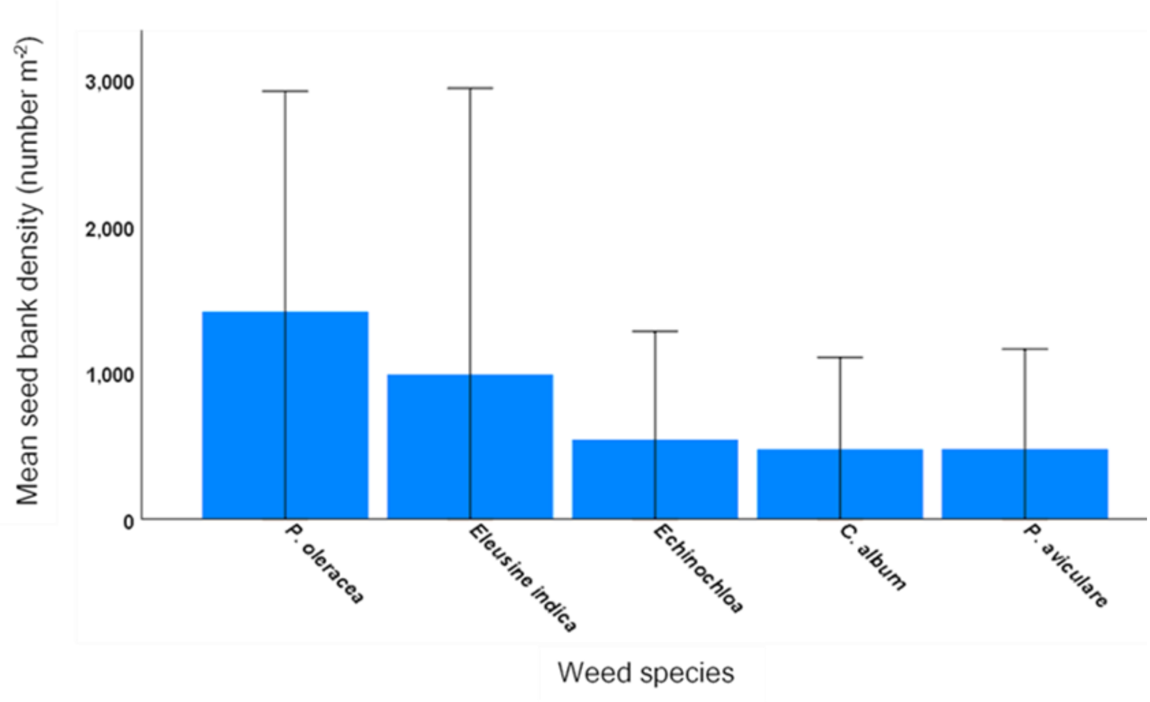
Weed seeds bank density of 12,762 ± 7,384 seeds m-2. Abundance was ian (Vic) farms with a mean weed seed bank density of 2,774 ± 932 seeds m-2 (Figure 2). The highest weed seed bank density recorded at a single site was 40,407 seeds m-2 in a field in the NT, while one of the sites in Qld did not yield any seedlings in the glasshouse germination trial.

State	Number of sites where each weed species was present							
	Tas	NSW	NT	Qld	WA	Vic	SA	Total
Portulaca oleracea L.	1	4	2	3	5	4	1	20
Chenopodium album L.	2	1	0	2	3	0	4	12
Solanum nigrum L.	3	3	0	0	0	1	4	11
Polygonum aviculare L.	1	2	0	0	3	1	4	11
Fumaria sp. L.	4	1	0	3	2	1	0	11
Stellaria media L.	4	0	0	0	1	4	1	10
Echinochloa sp. L.	2	2	3	1	0	2	0	10
Sonchus oleraceus L.	1	1	0	2	1	1	3	9
Capsella bursa-pastoris (L.) Medik.	3	0	0	0	2	4	0	9
Urtica urens L.	0	0	0	0	0	4	3	7
Sites surveyed	5	5	5	5	6	5	5	36

Figure 2. Abundance of weed seed in the seed bank in different states. Error bars indicate 95% CI for the mean.

Most common weed species found in seed banks on vegetables farms in Australia. Among the 63 recorded species, Portulaca oleracea L. was the most widely distributed weed, being found at 20 of the 36 survey sites (Table 1). Of all the species observed, 25 were found on only one site.

Table 1. Distribution of the 10 most widely distributed weed species across the survey sites. Note: Tas=Tasmania, NSW=New South Wales,



NT=Northern Territory, Qld=Queensland, WA=Western Australia, Vic=Victoria, SA=South Australia

State/ Territ.	Weed seed bank density (number of seeds m^{-2})				
	P. oleracea	*E. indica*	*Echinochloa* sp.	*C. album*	*P. aviculare*
NSW	626 ± 304		224 ± 181	71.1 ± 71.1	60.7 ± 46.6
NT	120 ± 120	7,122 ± 7,011	421 ± 209		
Qld	1,704 ± 1,654		2,609 ± 2,609	48.3 ± 30	
SA	5,222 ± 5,222			697 ± 257	837 ± 518
Tas	479 ± 479		43.2 ± 26.8	290 ± 180	108 ± 108
Vic	84.9 ± 27		618 ± 600		2,372 ± 2,357
WA	1,450 ± 571			1,944 ± 1,864	121 ± 85.1
Total	1,418 ± 752	989 ± 976	544 ± 369	478 ± 313	479± 340

Among all the recorded weed species, P. oleracea was most abundant in the soil, with a mean seed bank density of 1,418 ± 752 seeds m-2. Mean seed bank densities of the five most abundant species did not differ significantly ($p = 0.767$) (Figure 3). These five species constituted 50% of the total seed bank recorded across all sites.

Portulaca oleracea, the most abundant species in terms of the size of seed bank, was most abundant in SA with a mean seed bank density of 5,222 ± 5,222 seeds m-2 and C. album, P. aviculare and Echinochloa sp. were most abundant in Western Australia (WA), Vic and Qld respectively (Table 2). Eleusine indica (L.) Gaertner was present only in the NT . All the recorded species were grouped into monocotyledons and dicotyledons. The mean seed bank density of dicotyledonous weeds was higher (4,105 ± 978 seeds m-2) than that of monocotyledonous weeds (3,629 ± 1286 seeds m-2) but the difference was not statistically significant ($p = 0.769$). Monocotyledonous weeds were most dominant in the NT (12,262 ± 7,310 seeds m-2) while dicot weeds were more dominant in SA (10,594 ± 5,061 seeds m-2).

Figure 3. Abundance of the five most common weed species in the seed bank. Error bars indicate 95% CI for the mean.

Table 2: Seed bank density of most abundant weed species in different states and territories. Means and standard errors are shown.

DISCUSSION

This study appears to be the first research carried out on soil weed seed banks in Australian vegetable fields. The results showed a wide variation in species richness and viable weed seed population size across the sites. In a comparable study, the number of weed species recorded in 58 vegetable fields in England ranged from less than eight to more than 25 per field, and the seed bank size ranged from 1,600 to 86,000 seeds m-2 (Roberts and Stokes, 1966). Other similar studies in vegetable cropping in England reported 76 species of weed with the seed bank per site ranging from no seeds at one site to 24,300 seeds m-2 at another (Roberts and Neilson, 1982) and in a second study, 20 weed taxa per garden, with one garden recording 53 taxa (Thompson et al., 2005). Roberts (1968) reported lower abundance of 1,386 to 3,240 seeds m-2 in vegetable fields while Roberts (1963) reported a higher seed abundance of 2,773 to 46,819 seeds m-2. In a study of onion fields in the United States, abundance was between 11,000 and 20,000 seeds m-2 (Cavers and Benoit, 1989). The peak in seed abundance in the study by Roberts (1963) is considerably higher than the highest seed bank recorded per site per species in vegetable fields in our research (26,107 seeds m-2 for P. oleracea).

Seed bank species richness and abundance of weed seeds in soil can vary depending on the soil characteristics and fertiliser and manure application (Cavers and Benoit, 1989) and other management practices such as tillage, crop rotation (Bàrberi and Lo Cascio, 2001; Cardina et al., 2002; Steckel et al., 2007; Chauhan and Johnson, 2009) and mulching (Gibson et al., 2011). Differences in weed seed populations in soil among the survey sites may be due to differing farm management practices such as frequency and depth of tillage, residue management, weed management practices, and cropping history. Similarly, varying climatic conditions of the study sites may have affected this variability, since different weather patterns and climatic conditions can influence the relative pressure of some weed species by affecting their germination or growth and development (Chauhan and Johnson, 2008; Feng et al., 2015; Ramesh et al., 2017). In our study, these influences are illustrated by P. oleracea, a cosmopolitan weed species that occurred in 50% of the sites surveyed, while occurrence of some (40% of the recorded) species was limited to only one site.

The results from different studies also clearly show that weed species richness differs between land use systems and as a result of specific management practices. Crop management practices are also known to influence overall weed population dynamics (Cavers and Benoit, 1989). But even within the similar vegetable cropping systems surveyed across Australia in this study, the variation in species richness is relatively high. Factors such as paddock use history, weed management systems, climate and soil conditions, and crops grown are all likely to influence the ability of weeds to reach reproductive maturity and to produce viable seed (Mohler et al., 2018; De Cauwer et al., 2019). In addition, ecophysiological factors such as seed longevity, dormancy and capacity to move in the soil will also determine the types of weed seed present in the soil and their density (Benvenuti, 2007; Long et al., 2015; Davis et al., 2016).

Six of the 10 most commonly occuring weed species in our study (*P. oleracea, S. media, U. urens, C. bursa -pastoris, C. album, P. aviculare*) were also among the most frequently occuring species in vegetable fields in England and Brazil (Roberts and Neilson, 1982; Cardoso et al., 2016), and are widely known to be problematic weeds (Tei et al., 2005; Feng et al., 2015; CABI, 2018). Some of these species were also found in Australian rice fields (McIntyre, 1985), grazing lands (Kinloch and Friedel, 2005a) and grassy wood-lands (Graham et al., 2004), suggesting their adaptability to different ecosystems and geographical regions.

For example, P. oleracea, the most widely distributed species in vegetable fields in this study, is also found in Eucalyptus grassy woodlands in Australia (Graham et al., 2004). However, in general, specific weed species tend to be associated with specific crops or cropping systems (Fargione et al., 2003; Gunton et al., 2011; Pinke and Gunton, 2014).

Most of the species occuring more frequently in vegetable crops in this study were also found to have high seed bank densities in other studies. Some of these species, such as *P. oleracea* and *C. album*, are major contributors to the seed bank in arable lands (Cavers and Benoit, 1989). Their abundance in the seed bank in this study varied from those reported earlier: *P. aviculare* has been found elsewhere to have a seed bank density of 380 seeds m-2 in rice (McIntyre, 1985), and about 2,000 seeds m-2 in vegetables (Roberts and Stokes, 1966; Roberts and Neilson, 1982); *C. album* has between 2,400 seeds m-2 (Roberts and Neilson, 1982) and 5,400 seeds m-2 (Roberts and Stokes, 1966) and *E.indica* 10,300 seeds m-2 (Chuah et al., 2004). The high abundance of these species is likely to be a function of their dormancy, longevity and persistence in soil, production of a high number of seeds, and tolerance to wide temperature ranges (Guillemin et al., 2013; Feng et al., 2015; Long et al., 2015). Seeds of C. album (Bassett and Crompton, 1978) and *P. oleracea* (Miyanishi and Cavers, 1980) can remain viable in the soil for decades. They can also tolerate a wide range of temperatures, are small-seeded and form persistent seed banks. *Polygonum aviculare* seeds are innately dormant and can undergo cyclic changes in physiological dormancy depending on their exposure to different weather conditions and soil disturbances (Courtney, 1968) and hence support the formation of a more persistent seed bank. Similarly, *Echinochloa crus-galli* produces a large number of seeds. Freshly produced seeds are innately dormant, and can remain in the soil for 8-9 years, also favouring the formation of a persistent seed bank (Meun and Barrett, 1986). Finally, *E. indica* also produces a large number of seeds, and these can remain viable in the soil for more than three years (Hawton and Drennan, 1980).

We found that the soils of vegetable fields in Australia are infested with seeds of some of the most problematic weeds (HerbiGuide, 1988-2014; Eslami, 2011; Kristiansen, 2015) and their degree of infestation varies with geographical site. These findings suggest that niche-specific studies of seed banks in a particular agro-ecosystems are necessary to draw robust conclusions. This information can be used to support farmers in decision-making for effective weed management.

In this way, the farmers who participated in the study may already benefit from the specific picture of the weed seed bank on their farm, by understanding which weeds are present, the size of the seed bank, and stratification within the soil profile. This information could be linked to their current practices and potentially used to inform decisions about changing their weed management approach. For example, weed seed bank data that indicates seed from a particular weed species is most likely to be found near the surface may suggest shallow tillage operations to germinate and then control this seed bank, combined with activities to prevent the weed seeding within the crop.

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STOPPING THE INVASION OF CHINESE KNOTWEED (*PERSICARIA CHINENSIS*) – A HERBICIDE SOLUTION

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SUMMARY

Invasive weeds impact the economy and society globally and contribute significantly to the ecological degradation to the environment both terrestrially and aquatically. Weed incursions have continually established themselves in Australia since European settlement and will continue invading into the future. One new weed incursion which has been recently discovered invading two localised areas within NSW is *Persicaria chinensis* (L.) H. Gross, commonly known as Chinese knotweed. This weed has been assessed as a highly invasive species. With limited literature and research available on the control of this species of Persicaria, a field trial using registered herbicides was established to find the most efficient and effective herbicide options to control these incursions treatment. The application of a metsulfuron-methyl was the most effective with 100% control at 47 days after treatment (DAT), followed by a mixture of metsulfuron-methyl and glyphosate with 100% control at 111 DAT. Repeated treatments of a foliar spray are required for two other herbicides used in the trial. Current research for an effective herbicide has been very limited, with this study identifying effective herbicide options for controlling Chinese knotweed in Australia.

Keywords: invasive weed, new incursion, herbicides, metsulfuron-methyl.

INTRODUCTION

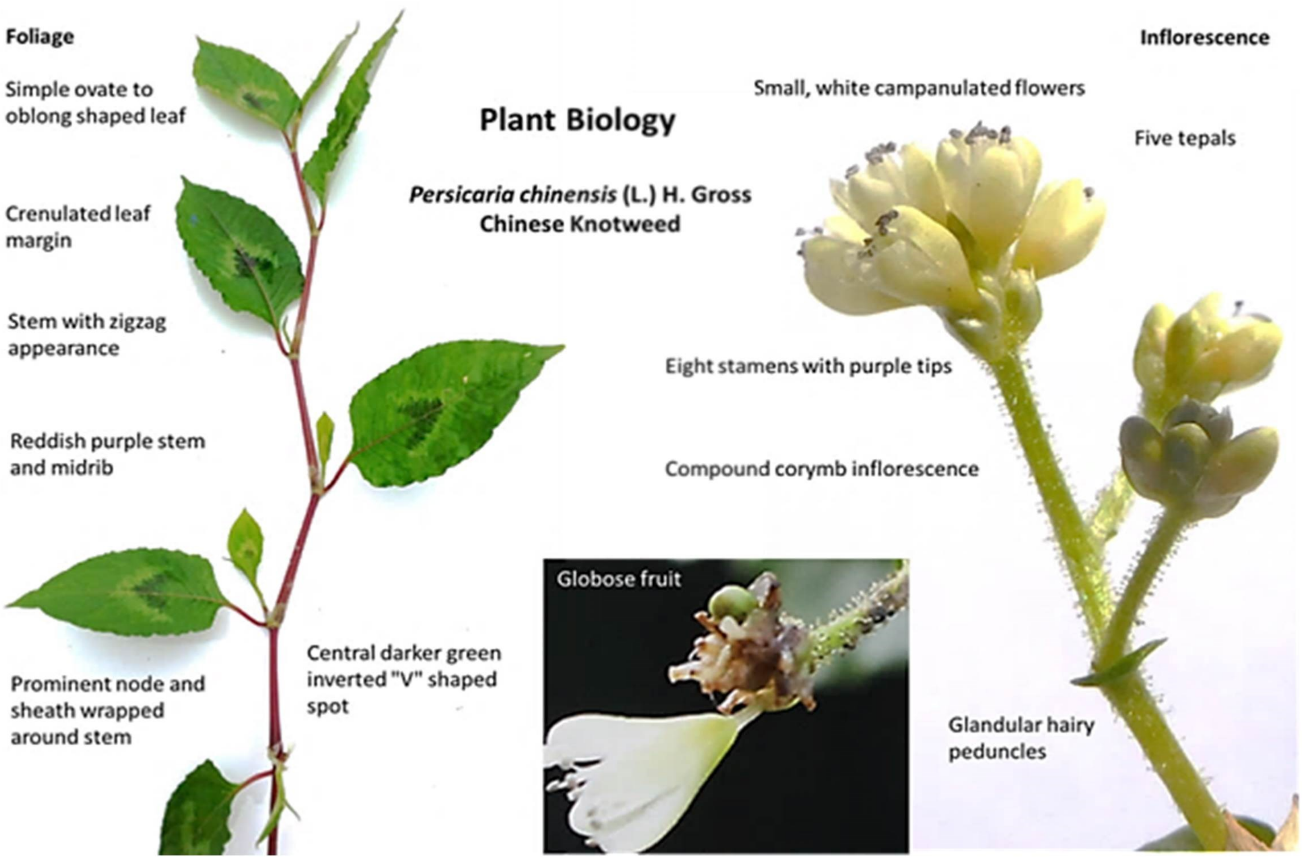
This paper has two aims: to review what is known about the biology of Chinese knotweed; and subsequently, to identify the most effective herbicide to treat and eradicate Chinese knotweed within riparian corridors of New South Wales.

CHINESE KNOTWEED (*Persicaria chinensis*)

Description

Persicaria chinensis (L.) H. Gross, (synonym. *Polygonum chinense*) known as Chinese knotweed, is a scandent, divaricately branched perennial plant with stems and branches that are reddish purple in colour, glabrous and spineless with prominent nodes, and have a zigzag appearance. The stipules form a sheath on the stem, are membranaceous and glabrous with no hairs at the margin (Stuart 2015, Sasidharan n.d). The leaves are simple, alternate, ovate- to oblong-shaped entire with an acuminate apex, truncate base, 50-100 mm long and 30-70 mm wide. The leaf margins are

minutely crenulated; the midrib violet-red, the upper surface of leaf with a central darker green inverted "V" shaped spot (eFloras 2011a and b, Sasidharan n.d.) The inflorescence is a compound corymb, arranged terminally or in terminal and auxiliary positions while the peduncles are glandular and hairy (eFloras 2011a and b). The flowers are campanulate, small, white or pinkish in colour, 2.0 to 3.5 mm bearing 5 tepals, and 8 stamens with purple tips (eFloras 2011a and b, EoL 2014). The fruit are globose in shape turning



dark purple when ripe. The seeds are trigonous (triangular in cross-section), small 3 to 4 mm round and black (Stuart 2015, Sasidharan n.d) (Figure 1).

Figure 1: Plant biology close up of Chinese knotweed looking at the foliage, inflorescence and fruit. (Images: Hignell)

Habit

Chinese knotweed is a rhizomatous herbaceous perennial from the Polygonaceae family from South-east Asia (IPNI 2012) and is known as a high-risk invasive species (Wong el. at. 2015). Chinese knotweed has been described as an upright, shrub-like perennial (Galloway and Lepper 2010), a twining perennial herb (Stuart 2015), a scrambling herb (Turner 1995) and a rhizomatous perennial that sometimes climbs (Wilson 2010). Chinese knotweed can reach a height of 1 to 1.5 metre (Turner 1995, Wilson 2010, EoL 2014, Stuart 2015). It is closely related to other invasive Persicaria species such as princes feathers (*P. orientalis*), Japanese knotweed (*P. capitata*), and mile-a-minute weed (*P. perfoliata*) (Randall 2012).

This plant grows rapidly, forming thick canopies that have the ability to smother native plants (Galloway and Lepper 2010). Naturally growing from sea level to 3000 m (eFloras 2011b), Chinese knotweed can be found growing in open moist grounds (BHPS 2002), gardens, riparian zones, roadsides (Galloway & Lepper 2010; U.S. Forest Service 2010; EoL 2014) and swamp margins (Wilson 2010; EoL, 2014).

As a new incursion into New South Wales, particularly invading riparian zones (PlantNET 2016), research to identify the most effective control techniques to reduce its impact on the environment is required. There is limited information regarding effective control using herbicides (U.S. Forest Service 2010).

MATERIALS and METHODS

Trial site

The study was conducted within the riparian corridor at Little Flaggy Creek, Kahibah Road, Kahibah, within the Lake Macquarie local government area on the Central Coast of NSW. Little Flaggy Creek flows from Charlestown to the west of the site to the east into Glenrock State Conservation Area then into the Tasman Sea. This site has been infested with Chinese knotweed since the discovery of the incursion in 2012 (PlantNET 2016).

The trial site has creek banks up to 2 m high with full sunlight and a minimal amount of dapple shading early morning on the eastern end of the site. The Chinese knotweed has been growing to between 1 and 1.5 m high, covering the entire northern side of the bank. There were 25 plots established to allow 5 replicates of each treatment at the site. Each plot size was 1.5 m by 3 m with a 100% ground coverage of Chinese knotweed.

Application

The applications of herbicides for this trial were performed under the APVMA permit, to allow the conduct of small scale trials with AGVET chemicals - PER 7250. Application of the herbicides was via a 10 L portable knapsack using a variable cone nozzle and a water rate of 3L per 4.5 m2. Four herbicide applications and one control were randomly selected in each of the 5 replicates. All the herbicide treatments were applied to actively growing Chinese knotweed before flowering stage.

Weather condition At the time of application on the 24 December 2015, starting at 8:00am, weather conditions were a partly cloudy morning with the dry bulb temperature at 20°C, the humidity was at 87% and a light breeze from the south-east at five km/hr. Light rain had fallen overnight but the moisture on vegetation had evaporated by application time. No rain fell within twenty-four hours after application.

Herbicides All herbicide applications were applied as a foliage spray and each treatment was applied according to recommended commercial standards as stated on the herbicide labels. Three individual herbicides and a mixture of two herbicides were used for this trial and were applied once only. Each herbicide was selected from a different 'mode of action' group to allow for the management of herbicide resistance.

The first herbicide was a glyphosate product, Eraze 360 Bi-aquatic™ herbicide; with an application rate of 100ml 10L-1. Glyphosate is a broad-spectrum herbicide of choice in agriculture, urban parks, gardens, and waterways due to its low toxicity to the environment (Sánchez-Bayo et. al. 2010).

The second herbicide was a metsulfuron-methyl product, Metmac 600 WG™, with an application rate of 1g 10L-1. Metsulfuron-methyl is a systemic selective herbicide targeting broadleaf and woody weeds and is very effective on weeds that include bulbs or tubers (Spencer 2012). There is an APVMA minor use permit PER14734 to use metsulfuron-methyl on Alligator Weed in waterways of NSW (APVMA 2015).

The third herbicide was a packaged mixture of amitrole and ammonium thiocyanate, labeled as Amitrole T™, with an application rate of 28ml 10L-1. Amitrole and ammonium thiocyanate is another broad-spectrum herbicide routinely used for clearing weeds in irrigation channels (Sánchez-Bayo et. al. 2010).

The fourth herbicide treatment was the Mix of glyphosate and metsulfuron – methyl. The application rate of the glyphosate was100ml 10L-1 and metsulfuron-methyl at 1gm 10 L-1.

Assessment

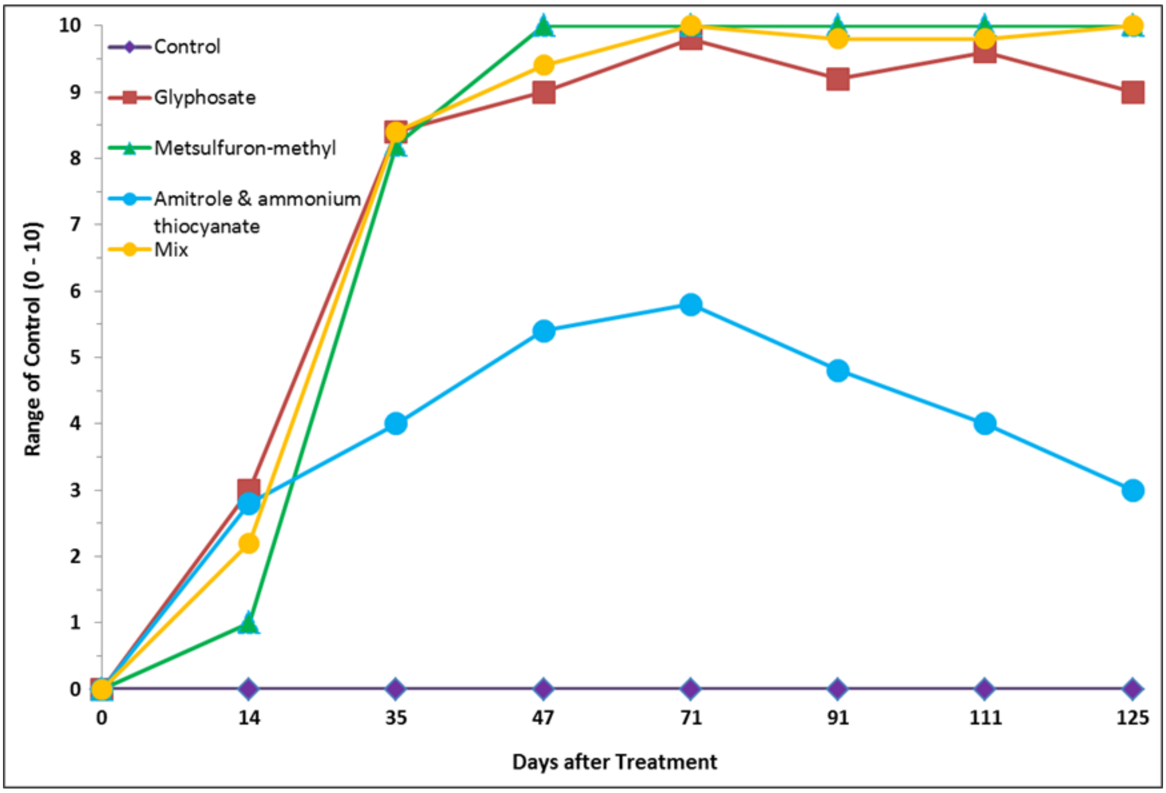
Control assessments were undertaken in the centre 1 metre of area in each plot so that any influences from the adjacent plots were negated. A subjective visual rating of 0 to 10 (Table 1) was used to assess the control efficacy of each treatment. The scoring indicates a commercially accepted rate of control by

Table 1. The subjective visual rating score used control efficacy assessment

Rate of Control	Visual Appearance	Percentage of Control
0	Nil Control with no wilting or leaf colour change	0%
1	Wilting, Leaf drop, Leaf colour change	10%
2	Wilting, Leaf drop, Leaf colour change, Dieback and/or Regrowth	20%
3	Wilting, Leaf drop, Leaf colour change, Dieback and/or Regrowth	30%
4	Leaf drop, Leaf colour change, Dieback and/or Regrowth	40%
5	Leaf drop, Leaf colour change, Dieback and/or Regrowth	50%
6	Leaf colour change, Dieback and/or Regrowth	60%
7	Leaf colour change, Dieback and/or Regrowth	70%
8	Dieback and/or Regrowth	80%
9	Dieback and/or Regrowth	90%
10	Total Control with no regrowth	100%

RESULTS

The results presented in Figure 2 indicate that there is little difference in the control efficacy of Chinese knotweed between the three herbicide treatments, metsulfuron-methyl, glyphosate and the Mix of these two herbicides. All three treatments significantly reducing the health and coverage Chinese knotweed in all plots at 35 DAT and continued to trend through to 125 DAT retaining a percentage control of 90% or above from 47 DAT.



The most effective herbicide of the trial was metsulfuron-methyl, with a control score of 10 from 47 to 125 DAT without regrowth. Metsulfuron-methyl was the slowest activating herbicide at 14 DAT, with only the visual appearance of leaf colour change observed. The Mix treatment was second by achieving a control rate score of 10 at 111 DAT and this continued through to 125 DAT with no regrowth present. Glyphosate was the fastest activating herbicide at 14 DAT with wilting and leaf drop, then matched the rate of control at 35 DAT with metsulfuron-methyl and the Mix but evidence of regrowth was present at 91 DAT and again at 125 DAT. The packaged mixture of amitrole and ammonium thiocyanate had poor control on Chinese knotweed. Its control efficacy peaked at 71DAT with a score of 6, then declined steadily and regrowth of Chinese knotweed became evident after 71 DAT.

At 35 DAT, metsulfuron-methyl, glyphosate and their Mix had a control rate of 8, exhibiting a few living stems and green leaves. The packaged mixture of amitrole and ammonium thiocyanate is showing signs of approx. 40% of leaf drop and living stems plus the bleaching of foliage, with a control rate of 4.

At 91 DAT, the metsulfuron-methyl treatment had no living Chinese knotweed and had a control rating of 10. Both the Mix and glyphosate exhibited a few live stems and a few discoloured leaves, while glyphosate had one branch of regrowth though both have a control rate of 9. The packaged mixture of amitrole and ammonium thiocyanate showed signs of leaf drop, bleaching of the leaves and tip regrowth with a control rate of 5.

DISCUSSION

No single herbicide can kill all weed species (Harrington 2000) but trialing various herbicides in a riparian zone, allows better choices to control Chinese knotweed in Australia. Consideration must be given to the accuracy and efficiency of an application of herbicide to ensure minimal export of the herbicide into the aquatic environment (Kent and Preston 2000). For this study, broad-spectrum herbicide registered for aquatic use or having an APVMA permit for minor use, directs the selection.

From the results of the study, the effectiveness of metsulfuron-methyl delivered the highest rate of control at 47 DAT with 100% kill. That level of control continued over the length of the study to 125 DAT, with no emergence of other weeds within metsulfuron-methyl plots, which was probably due to the persistence of metsulfuron-methyl in the soil (Kent and Preston 2000).

Glyphosate is the most commonly used knockdown herbicide and can be applied over the full growing season and will translocate throughout the plant (Harrington 2000). This study has shown that although glyphosate was the quickest to show signs of control such as wilting and leaf drop at 14 DAT and continued to increase in control, one application is insufficient to control Chinese knotweed due to the regrowth that occurred from 91DAT.

Many herbicides have a narrow spectrum of weed control, so to increase control efficacy, a combination of herbicides applied to the target weed can retain longer residual, increase the herbicide effectiveness and delay the development of herbicide resistance (Damalas 2004). The Mix the combination of a knockdown herbicide glyphosate and metsulfuron-methyl, a systemic known for its effectiveness on bulbs and tubers (Department of Primary Industries, Parks, Water & Environment, 2002) gave 100% control after 111 DAT. Therefore, the Mix appears to be a desirable combination to control Chinese knotweed.

Another broad-spectrum herbicide treatment, amitrole and ammonium thiocyanate, is an efficacious product to control broadleaf weeds and suitable to use as an alternative to glyphosate (Sánchez-Bayo et al. 2010). Its systemic action, though slower than glyphosate at 14 DAT, showed what is commonly observed with a Group Q herbicide, such as the bleaching of leaves and cessation of growth at 35 DAT. This stunted growth habit allowed other weeds that germinated at the site to take over each amitrole and ammonium

(Galloway and Leeper 2010), Indian subcontinent, Sri Lanka and West Java (Panda, 2011), used a glyphosate based product to control *Persicaria perfoliata* (mile-a-minute) and *Polygonum persicaria*, (redshank) and Chinese knotweed. Research is limited with the use of metsulfuron-methyl on the Polygonaceae family, though in Norway, it has been found that *Persicaria maculosa* (syn. *Polygonum persicaria*) (ladysthumb) first evolved resistance to Group B/2 tribenuron-methyl herbicides in 2009 and they may be cross-resistant to other Group B/2 herbicides (Heap 2016).

The consideration of alternating herbicides rather than using the same mode of action herbicides can reduce the risk of weed resistance (Rattray et al. 2006). Rattray, Freebairn and Gurner (2006) states as herbicide resistance develops, there is often a decision to increase herbicide rates for control, but avoiding this situation suggests that herbicides can be used more effectively for longer. Three different 'mode of action' groups (B, M and Q) were used in this study. With the result of effectiveness with both herbicides, metsulfuron-methyl and glyphosate on Chinese knotweed, there is the choice of using either group or the combination of both groups as the Mix, to prevent the herbicide resistance especially with Group B.

The use of herbicides as a control is the most efficient way to treat Chinese knotweed due to the morphology, especially its underground rhizomes. This study has shown that the preferred control for Chinese knotweed is a foliar application of metsulfuron-methyl or its mixture with glyphosate. Weed managers may choose to select a broad-spectrum herbicide and use the chemical glyphosate; however, this herbicide will give a lower level of control and will require further treatments. The continual monitoring of sites after herbicide applications will be required to control any further regrowth. If one small plant were left to regrow, it would develop into a significant infestation within a short period.

Herbicides are an integral part of weed management and to maximise their efficacy, weed managers needs to have an understanding of their characteristics so they can minimise adverse impacts to the environment while achieving an effective control of the targeted weed. For Chinese knotweed, current research for effective herbicide options has been very limited. There is a need for continuing research and monitoring of this study, and future studies to gain long-term data on effectiveness of herbicide application. This research has identified some effective herbicide options for the control of Chinese knotweed in Australia and may help in acquiring a minor use permit from the APVMA to treat Chinese knotweed in riparian corridors.

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Our staff are technical experts who can help you with agricultural production, biosecurity, natural resource management and during emergencies.

Our programs support you with information, networks and resources to help you:

- improve your agricultural productivity
- control declared pests and meet your legal obligations
- maintain market confidence in our 'clean and green' agricultural products
- manage and improve our natural resources.

We help people make better decisions about the land they manage and assist rural and regional communities to be profitable and sustainable into the future.

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- promote understanding of the causes of weed dispersal, invasion and establishment,
- promote integrated strategies for control,
- develop, initiate and co-ordinate the delivery of collaborative, multi-stakeholder on-ground regional weed management projects, and to

Green Cestrum (*Cestrum parqui*)