Weeds of National Significance

Proceedings

of the *2nd National Willows Research Forum*

22nd & 23rd July 2010, Beechworth, Victoria

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09.15	Water savings from willow removal	*Tanya Doody, CSIRO*
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4.00	Synthesis of research gaps	
	Prioritising future research needs	
5.15pm	**Close**	

22 July 2010

Forum dinner

Latrobe at Beechworth
SAMBELLS BAR & BISTRO

6.30pm pre dinner drinks
7pm dinner

Day 2—23rd July 2010
FIELD TRIP

07.45am	Meet out the front of reception building at Latrobe at Beechworth, Albert Road and board bus for 8am departure
08.00	Bus departs Latrobe at Beechworth
09.45	Arrive Eskdale *Visit post willow removal monitoring site* *(a pilot study for investigation of stream function).*
10.15	Board bus (to Myrtleford) *Stop at Running Creek, Dederang to view bushfire recovery willow site.*
12.00	Arrive Myrtleford *Visit willow water use study site*
12.45	Lunch and return to Beechworth
1.30pm	Arrive Beechworth; field trip concludes

Participants

Name	Role	Organisation
Robin Adair*	Statewide Leader - Weed Sciences	Department of Primary Industries, Vic
Ben Berry	River Murray Vegetation Officer	NSW Office of Water
Andrew Briggs*	Waterways Project Officer – Team Leader	North East CMA, Vic
Angela Calliess	Senior Project Manager	Greening Australia—Capital Region, ACT
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Daniel Clements	Aquatic and Riparian Research	Department of Primary Industries, VIc
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Kiowa Fenner	Regional Weed Management Officer	Department of Primary Industries, Parks, Water and Environment, Tas
Andrew Ford	CEO	Mersey NRM Group, Tas
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Lori Gould	Senior Project Manager	Greening Australia—Capital Region, ACT
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Tara Hopley*	Student	CSIRO Plant Industry, ACT
Trevor Hunt	Technical Officer	Department of Primary Industries, Vic
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Mark Webster	River Murray Works Overseer	NSW Office of Water
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** Denotes presenter*

Long term monitoring and evaluation of willow management

Fiona Ede

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Abstract

Despite significant investment over many years in willow management activities, there has been limited evaluation of the effectiveness of this management in achieving the desired outcomes, particularly those relating to river health.

An on-line survey was undertaken in autumn 2009 to gain a better understanding of the current extent of monitoring and evaluation of willow management activities. Responses were received from 32 agencies. Most respondents undertook some level of monitoring, but the proportion of the overall budget for management projects which was allocated to monitoring was generally low and much of the monitoring informal and/or unstructured.

The most commonly measured variables related to the effectiveness of willow management and revegetation activities, while fewer monitoring programs assessed water quality and biodiversity variables. Photo-points were included in the majority of monitoring programs.

The most important barriers to undertaking monitoring were financial resources and time constraints.

The development and implementation of a national monitoring framework would require appropriate resourcing and input from a range of stakeholders, but would provide on-ground managers with improved monitoring tools and potentially could improve willow management outcomes.

Scope

In order to determine the extent of current monitoring activities associated with willow management, an on-line survey was sent to community and professional willow management agencies in autumn 2009. The survey was broken down into several parts. The first section sought information about the nature of the agency responding and the extent of their current, past and future willow management activities. The next section asked questions relating to the extent of monitoring undertaken by the agency, including resource allocation, and the barriers which limit monitoring activities. The third section focussed on the variables included in monitoring programs and the frequency and timing of monitoring of these variables. Questions relating to the use of monitoring data and standard monitoring guidelines comprised the final section.

Results

Responses to this survey were received from 32 agencies from five states and territories, and included a broad range of both community and professional willow management agencies. Most agencies reported spending 1-10% of their total on-ground resources on willow management.

1. Current monitoring and evaluation

- most agencies monitor some or most projects, with only six reporting that they monitor all projects
- up to 2% of total project budgets is generally allocated to monitoring

- four agencies reported spending more than 5% of project budgets on monitoring
- most monitoring activities are informal and largely unstructured
- variables relating to the effectiveness of willow control measures are most frequently monitored
- many agencies also monitor revegetation outcomes and establish photo-points
- monitoring of water quality variables and biodiversity variables occurs less frequently
- Waterwatch programs contribute to the assessment of water quality for some agencies
- formal monitoring programs often include a range of both physical and biological monitoring variables
- the frequency of monitoring differs between variables within programs, with water quality variables monitored more frequently than other variables
- however, willow management effectiveness and photo-points tend to be monitored over a longer time frame after completion of works.

2. *Use of monitoring information*
   - monitoring data is used to assess effectiveness of willow control by most agencies
   - it is also used to determine where follow-up willow or other weed management is required and to plan future willow management projects
   - monitoring data provides important information for reporting to stakeholders, including funding bodies, the local and scientific communities, the parent agency and state agencies.

3. *Barriers to monitoring*
   - financial resources and time constraints are the two most important barriers currently limiting monitoring activities
   - lack of skills, organisational culture, uncertainty about monitoring methods and uncertainty about the usefulness of monitoring data are less important in limiting monitoring for most agencies.

4. *Monitoring guidelines*
   - standard monitoring guidelines are used to develop monitoring programs by less than 40% of agencies
   - several guidelines exist to assist with monitoring and evaluation (M&E) of general natural resource management (NRM) activities; water quality and aquatic systems; riparian management and river health; and weed management activities.

Future Activities

The results of the survey indicate that the development of a national monitoring framework for willow management activities would be welcomed by many agencies and it is unlikely to be technically difficult. Similarly some form of national database to allow the collation and analysis of monitoring data would also be beneficial.

However, universal implementation of a monitoring framework is likely to be hindered by resource constraints within agencies, as would contributions by agencies to a national database system. The -

issue of resourcing will need to be addressed to ensure the successful adoption of a national approach to monitoring and evaluation of willow management programs.

The development of a monitoring framework and database will require input from a range of stakeholders including funding bodies, state and federal agencies, on-ground managers and monitoring experts. The framework would provide protocols for undertaking monitoring activities on-ground and guidance on the most appropriate activities to be included in the monitoring program at any site.

The implementation of a monitoring framework nationally would enhance the evaluation of willow management activities. The data collected in the process could be synthesised and incorporated into an Adaptive Management cycle, resulting in improved willow management.

References and related publications

A full analysis of this project (which includes a short list of available monitoring and evaluation guidelines) is contained in:

F. Ede (2009). *Monitoring and evaluation of willow management – Stage 1: Report of current practices in Australia*. Department of Primary Industries, Victoria. 32 p.

Available from the author (fiona.ede@dpi.vic.gov.au) or www.weeds.org.au/WoNS/willows/

Acknowledgements

This project was funded by the National Willows Taskforce, through the Australian Government Weeds of National Significance Program.

Water savings from willow removal

Tanya Doody[1,2] and Richard Benyon[3]

[1]CSIRO Water for a Healthy Country Flagship, [2]University of Adelaide Soil and Land Systems
[3]Melbourne University; tanya.doody@csiro.au

Abstract

In Australia, willow species (Salicea.spp) potentially extract significant amounts of water from streams (Doody and Benyon, in press). Willows located in upstream areas of the Murray-Darling Basin, affect flow volume and passage of flow to downstream water bodies such as the Murrumbidgee and Murray River. Potential water savings by removal of willows could justify the expenditure involved with their removal, as well as achieving other environmental benefits. Research was undertaken to quantify the water savings possible from willow removal. Four years of water balance measurement within southern New South Wales and northern Victoria, have determined that potential water savings of 5.5 ML ha-1 year-1 of crown projected area are achievable by removing willows growing in stream or in areas where their roots are permanently inundated. This estimated water saving incorporates the impact of several naturally occurring environmental events on willow water use, including flood, drought, heat stress and defoliation by willow sawfly. Higher up the stream banks, comparative studies of native riparian and willow water use indicate replacement of willows with native species will have no net effect on the overall water balance.

Scope

Willows were introduced into Australia, particularly the River Murray region during the 1800's for a range of purposes including stabilisation of stream banks, production of materials to make baskets, cricket bats, and to provide shelter. However, Salix spp. has since flourished in Australia and various willow species, including weeping willow (*Salix babylonica*), have spread along creek and stream system. In many locations, willows occupy stream banks, floodplains and stream beds. Willow infestations are now extensive, forming dense stands of trees or shrubs with extensive thick root mats, along creeks in south central New South Wales and elsewhere in Australia, with substantial adverse impacts on stream and wetland hydrology and biodiversity. Serious concerns are now held by catchment managers in relation to the environmental impact of willows and their influence on scarce water resources as a result of high water extraction rates.

In southern New South Wales, the Yanco Creek system has become extensively willow infested primarily with *Salix babylonica* which have spread from the stream edge to the natural floodplain of the creek and into the stream-bed. The creek system is complex; supplying water to at least eight towns and numerous private irrigators in the region, and without instituting mechanisms to save water, irrigators might be forced to reduce their water allocations.

A plot based water balance study to determine willow evapotranspiration (ET) rates was conducted over 4 willow growing seasons beginning in 2005, to quantify the net impact on evapotranspiration of removing willow trees from creeks used to transport irrigation water. Research including a comparative field study in 2005 and 2009, was conducted to compare rates of evapotranspiration between willow and natural riparian tree species, predominately River Red Gum trees.

Evapotranspiration was determined from direct measurement of tree transpiration, soil, open water and shaded water evaporation and interception loss as illustrated in Figure 1. Transpiration was-measured using Greenspan sapflow sensors and soil evaporation was measured using mini-lysimeters. Open water and shaded water evaporation was determined using mini-evaporation pans. Interception was measured in riparian plots by through-fall gauges, however in willow plots interception could be estimated from throughfall collected next to the mini evaporation gauges.

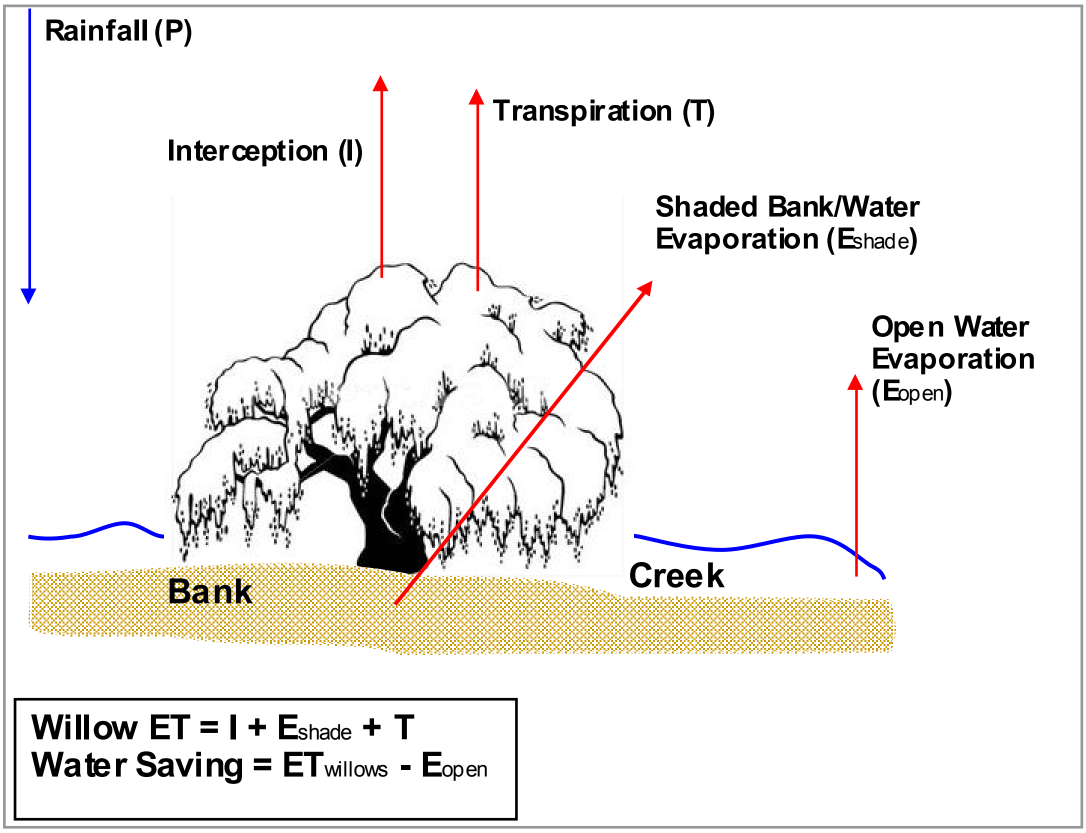

Figure 1. Conceptual model of willow evapotranspiration and determination of potential net water savings.

Results to date

Several findings have evolved from the research over the 4 year period. The most significant finding being that the rate of willow transpiration is dependent on the location of the willows within the floodplain environment. Willows located on the stream bank without reliable, permanent access to water, had similar transpiration rates as the adjacent native riparian River Red Gums as discovered in the first season of measurement (Figure 2). This observation lead to a project expansion in early summer 2005/2006 to monitor transpiration rates of willows located within the permanently inundated creek bed. Following measurement years only monitored evapotranspiration of 'in-stream' willows.

To reduce confusion, a conceptual diagram was developed (Figure 3), to clearly define the location difference. 'In-stream' willows are those trees that are constantly surrounded by water or have saturated soil and permanent access to water with relatively stable creek levels. 'Bank' willows are those trees which during winter might be inundated but due to intermittent or perennial creek characteristics, the trees are generally situated in a water limited environment throughout the drier months, characterised by poor tree vigour and leaf area. Removal of such trees will have a substantially lower potential for achieving water savings.

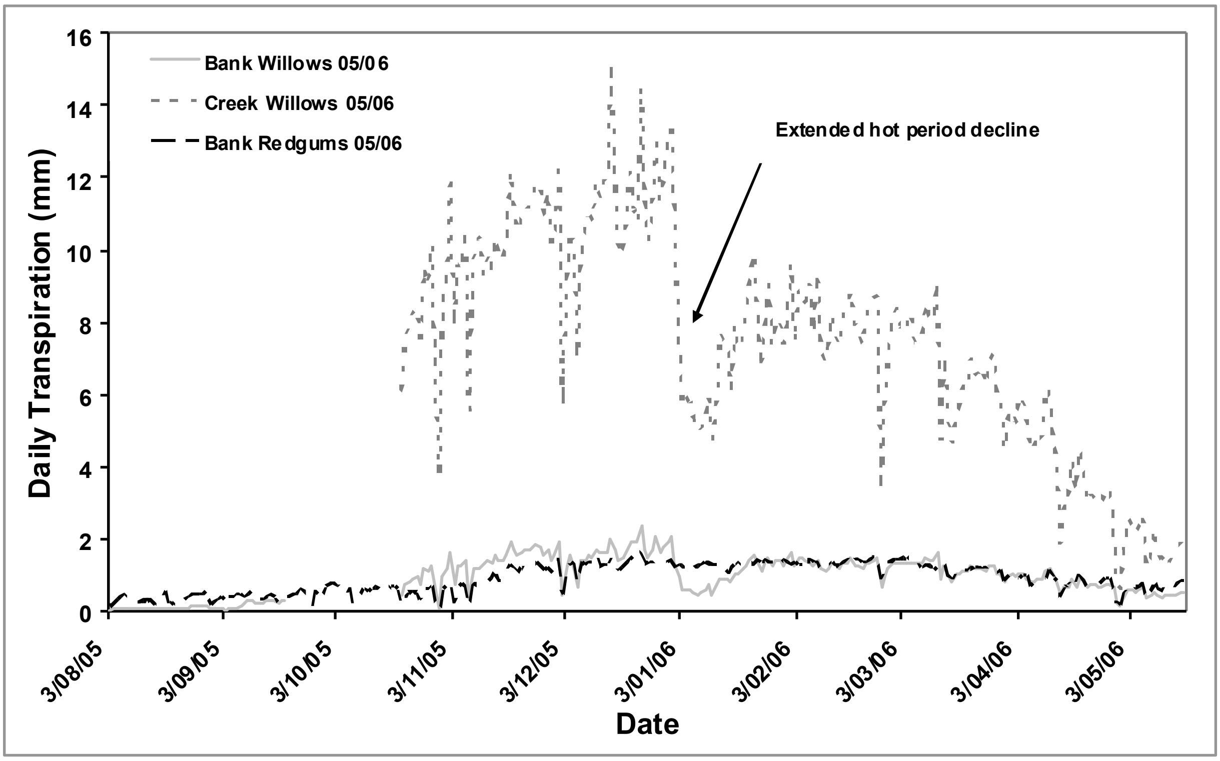

Figure 2. Daily transpiration of Red Gum trees and willows situated on the bank and in the creek in 2005/2006.

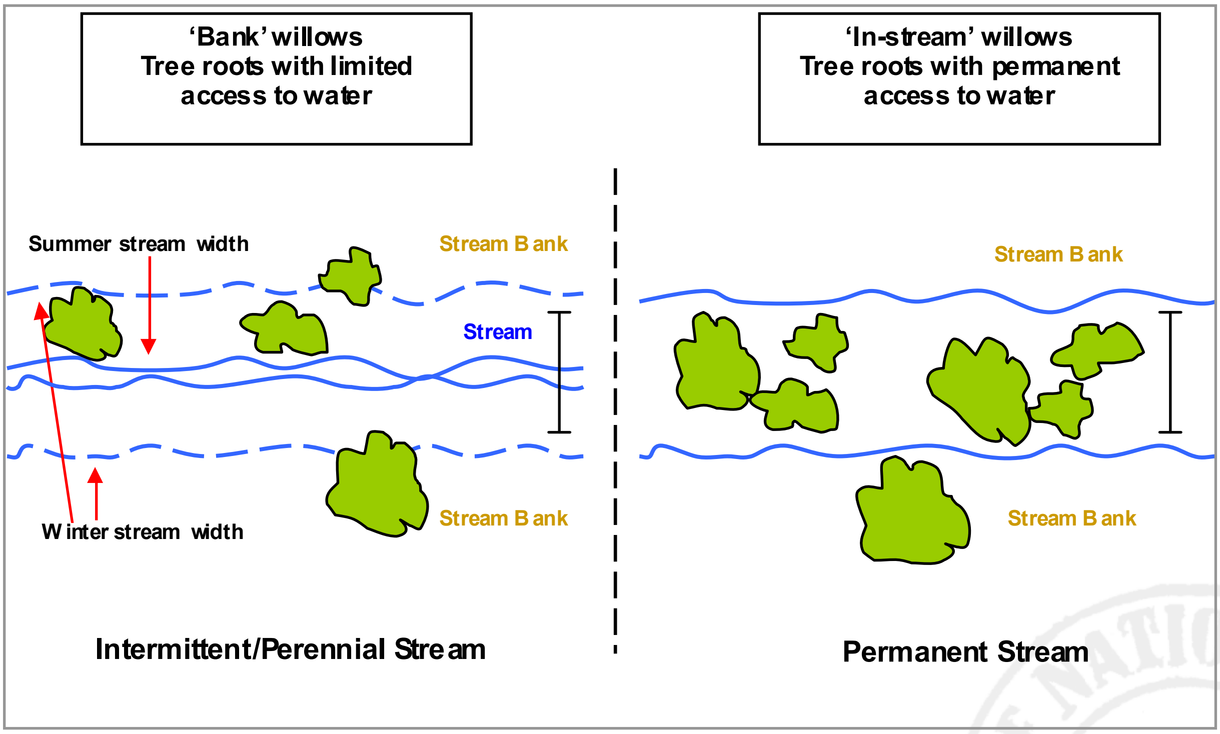

Figure 3. Conceptual illustration defining the location of 'In-stream' and 'Bank' willows.

Tables 1 and 2 highlight the results of three years of research (fourth year is currently underway) to quantify water savings from willow removal from creeks and streams. These results indicate that in 2005/2006, a potential net saving of 9.4 ML ha^{-1} of willow crown projected area year^{-1} was possible if willows were removed from the permanently wet part of the creek, based on the difference in total evapotranspiration between in-stream willows and open water. In years 06/07 and 07/08, this saving was substantially less at 1.5 and 5.5 ML ha^{-1} of willow crown projected area year^{-1}, respectively. However, in-stream willow trees were extremely stressed through-out these two periods as a result of drought, heat stress and willow sawfly defoliation events. These potential water savings are therefore important, indicating willow evapotranspiration rates are still higher than open water evapotranspiration even under naturally induced situations of stress. Averaged over the three year research period, potential water saving of 5.5 ML ha^{-1} of willow crown projected area year^{-1} is possible by removing willows classified as in-stream/permanently inundated.

Table 1. Measured or estimated water balance components and calculated total evapotranspiration from red gums, willows and open water from August 2005 to July 2006.

Water Use Site	Rainfall (mm)	Interception (mm)	Evaporation (mm)	Transpiration (mm)	Total ET (mm)	Saving ML ha^{-1}
Red Gums	314	52	261	240	553	-
Willows - bank	314	26	257	280	563	-
Willows - creek	314	26	751	1633	2410	+9.4
Open water	314	-	1472	-	1472	

Table 2. Measured water balance components and calculated total evapotranspiration from willows and open water for 2006/2007 and 2007/2008.

Water Use Site	Rainfall (mm)	Interception (mm)	Evaporation (mm)	Transpiration (mm)	Total ET (mm)	Saving ML ha^{-1}
Willows 06/07	241	33	789	934	1755	+1.5
Open Water 06/07	241		1604		1604	
Willows 07/08	401	110	812	1024	1947	+5.5
Open Water 07/08	401		1396		1396	

Implications for management

Benefits to the environment are therefore achievable with removal of in-stream willows, with potential water savings of 5.5 ML ha^{-1} of willow crown projected area year^{-1} possible; indicating that environmental management plans should consider the removal of in-stream willows in order to return valuable water resources to river and creek systems.

Future research needs

Use of fine scale remote sensing to delineate canopy crown areas of in-stream willows in order to apply the water saving across wider catchment areas.

References and related publications

Doody TM, Benyon RG (In Review). Quantifying water savings from willow removal in Australian streams. *Journal of Environmental Management*.

Acknowledgements

Reported research was funded by Water for Rivers in particular, thanks to Phil Deamer.

Leroy Stewart, Vijay Koul, Michele Michael, Colleen Bernie Tivi Theiveyanathan and Mark Tunningley of CSIRO for field assistance.

Jeremy and David Barlow for providing access to the field site at Jerilderie and Jeremy for his considerable in-kind assistance and the assistance of Bruce Crittendon. State Water New South Wales provided in-kind support for the Yanco Weir research.

Comparisons in food resource use in a small stream with native and introduced *Salix* riparian vegetation

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Abstract

Many *Salix* spp. are listed as weeds of national significance and are thought to impact on stream structure and function. Differences in food resource use by macroinvertebrates between three sites with a native riparian zone and three sites with a *Salix* spp. dominated riparian zone were examined on Little Snowy Creek in north eastern Victoria. Invertebrates of the families Leptoceridae and Leptophlebiidae were collected along with terrestrial vegetation and cobble biofilm samples for Stable Isotope Analysis (SIA). Coarse Particulate Organic Matter (CPOM), Cobble biofilm ash free dry weights and cobble biofilm chlorophyll-a samples were examined to determine resource availability and to calculate autotrophic index. At the time of sampling, native riparian sites had a higher amount of allochthonous material available in-stream, however, the Carbon:Nitrogen ratio suggested that food consumed at willow riparian sites had a higher nutritional value. Results indicate that there were different food resource use between sites with a willow riparian zone and site with a native vegetation riparian zone. SIA indicated that at native sites mostly biofilm, *Leptospernum spp* and *Pomaderis aspera* were being consumed by the invertebrate herbivores, with each invertebrate family favouring a different resource at two of the sites. It was found that a mixture of biofilm, aquatic vegetation, unknown grass spp. and some *Salix* spp. were being consumed at willow riparian sites.

References and related publications

Bunn SE and Boon PI (1993). What sources of organic carbon drive food webs in billabongs? A study based on stable isotope analysis. *Oecologia* **96**: 85-94.

Hladyz S, Cook R, Petrie R and Neilsen D (In Review, 2010). Comparison of leaf and cobble substrata in influencing biofilm energy flow to a primary consumer in a lowland river.

Biological control of invasive willows in Australia: developing a strategy

RJ Adair and SI Keel
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Abstract

There are at least 134 *Salix* taxa present in Australia. Most are restricted to horticulture and generally regarded as benign, but 28 taxa are recorded as naturalised and cause substantial ecological and economic harm. Invasions are restricted to waterways and wetlands of southern Australia, particularly in south-eastern Australia. Most naturalised species or hybrids have not realised their potential distribution and invasions are likely to expand in the absence of effective control programs. While mechanical and chemical control options are practised with high levels of success in many waterways across the invasion zone, these methods are costly and require regular maintenance and follow-up programs to prevent reinvasion. Biological control of invasive *Salix* in Australia has been under consideration since 2005, but perceived conflicts of interests with commercial and cultural values have prevented consensus on the directions and general strategies for a biological management approach to *Salix* invasions. In 2008, the Department of Territory and Municipal Services (ACT) and the Office of Water (Department of Sustainability and Environment, Victoria) in conjunction with the National Willows Taskforce developed an options plan to: (1) identify and assess strategies for biological control of willows, (2) identify knowledge gaps that may prevent implementation of biological control and (3) identify suitable targets for biological control.

Potential conflicts of interest present a significant challenge to the development of biological of invasive willows in Australia. Although complex commercial and social issues may be involved, stakeholder engagement, consultative processes and transparent decision making are likely to reduce sources of contention and lead to agreement on directions for biological control of willows. Resolution of potential conflicts of interests prior to the nomination of targets for biological control is required to reduce the prospect of declaration and development of a Commission of Inquiry under the Commonwealth Biological Control Act (CBCA). Specific industry-focussed resolution workshops are recommended for effective dialogue and conflict resolution. Major sources of potential conflict of interest currently exist and include heritage trees where *Salix* may be listed on registers of significant or heritage trees, or where *Salix* may occur on heritage listed properties. Inadequate data are currently available on the location and species identification of *Salix* specimens with heritage status. The commercial utilisation of some *Salix* taxa is also an area of considerable potential conflict of interest. In Australia, cricket bat production utilises *Salix alba* var. *caerulea* producing 350,000 bats per annum and valued at around $5m with potential for considerable expansion. Development of biological control of invasive *Salix* must avoid damaging the health of cricket bat plantations either through agent selectivity or the development of prophylactic procedures that alleviate attack by biological control agents. Although nursery, floricultural and basket weaving industries are permitted to utilise non-declared *Salix* taxa, the value of these industries to the Australian economy, the species involved, and crop sources are poorly documented. These knowledge gaps need to be addressed before biological control of invasive *Salix* can proceed.

The use of *Salix* as a potential biofuel crop in Australia is a possible area of conflict of interest with the development of biological control. *Salix* is widely used as a biofuel in Europe, and although advocates recognise potential in Australia due to rapid growth, low herbivory loads, and low nutrient demands, the declaration status of nearly all invasive taxa prevent cultivation for commercial purposes. However, the use of *Salix* harvested from weed control programs remains a possibility, as does the development of selected, sterile and approved biofuel clones. Debate at a national level is required to consider the potential of *Salix* as a biofuel crop in Australia.

Perhaps the most difficult area to resolve from the biological control perspective is the divergence of views within rural and urban communities on the value of willows. Addressing these concerns can only be effectively undertaken by wide ranging public information sharing sessions, but these need to be undertaken to reduce the risk of triggering a CBCA inquiry with the nomination of *Salix* as a target for biological control.

The selection of *Salix* species as targets for biological control is controversial as a multitude of decisions need to be undertaken that balance pragmatic, biological, political and social concerns. To address the divergence of factors involved in target selection, a decision support system (DSS) was developed that uses a series of hierarchical questions incorporating information on distribution, commercial/heritage value, prophylactic systems, mode of reproduction, degree of hybridisation or intraspecific variation, life form, knowledge of natural enemies, climatic similarities between natural and introduced range, level of declaration, and level of stakeholder consultation. Scores generated by the DSS enable *Salix* taxa to be ranked for suitability for biological control. Limited information on distribution records, level of intraspecific variation, impact and risk assessment, and effectiveness of biological control exclusion techniques prevented the construction of specific scores within the DSS.

However, as a general strategy, a two-phased approach is recommended as the most appropriate means of progressing biological control of *Salix* in Australia.

1. The first phase should proceed with the identification and selection of non-lethal agents that disrupt reproductive systems of selected *Salix* taxa where reduction of seed and pollen loads would contribute to reduced potential for hybridisation and less seed released into the environment. Candidate targets could include: *S. fragilis, S. nigra, S. purpurea, S. daphnoides* and *S. viminalis*. This approach may allow the safety of biological control of willows to be demonstrated, while providing environmental benefits.
2. The second phase would develop agents that are lethal or significantly disrupt the health of selected unwanted taxa where candidate targets could include: *S. cinerea, S. nigra, S. fragilis,* and *S. x sepulcralis.* Sufficient host specificity occurs within natural enemies of *Salix* to achieve selective control of most, if not all, invasive *Salix* in Australia.

The National Willows Taskforce has a key role in the promotion of research projects that address information gaps associated with the selection of biological control agents, the development of a lead agency or consortium for progressing biological control, and briefing the Australian Weeds Committee on developments with biological control of *Salix* prior to application to the NRM Standing Committee.

Genetic analysis of willow dispersal in Victoria

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[2] Australian National University, Research School of Biology, Acton, ACT, Australia; tara.hopley@csiro.au

Abstract

Willows are aggressive exotic components of many river systems in south-eastern Australia and they have the potential to expand their range. Current controls efforts for the most highly invasive species, *Salix cinerea*, are extensive, costly and not always successful due to rapid post removal reinfestation. An improved knowledge of the dispersal dynamics of this species will help to minimise future expansion and make current control efforts more effective. A survey of populations in the Ovens River catchment of south-eastern Australia has been undertaken to determine seed and pollen movement within and between populations of *S. cinerea*. Preliminary paternity analysis using molecular markers show that up to 50% of seed on trees are sired from outside the home population. Genetic profiling of populations in surrounding rivers has allowed us to identify the most likely pollen sources thus providing data on the scale of pollen movement. Parentage analysis to ascertain the origin of seedlings in these same populations will allow us to directly measure the scale of seed dispersal. The results from this study will provide information on patterns of willow seed and pollen movement and its relationship to landscape structure. These results will assist land managers responsible for controlling willows to develop more effective eradication strategies.

The ecology of willow sawfly: population structure and distribution

Valerie Caron[1], Fiona Ede[2] and Paul Sunnucks[1]

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[2]Aquatic and Riparian Weeds, Department of Primary Industries, Frankston, Victoria
valerie.caron@sci.monash.edu.au

Abstract

The willow sawfly, *Nematus oligospilus* Förster (Hymenoptera: Tenthredinidae) is native to Europe and North America, but was accidentally introduced into several countries of the Southern Hemisphere where it has established on willows. Since its arrival in Australia in 2004, the willow sawfly has spread across the continent. In high population densities, the willow sawfly defoliates willow trees and can cause substantial damage. However, some willow taxa are more affected than others. The willow sawfly reproduces parthenogenetically in its invasive range, males are extremely rare.

The main aim of this study was to get a better understanding of the ecology and evolution of the willow sawfly in Australia. A field study was conducted to assess the expansion of the willow sawfly and its impacts on different willow taxa. The prevalence of the different willow sawfly clones was also assessed. More than 100 sites were surveyed in 2008 and 2009 across Victoria, New South Wales, Tasmania and South Australia. Western Australia was surveyed in 2010. Forty-one microsatellites markers were developed to differentiate the different clones.

Willow sawfly is widespread in Australia (Figure 1) and was found at most sites sampled. The distribution in Tasmania and western Victoria expanded between the 2008 and 2009 field seasons. By 2010, the willow sawfly was already well established in Western Australia. Willow sawfly population densities varied between sites and willow taxa; crack willows (*Salix fragilis/S.* x *rubens*) being the most affected. Willow defoliation was mostly found in north east Victoria and south east New South Wales. Results from DNA analyses showed that only a few closely related clones occur in Australia, indicating that either one or a small number of introductions have occurred.

It appears most likely that the distribution of willow sawfly will continue to expand until it reaches the limits of willow distribution. Despite the low genotypic variation in the Australian population indicated by microsatellites, the willow sawfly thrives on different willow taxa over a large geographic area.

Further studies are necessary to quantify the long term impacts of the willow sawfly on willow tree growth, dispersal ability and reproductive output.

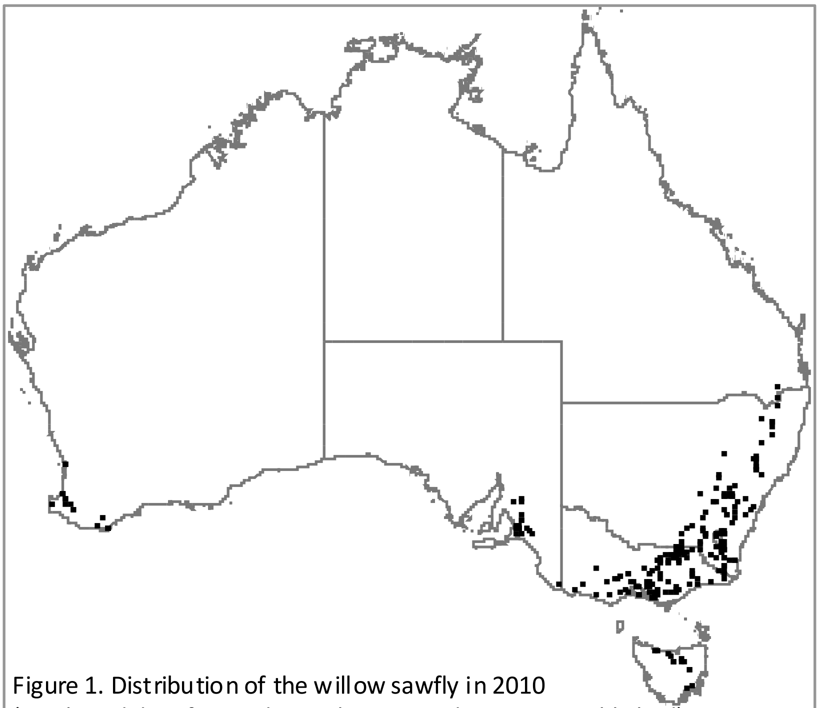

Figure 1. Distribution of the willow sawfly in 2010 (combined data from Ede *et al.*, 2009 and Caron, unpublished)

References and related publications

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Developing a long term strategy for managing willow invasion on the Bogong High Plains

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Abstract

One of the major threats to the alpine bogs and fens on the Bogong High Plains (BHP) is invasion of grey sallow willow (*Salix cinerea)*. While the main mitigation strategy is to control willow it is unclear whether current levels of control are sufficient and how control effort should be directed. We have used structured decision making to assist managers identify an effective management strategy. We developed a simple model that predicts the long-term performance of management on willows on the BHP for different scenarios. We find that for current budget levels the optimal management strategy is to focus all control effort in the bogs on the BHP, regardless of uncertainty about the system parameters. In contrast, the effectiveness of this strategy is highly uncertain reflecting our uncertainty about fire frequency, post-fire bog recovery rates and seed dispersal distances.

Scope

We report on a decision analysis for long-term willow management on the Bogong High Plains (BHP). The process was initiated in October 2009 at a workshop that included representatives from the management agencies responsible for managing willows on the BHP and surrounding areas (Parks Victoria, Victorian DSE and North East CMA). At the workshop, participants framed the problem and identified the objectives, performance measures and possible management actions. We have developed a simple model for the dynamics of willows on the BHP that predicts the long-term performance as a function of the actions taken. Uncertainty about how the system works is represented in the model by choosing the parameters from probability distributions.

We analysed this simple model to address three key questions regarding the management of willow on the Bogong High Plains, and a fourth question regarding the decision analysis itself:

1. What is the most effective management strategy?
2. Can we improve our strategy through learning?
3. How much effort do we need to allocate to willow control?
4. What additional resources (if any) should we allocate to refining the management strategy described in this decision analysis?

Results

Managers identified their fundamental objective as protection of the integrity and function of alpine bogs on the Bogong High Plains through reduction of willow (*Salix cinerea)*. From this, we developed a performance metric: the expected percentage of years (over the next two centuries) that at least 90% of the area of bogs is in satisfactory condition (clear of willows, or with only low density of seedlings).

Possible management actions are to control willows in the bogs or to control willows nearby that might act as source populations. We identify three kinds of source population (based on cost of-control and location relative to bogs):

- BHP reaches (areas on the BHP that are not bogs)
- high reaches (steep areas close to the BHP that are difficult to access)
- low reaches (within 10 km radius of BHP).

What is the most effective management strategy?

The optimal strategy is to allocate all available effort to the bogs until the available budget is 2000 person-days (approximately 4 times 2008-09 budget). Thereafter, effort starts to be allocated to the control of source populations.

We also predicted how expected performance (number of years in satisfactory condition) might change with budget when we use the optimal strategy (Figure 1). Not surprisingly, as the resources invested in management increase so does the expected performance. Note however that the relationship is one of diminishing returns - the improvement in performance decreases as the amount invested increases. Investment at current levels (Figure 1, vertical line) suggests that we can expect to have the bogs in satisfactory condition approximately 40% of the time. However this prediction is uncertain because we are uncertain about fire frequency, bog recovery rates and willow dispersal parameters.

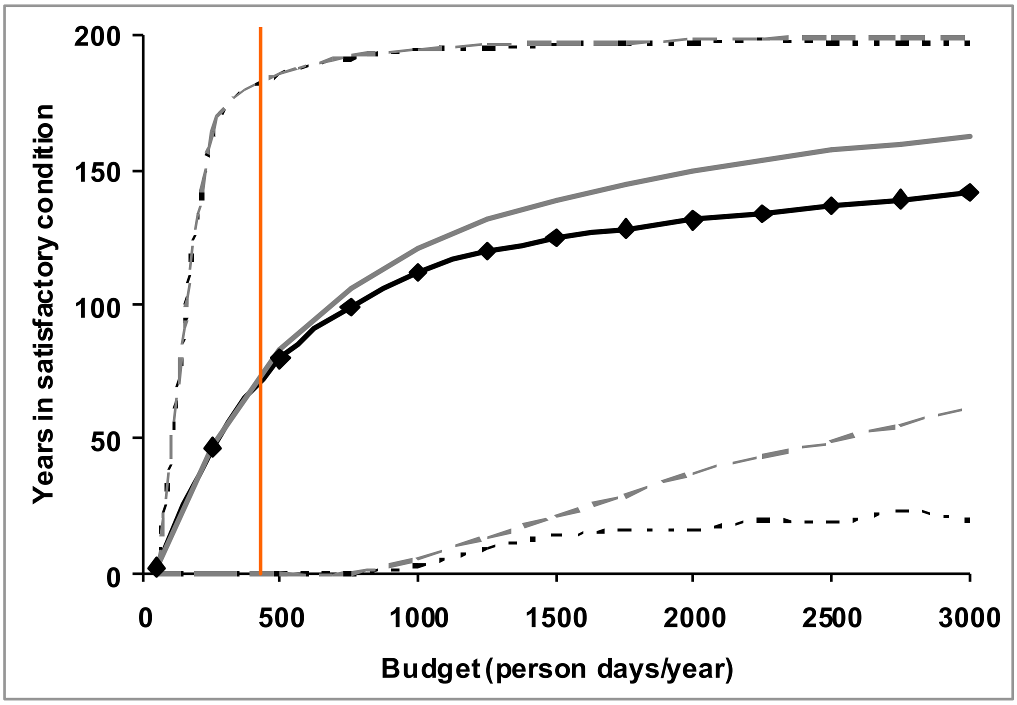

Figure 1. Summary of how the effectiveness of management and the expected value of information changes with available budget. The black line shows the *expected* performance of our optimal action given our current knowledge. The dashed black lines are the 90% quantiles (representing uncertainty). The solid grey line shows the expected performance if we knew the parameter values prior to allocating our effort and indicates how much we could improve our performance if we had perfect information. The dashed grey lines are the 90% quantiles for perfect information. The vertical line indicates the resources allocated to control in 2008-2009 by Parks Victoria.

Can we improve our strategy through learning?

We could try to improve our predictions through learning about the system in advance (improving our parameter estimates). Sensitivity analysis show that the expected performance depends most on fire frequency, with management more likely to succeed when fires are infrequent, and to a lesser extent on bog recovery rate and willow dispersal. Hence, investing effort in learning about these parameters could improve our predictions about management but would it change our management strategy?

We used a value of information analysis to see if knowing more about the system would change our management strategy (Figure 1). The grey line shows the expected performance if we knew how the system worked (i.e. knew the parameter values) before making our management decision. A difference in performance means that we would make different allocations if we had perfect information. The results show that the increase in performance with perfect information is expected to be small for current levels of investment (2%), demonstrating that knowing the details does not change the optimal allocation. For low-medium budgets, the optimal allocation is robust to uncertainty in how the system works. Even at high levels of investment the expected value of perfect information is modest with a maximum predicted increase in performance of 10% when budgets are high (2500-3000 person-days).

How much effort should be allocated to willow control?

The management model predicts that expected performance increases sharply up to an investment level of 1000 person-days or so and after this, plateaus (Figure 1). These results suggest the greatest efficiency (improvement in bog condition for dollar spent) if about 1000 person-days were invested. Doubling investment from 500 person-days to 1000 person-days would result in a 15% increase in the expected time that the bogs were in satisfactory condition (from 40% to 55% of the time). To get this same increase in performance again (from 55% to 70% of the time in good condition) would require an additional investment of 2000 person-days (i.e. a total of 3000 person-days).

With finite resources available for conservation management more broadly, the resources allocated to willows are resources taken away from another arena. Hence, it is useful to ask whether it is feasible to reach the objective, how much it will cost, and if this is the best use of our resources. To address this last question completely would require formulation of the larger problem of how resources would be allocated if not to willow management, which is beyond the scope of this study. However, increasing the accuracy of the model predictions would aid assessments of the expected performance associated with different budget levels and may assist managers with this higher level decision.

Implications for management

The optimal management strategy is to focus all available effort on control of willows in bogs unless the annual budget is at least 2000 person-days. This strategy is unaffected by uncertainty of how willows grow or respond to management unless the budget is high.

However, there is much uncertainty about the establishment, growth, and control of willows, which means that it is difficult to predict how effective we can expect management to be, irrespective of the level of investment. This translates to a substantial amount of risk in the outcome of investment in willow management and makes it challenging to identify a suitable budget. Increasing the accuracy of the model predictions would aid assessments of the expected performance associated with different budget levels and may assist managers with this higher level decision.

Future research needs

The model simplifies the system considerably; there are many ways to develop and extend the analysis.

- Use expert elicitation and/or targeted monitoring to refine parameter estimates (reduce uncertainty) and improve our ability to predict the expected performance of management.
- Extend the system model to include the possibility that dispersal is predominantly from the northwest.
- Use the model to identify optimal allocations when there are constraints on where the budget can be allocated, because of the sources of funding.
- Refine and extend the analysis to identify dynamic allocation strategies that can change depending on the state of the system (e.g. time since fire).

We are seeking input from the representative management agencies about the appropriateness of this framework for the problem, and what steps should be taken next.

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Willow biochar: bringing riparian restoration into the black

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Abstract

The current practice of burning debris heaps (typically *Salix* spp. and *Populus* spp.) resulting from waterway restoration works is attracting increasing scrutiny from community groups and government institutions due to concerns about greenhouse emissions, fire and occupational health and safety. Any future restriction on this practice poses a major risk for many river health programs due to the lack of viable alternatives. The North East Catchment Management Authority (www.necma.vic.gov.au) has taken a proactive approach to these issues. Following an internal review of debris disposal options, the CMA commenced a feasibility study into the development of a mobile device to convert woody debris into biochar. In a project funded by the Victorian State Government the North East CMA engaged Victorian firm Earth Systems to undertake this study. The study demonstrates that a mobile device could be commissioned to carry out biochar conversion in an economical and environmentally sound fashion. The proposed technology indicates a massive reduction in CO_2e/yr is achievable, whilst simultaneously eliminating many of the risks associated with open burning of debris heaps. Furthermore, this technology may result in a commercial value being placed on willow debris, alongside significant potential benefits for agriculture and other beneficial end uses. Further research to verify the findings of the feasibility study and develop a commercially viable operation to roll out this technology across the willow management industry (in concert with other relevant primary industries) is underway.

Scope

Whilst based in the north east of Victoria, the scope of this research is extremely broad. It is intended that field work will be carried out across Victoria and potentially interstate. There has also been considerable interest from willow management agencies in New Zealand.

Results

- biochar is produced at a 30% yield (per weight of dry matter)
- very clean - ~90% pure carbon
- wood moisture content is an important factor – need to allow material some time to dry before processing
- smoke emissions from process are minimal
- char surface area up to 570m^2/g – very good nutrient holding potential
- energy release from the combustion of pyrolysis gases is over 3 times that necessary to drive the process (4.32 MJ/kg wood)
- one unit has the potential to reduce host entity emissions by ~980tCO_2e/annum
- equivalent to installing around 400 1.5kW solar rooftop systems
- full-size unit cost estimated at <$100,000.

Implications for management

The technology under development from this project has the potential to offer significant gains to the willow management industry, namely:

- a safe, practical and economically viable alternative to burning willows
- potential economic values on willow and the many possible management scenarios from this, for example:
  - providing an incentive for landholders to remove or manage their willows for their own gain
  - where willows are lopped and deliberately not poisoned
  - for those groups who advocate the establishment of other vegetation prior to complete willow removal.

Future research needs

Further research is commencing to:

- verify small-scale tests at bulk scale (particularly with respect to gas yields and emissions)
- field trials (for both production and use of willow biochar)
- alternative feed stocks
- market development.

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When not to remove willows from streams

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Abstract
Management 'innovations' tend to follow a similar seven step path leading to maturity or oblivion:
1. proposal,
2. scepticism/hostility,
3. trial,
4. acceptance,
5. over-shoot,
6. push-back,
7. balanced approach or decline.

Willow management is no different. Up to the 1980s, communities and governments were enthusiastically planting willows (for good reasons). Then the negative effects of willow infestations were gradually recognised following sound research, and community experiences. The spread of seeding willows also signalled an emerging threat. The result was widespread removal of willows from streams from the late 1980s to the present. Initially the community was distressed at the 'wastelands' produced by industrial-scale willow removal. But this concern has settled down as the longer-term rehabilitation benefits of native vegetation communities has emerged. Today, many stream systems are now almost willow free in Victoria, and the seeding willow threat continues to be managed.

However, we are now potentially in the 'over-shoot' situation, where willow removal is being seen as an end in itself rather than as part of balanced rehabilitation program for a stream system. Willows are a Weed of National Significance, but that does not mean that every willow has to be removed. It is quite predictable (and appropriate) that we find that there is now 'push-back' from various quarters in regard to wholesale willow removal. There appear to be three lines of argument against willow removal. I will summarise these here, but provide more evidence for each point in my talk:

1. *Willows are better than grass.* In many places, willows have been removed, but there has been no revegetation with native species, or no attempt to allow native species to regenerate (e.g. by managing grazing), and the riparian area reverts to grass or grassy weeds. In these circumstances, it would usually have been better to leave the willows. There is abundant research showing that willows are better than grass alone. They provide shade, some food, and other modest benefits. The only situation that I can think of where you would rather have grass than willows, is where they are seeding willows that are a threat to other healthy reaches.
2. *Removing willows mobilises large volumes of sediment.* Willows trap large volumes of fine sediment and its associated nutrients. This sediment will be released as the willow roots rot away. This is inevitable, but it is not clear if this represents a problem for receiving waters or not.

3. *Willows stabilise high energy streams.* There is good evidence that willow root plates provide more resistance to hydraulic shear forces than do equivalent native vegetation. Many streams in upland valleys in south-eastern Australia have been massively incised since European settlement. Such incised streams carry all flows from the catchment, and experience very high shear forces. These streams move through a predictable sequence of recovery following incision, eventually stabilising with a new inset floodplain. The rate at which these streams stabilise can be accelerated with resistant vegetation, such as willows, that also trap sediment. Wholesale removal of willows from this type of stream can trigger erosion in some circumstances. It is this type of incised stream that has been the focus of work by the natural sequence farming movement. In some cases there is an argument for leaving willows in such streams, or for removing them in a staged way. However, the value of willows in this specific type of stream does not justify the general argument that willows should be left everywhere in the landscape.

There will be other situations where willows should be left in position. Usually the argument is not about whether willows should be left in perpetuity, but how they should be gradually removed, in a sustainable way. To a large extent the arguments about willow removal today are due to the poor evaluation that has taken place of stream condition following willow removal. Given the size of the willow removal 'industry' over the last two decades, there has been a woefully inadequate amount of well designed research carried out into recovery of streams after willow removal. Given this gap, it is perfectly appropriate that the public ask what has been the outcome of public investment. The strong research that will be done over coming years will lead us to a balanced approach to willow management.

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WEED OF NATIONAL SIGNIFICANCE