Willows: weeds of retention

Dr Michael Wilson
Research conducted whilst at the Centre for Environmental Management, University of Ballarat
Current address: Murray-Darling Basin Commission, PO Box 409, Canberra, ACT 2601,
michael.wilson@mdbc.gov.au

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Summary

Removal is the dominant strategy advocated and implemented by management authorities when confronted by willows, the majority of which are Weeds of National Significance. There is much discussion and debate over possible effects of willow removal on stream ecosystems. In this paper I present research that demonstrates that a cleared reach has significantly worse ecosystem benefits than either a willow lined or mature native vegetation lined stream. The only benefit of removing willows, other than where vegetation of any type would be removed for infrastructure protection, is that native trees and shrubs are easily planted. This does not compensate for the potential negative consequences of clearing. In the streams we have studied, clearing will mobilise sediment, nutrients and organic matter, will make heterotrophic streams more autotrophic, will threaten habitat values for invertebrates and fish and will threaten pool-riffle sequences. There is a better way to manage willows; succession. Existing stands can be retained and native vegetation (or whichever species mix is preferred) can be planted alongside and under the willows. The shade intolerant willows will be out-competed over time. This strategy can be immediately implemented, as current funding and vegetation establishment techniques are suitable. The fact that a stream ecologist and a farmer (Peter Andrews, Natural Sequence Farming) have independently arrived at the same conclusion in relation to willows is noteworthy. A good understanding of the ecological values associated with retention of materials, energy and nutrients in streams would compliment hydrological studies in Natural Sequence Farming systems and help shift public policy and perceptions away from simplistic approaches to weeds.

Outline

In this paper I synthesise findings from research conducted by my students and myself over the last decade. I utilize a simple diagram that compares three stream reach types: willow-lined, cleared and native vegetation-lined reaches. The diagram relates directly to the primary management strategy advocated under the Weed Management Guide for Willows prepared by the CRC Weed Management for established trees in farmland (available www.weeds.org.au/WoNS/willows). It is generally suggested that willow infestations be cleared and native seedlings (or seed) planted. Not withstanding the logistical and financial costs of this strategy, there is a wide-spread acceptance that removal of willows is beneficial *per se* and that even without replanting positive environmental outcomes have been achieved. This manifests, for example, when

Catchment Management Authority (CMA) funding and key performance indicators are related to “kilometers of willows removed”.

Each parameter evaluated during our research has been measured directly within each of the three reach types or has been estimated based on literature and other research. Where the value presented is an estimate based on other people’s work a question mark (?) has been used. This does not necessarily imply that the estimated value is unknown, simply that the value was not directly estimated in the context of the particular research being presented. The methods used to evaluate the parameters are often complex and their documentation is beyond the scope of this paper. Much of the research has been documented in detail in theses and publications which are cited in the references. Similarly a literature review is beyond the scope of this paper and readers are directed to Wilson (2001) and Zukowski & Gawne (2006).

Sediment and organic matter retention

Aggradation (storage of sediment and organic matter) appears to be a key feature that distinguishes willow and native-vegetation lined streams (Figures 1 - 3, Wilson 1999, Wilson 2001, Boyer 2003). In central Victorian stream reaches there was an estimated 187t more sediment (Figure 1) and 30t more organic matter (Figure 2) stored per kilometre of stream in willow-lined reaches than those lined by native vegetation that regenerated following the 1850’s gold rush. All study reaches have been in a nature reserve for about 100 years and the native vegetation was multi-strata dominated by eucalypts, *Acacia* and *Pomaderris* with a grass, herb and fern groundcover. For reaches cleared of riparian vegetation I have assumed the amount of sediment and organic matter stored would be even lower (Figures 1 and 2) as there would be no vegetation control on material retention. For ‘reference’ reaches I am again making an assumption as there were no comparable reaches in the Ballarat district that had not been cleared in the gold rush or for forestry or agriculture.

A reference reach was assumed to contain complex native vegetation, a heavy load of large woody debris and a dynamic balance between sediment source from the landscape and stream power. Under these circumstances it was expected that the stream beds would store a substantial amount of sediment and organic matter. Evidence for this assumption comes from observations made by geologists and others in the gold rush (discussed in detail in Wilson 2001). For example Howitt (1857) wrote that in Sailors, Wombat and Spring creeks

> “The old ground has been worked so often that vast quantities of sludge have accumulated in many places; and when sometime back a flood carried away much of the sludge and tailings, and opened new courses, the miners took advantage of the changes thus effected and worked the lower stratum, which was found to contain a great deal of gold”.

I studied these exact same reaches and 150 years after Howitt made the above observations, all channels except those lined by willows are bedrock and boulder dominated (Figures 3a and b). In the non-willow reaches there was an average of only 5cm of finer sediment and organic matter overlying the bedrock. Gold fossickers still visit these creeks and are able to pan these small accumulations very quickly and there is no possibility of floods revealing a 'lower stratum' as described by Howitt (1857). So I contend that the reaches that now appear as in Figure 3b were so deep with in-fill sediment that they were worked by miners in two separate phases. The stone walls built up by the miners to affect this work are still visible above the current bed level in native-lined streams, but are below the bed level in willow lined reaches. They would have been constructed below the pre-gold rush sediment levels to hold back bank sediments during works. (Interestingly, I believe Heritage Victoria recently suspended willow removal work in Spring Cr due to destruction of these gold rush stone walls).

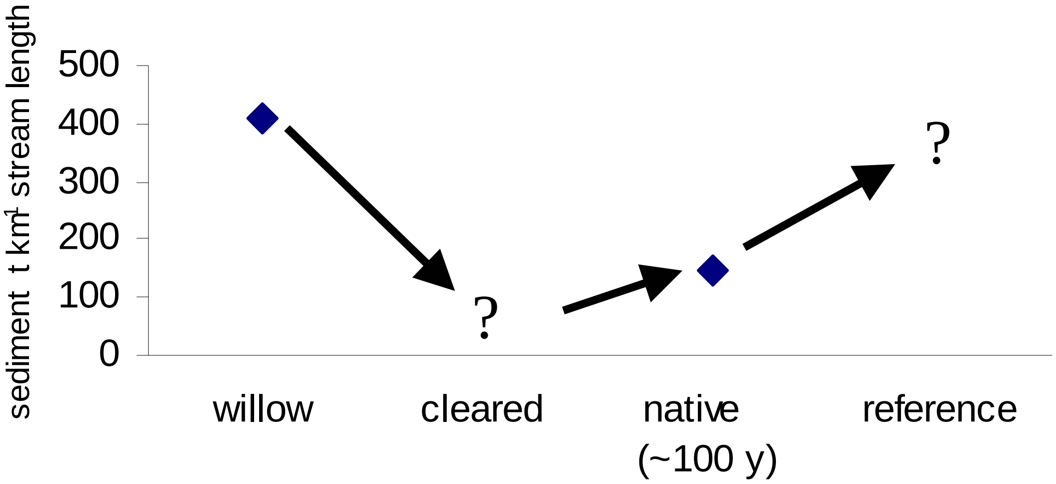

Figure 1. Sediment storage per km of stream length estimated for willow-lined, native vegetation-lined, cleared and reference streams in the Ballarat district, central Victoria. Adapted from Wilson (1999)

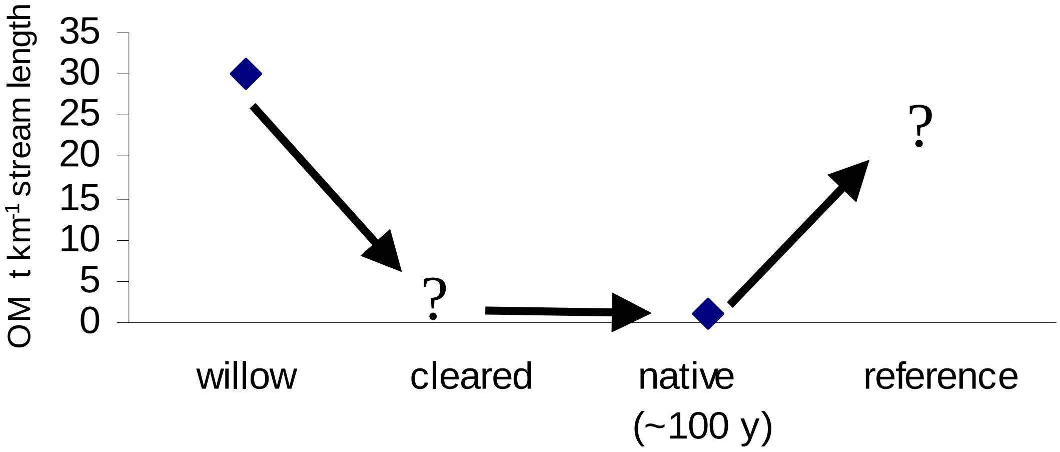

Figure 2. Organic matter (OM) storage per km of stream length estimated for willow-lined, native vegetation-lined, cleared and reference streams in the Ballarat district, central Victoria. Adapted from Wilson (1999)

a b

Figure 3. Willow-lined (a) and native vegetation-lined (b) reaches in adjacent catchments with nearly identical gold rush(1850's) disturbance history, geology and current catchment land-use. Both reaches are in the same nature-reserve (Wilson 2001). a) Willow channel infill with surface stream channel now 'perched' on 40 cm of aggraded sediment stabilized by willow roots b) Incised and bedrock-boulder dominated native vegetation-lined channel.

I conclude that willow-mediated aggradation in these channels is converting them from incised channels (Figure 3b) to in-fill channels (Figure 3a) that are more characteristic of pre-European conditions. This conversion has occurred in 40 years (the time since local willow colonisation) and there is no evidence that after 100 years native vegetation protected in a nature reserve can achieve the same conversion. I am not suggesting that willows be planted in nature reserves to achieve this aim, I am simply stating that if eucalypt-*Acacia* dominated native vegetation lacks transformative power in a nature reserve then in urban and agricultural landscapes it alone will not mediate conversion of incised channels to in-fill channels.

Willow removal, even if followed by planting of tube-stock eucalypts and *Acacia*s has the potential to release hundreds of tons of sediment and tens of tons of organic matter per kilometre as the material trapped by willow roots is released as they breakdown. If the sediments, organic matter (and the nutrients such as phosphorus contained with in them) can cause harm to downstream ecosystems then their capture by willows is beneficial. If the sediments that are captured are restoring channel morphology to something akin to reference condition then this is beneficial. If the sediments are sourced from 'leaky' agricultural and urban catchments, then their capture and long-term stabilisation where they are needed (in-filling incised channels for example) is more beneficial than their continued journey downstream to where they might cause harm (for example by contributing to siltation, sand-slugs or reservoir eutrophication).

Litterfall

Willows and eucalypt-*Acacia* dominated native vegetation contributed the same amount of litter to streams in Central Victoria. The values are in the range documented for upland streams flowing through native vegetation in south-eastern Australia (see Wilson 2001 for references). The timing of litterfall is very seasonal in both vegetation types. Native vegetation exhibited a strong seasonal pattern with 50% of litter falling in summer. Willow riparian vegetation was less dominated by a single season with 40% of annual litterfall in both summer and autumn (Table 1). Depending on season a greater or lesser amount of willow leaves will fall in summer as drought can cause willow leaf drop. The key point is that both native vegetation and willows yield a pulse of litter through summer and autumn.

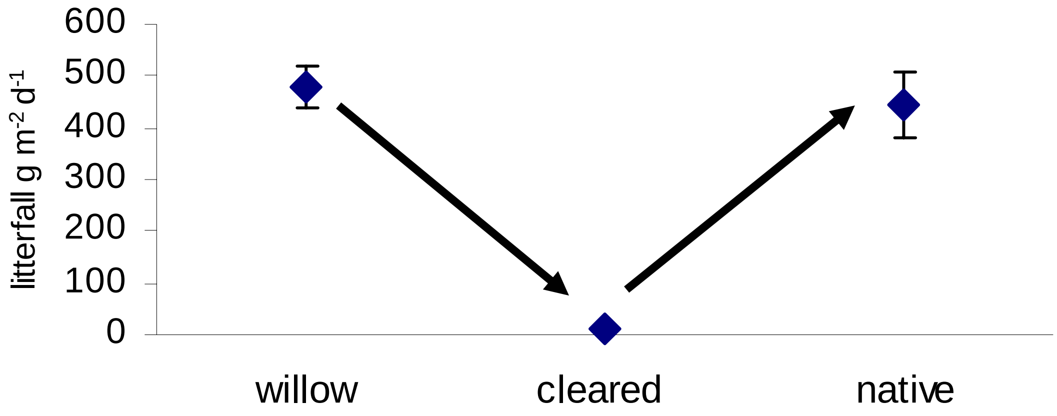

Figure 5. Annual total litterfall, excluding large woody debris (diameter >10cm) for willow-lined, native vegetation-lined and cleared streams in the Ballarat district, central Victoria. Adapted from Wilson (2001), mean ± SE.

It is often argued that native vegetation supplies a sustained supply of litter throughout the year whereas willows drop all their litter in autumn. This seems logical as there are leaves present throughout the year in the evergreen native forests. However, empirical data shows a much more complex pattern (Table 1). There was a four-fold difference between the seasons of maximum and minimum litterfall in native vegetation, and an eight-fold difference in willows. In native vegetation, autumn, winter and spring each contributed 20% or less of the total. In willows two seasons contributed about 40% each, one season 20% and one 5%. So it is not reasonable to say that willows drop all their litter in autumn, rather they supply a sustained amount of litter over summer and autumn, the same amount of litter as native vegetation in spring and half the amount in winter.

The annual weight of leaves, twigs, bark and flowers was very similar at the willow and native sites. Leaves constituted 41-58% of the dry weight of litter at all sites, but were least important at all but one site (10-21%). The exception was at a site with a dense Tea-tree and Bottlebrush understorey where leaves constituted 46% of the winter litter. Twigs dominated winter litter at all other sites and were the next largest component of annual totals (16-25%). Bark, flowers, capsules and leaf scales constituted between 1-19% of annual totals, with flowers and leaf-scales sometimes quite important in spring (particularly spring catkin fall from a member of the *Salix cinerea* complex).

The story of litterfall in willow stands is far more complex than that portrayed by typical weed fact sheets and willow management plans. An analysis of litterfall literature in Australia shows that the seasonal pattern at willow sites was similar to that observed in an Australian cool temperate *Nothofagus* forest (Turnbull and Madden 1983) and wet sclerophyll forests (Ashton 1975). The willow and native sites had similar proportions of non-leaf litter (42-59% of the annual total at all sites, Wilson, 2001), which is a recognised characteristic of Australasian warm temperate forests (Bray and Gorham 1964, Campbell *et al.* 1992). As expected there were strong contrasts in the litterfall pattern in native vegetation with understoreys dominated by tea-tree-bottlebrush compared to *Acacia-Pomaderris*. In winter these contrasts were far greater than the contrast between willows and natives.

	Daily litterfall (% annual total)			
	Spring	Summer	Autumn	Winter
Mean native	20	51	16	12
Mean willow	19	37	41	5

Table 1. Seasonal pattern of litter fall as percentage of total litter falling in each season for five stream reaches characterized by native (n=3) or willow (n=2) riparian vegetation communities in the Ballarat district, central Victoria. Adapted from Wilson (2001).

Why is litter important? The main reason is an energetic one – the majority of the energy driving aquatic ecosystems in shaded streams comes from litter. So everything from the microbes, the invertebrates, the fish and the platypus are ultimately dependent on the litter. In the next section I look at some work we have done on stream energetics.

Community Metabolism

There are many parameters that can be used to describe the energetics of a stream but I chose community metabolism which is a single over-arching measure of the total photosynthetic and total respiratory activity of every living organism in the study reach. The ratio of photosynthesis to respiration is called the P/R ratio. When this ratio is above one (>1) it tells you that the stream is producing more organic matter from photosynthesis than it is using up in respiration i.e. it is a ‘producer’ (or autotrophic) stream. A ratio less than one (<1) tells you that the stream is using up more energy in respiration than it is producing in photosynthesis i.e. it is a ‘consumer’ (or heterotrophic) stream. A consumer stream gets the extra energy required from litterfall and other external sources (e.g. organic matter in run-off and soil water flowing into the stream) though these are typically small in relation to litterfall.

Our results are consistent with common sense. A willow canopy and a native canopy both shade the stream and this limits photosynthesis, resulting in ‘consumer’ reaches under both canopies. In Figure 6 this is indicated by P/R ratios of 0.2 in both these types. As shown earlier the willow and native canopies deliver a similar annual total of litter to the stream and both heavily shade the stream in the seasons of maximum productivity so the overall energetics are very similar. Heavily shaded, heterotrophic streams would have been the norm for the study streams prior to catchment clearing for gold, forestry and agriculture.

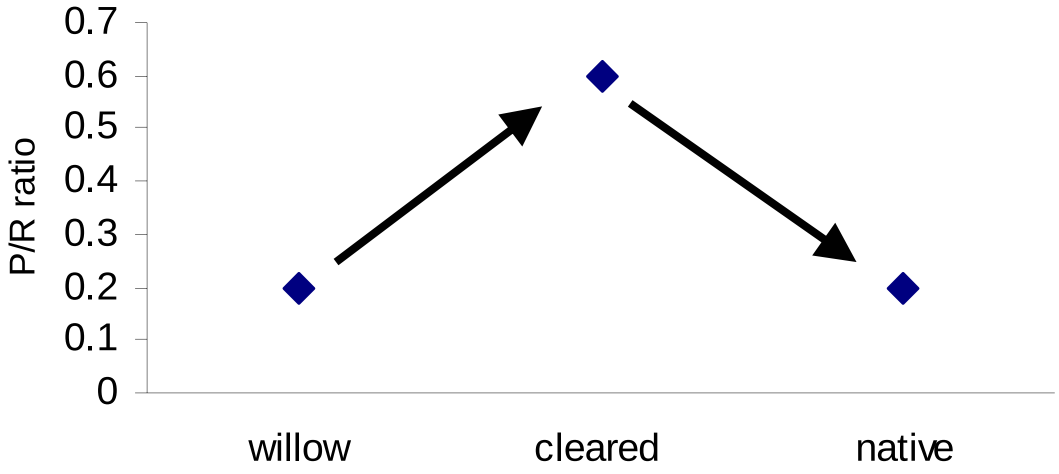

Figure 6. Photosynthesis to respiration ratio (P/R) for willow-lined, native vegetation-lined and cleared streams in the Ballarat district, central Victoria. Adapted from Major (2001) and Wilson (2001).

Reaches with no canopy are radically different. There was enough light reaching the stream to increase photosynthesis 10-fold. The consequence for overall stream energetics was that open reaches had P/R ratios of 0.6. The reaches with a canopy were strongly heterotrophic but those without a canopy become weakly heterotrophic. Clearing of a canopy regardless of whether it is willow or native results in a fundamental shift in energetics towards autotrophy. This is commonly seen with large strands of filamentous green algae in cleared reaches. Flow-on effects of this energetic shift would be expected through the whole ecosystem but have not been studied in relation to willow clearing. However, we have done some work on macroinvertebrates and fish habitat that are reported in the next section.

Invertebrates and Fish

Chandramali Jayawardana completed her PhD studies last year (2006) where she looked at macroinvertebrates in willow, *Phragmites*, tea-tree/bottlebrush and bare bank habitats (in a fully replicated spatial design across all seasons where all habitats were present in each site, sites were nested within rivers and rivers were replicated). She has published a couple of papers comparing willows, *Phragmites* and bare banks (Jayawardana et al 2006a, 2006b), but her overall conclusions come from her thesis. She showed that the willow and *Phragmites* habitats had similar macroinvertebrate assemblages and were richer than the bare bank and tea-tree/bottlebrush habitats. During winter high flows the differences between the two rich habitats and the two poor habitats were even greater, suggesting that the complex root mats of willows and the dense stands of *Phragmites* were important habitats for macroinvertebrates under high flows.

Minal Khan (2004) completed a PhD in 2004, investigating fish communities in streams of the Ballarat district. She focused on River Blackfish (*Gadopsis marmaratus*), a nocturnal ambush predator, which remain the dominate species in Birch Creek – a regionally significant population of this vulnerable species. In various studies Minal found that undercut banks constituted 4-19% of the available habitat, but 60-70% of Blackfish used these as day time refuges (Khan 2004a and 2004b). Virtually all these undercut banks were below willows.

In an effort to better understand these undercut banks Paul Jaskerniac (2003) completed a third year major project, describing their form. He showed that they had an overhanging cover of sediment and organic matter reinforced by dense willow roots (Figure 8). There was a willow rootlet fringe that was characteristically pink in spring. But the big surprise was the abundance of deep complex ‘tunnels’ up to 1.84m deep running perpendicular to the stream bank. The tunnel entrances were up to 20cm in diameter. Platypus are also known to be associated with willows in the Shoalhaven River, NSW (Tom Grant, University of NSW pers com Oct 2006). The complex physical structure of willow lined banks appears to be suitable habitat.

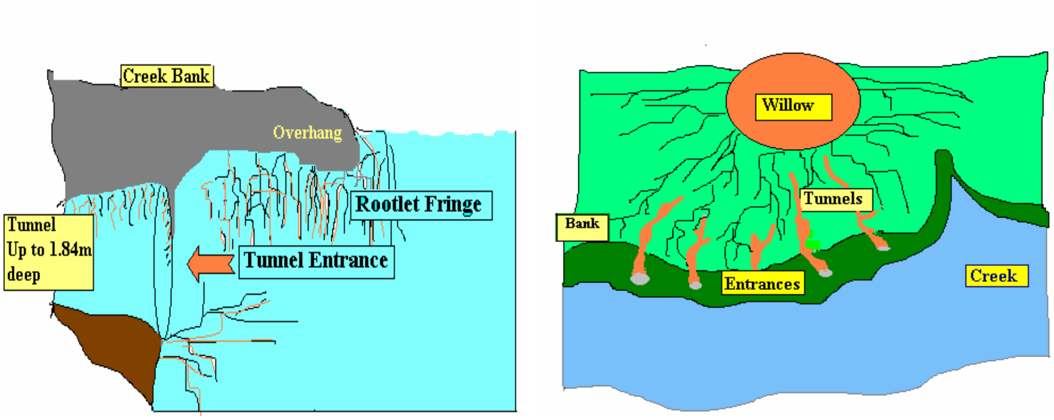

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Figure 8. Cross section (a) and plan view (b) of tunnels and overhangs under willows in Birches Cr that are the dominant day-time refuge for River Blackfish. Adapted from Jaskerniac (2003).

Interestingly the literature shows that in low disturbance streams River Blackfish are strongly associated with debris dams and large wood in the stream (ie large woody debris). In agricultural streams, where there was almost no large woody debris, River Blackfish were associated with undercut banks. This suggests that there is some breadth in their habitat requirements and that willow undercuts can be valuable in the absence of large woody debris.

We studied the volume of large woody debris per area of channel under replicate willow-lined and native-lined channels. There was a greater load of large woody debris in native vegetation-lined streams than willow-lined streams (Figure 9). The data were from streams where the willows had been present for about 40 years, with gold rush clearing and channel stripping and then domestic grazing preceding the willows. The native vegetation was about 100 years old having colonised following the gold rush. We would predict that loads at a cleared site would decline to zero, as there would be no new supply of wood. We would expect a site with no gold rush or other clearing to have much higher loads than those found in streams under 100 year old forests; after all 100 years is middle-aged for many eucalypts and limb fall and senescence may be more common in older eucalypts. So under 40 year old willows there was a load half that under 100 year old native forests, which we presume was a much smaller load than under centuries-old native forests.

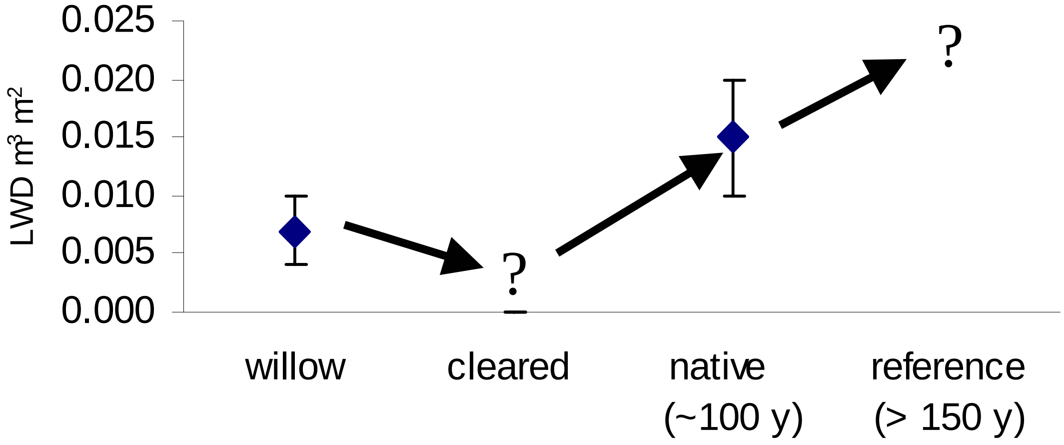

Figure 9. The volume of large woody debris (all pieces of wood with a diameter > 10cm) per square metre of channel in willow-lined and native vegetation-lined streams in the Ballarat district, central Victoria. Also the presumed load for cleared and 'reference' streams (i.e. those undisturbed by post-European catchment or riparian clearing). Adapted from Cameron (2000) and Wilson (2001). Mean ± standard error.

Pool-Riffle Sequences

Pool-riffle sequences, like large woody debris and undercut banks, are important habitats for aquatic organisms. The relatively still pools contrast with the turbulent flowing riffles and the alternating pattern of these two habitats is considered a healthy attribute of many upland streams. In 2003, Julie Boyer undertook her honours research on the pool-riffle sequences along the Yarrowee River and Jim Crow Creek in the Ballarat district. She mapped the vegetation types along tens of kilometres of these streams and then mapped the pools, riffles and runs in each reach. By matching the vegetation type to the stream habitat type she could explore their association (e.g Table 2 from the Yarrowee River).

	Vegetation type		
	Willow	**Native**	**Grassland**
% total stream length	76	20	4
% total habitat length associated with each vegetation type			
Pool	91	7	2
Riffle	91	6.5	2.5
Run	60	33	7

Table 2. The associated between pools, riffles and runs associated with three riparian vegetation types; willow, native vegetation (eucalypt-*Acacia* dominated) and grassland (exotic pasture dominated) along the Yarrowee River, Ballarat (Boyer 2003)

The key point is that there was a disproportionately large association between pool-riffle sequences and willows. Native vegetation and grasslands together lined 25% of the stream but were associated with less than 10% of the pool-riffle sequences. The association was statistically significant (G-test $P<0.001$, Boyer 2003). An association between two things does not always mean that one thing caused the other. So Julie undertook a second study to survey the stream bed to see what channel features were associated with the pools (Figure 10). Virtually every pool studied was formed by a debris weir at the downstream end. By laser survey, Julie showed that the weirs rose above the surrounding channel bed height, forming a pool. Excavation and probing of the weirs showed them to be constructed of debris and sediment armoured by willow root maps. A fallen branch or piece of large wood was sometimes a major component of the weir and the root mat and sediment accumulated and cemented the wood in place.

The Yarrowee River receives the bulk of Ballarat's storm water (from a population of approximately 80 000) and the hydrological conditions in the channel are extreme. Yet under these conditions, willow-armoured weirs were creating beneficial habitat patches. This is entirely consistent with our other findings on sediment and organic matter retention discussed earlier.

This research is compelling and carefully documented evidence that supports some observations by Peter Andrews (2006). He states that plants are fundamental to repairing the degraded landscapes he is concerned with, even when the plants are considered weeds. He pays particular attention to willows in terms of channel-floodplain restoration.

Our research simply places observations of landscape self-repair in a scientific context, and there should be no surprise that these observations match those of a practitioner of landscape repair. The 'leaky weirs' advocated for use in channel-floodplain restoration by Natural Sequence Farming (Andrews 2006) appear to have much in common with the weirs created by willows in the Yarrowee River and Jim Crow Creek. Julie Boyer's research was motivated because pool-riffle sequences are extremely valuable habitat and on that basis alone it is worthwhile. But it becomes even more valuable when it can contribute to ideas focused on restoring the whole of the floodplain complex in agricultural landscapes.

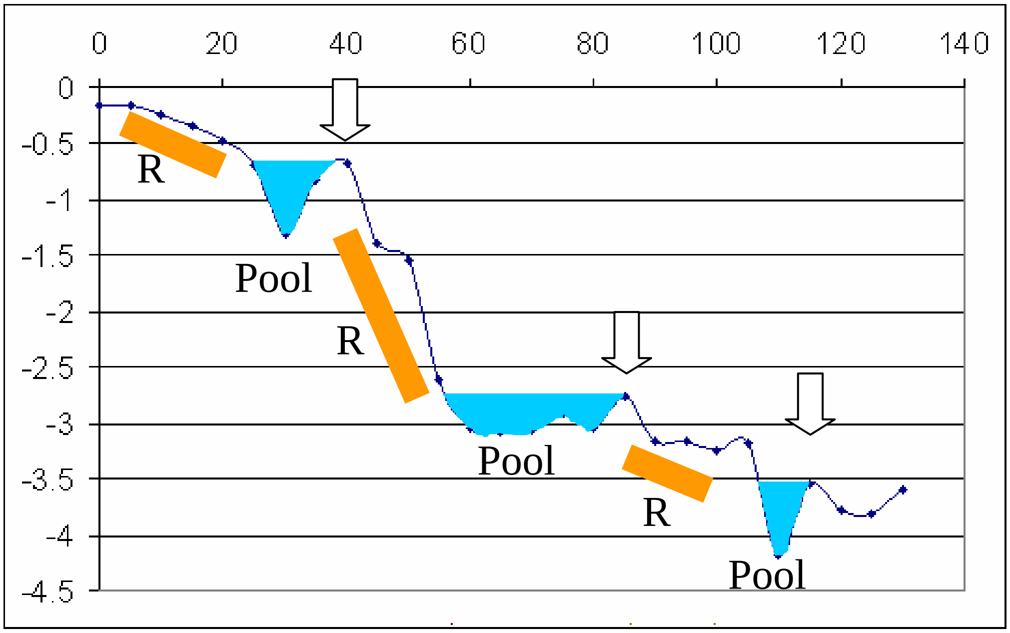

Figure 10. Longitudinal cross section of a 140m reach of the Yarrowee River, Ballarat showing a pool-riffle sequence. The arrows indicate debris weirs, R = riffle. Note the vertical exaggeration; both axes are in metres (Boyer 2004).

Conclusions

Willows are clearly powerful ecosystem engineers. They are not the same as native plants, just as native plants are not the same amongst themselves and conclusive differences can be shown between reaches lined by willows and those lined by native vegetation. However, the fact that they are different is a completely different issue as to whether they cause harm. I believe that the presence of willows along streams in agricultural zones can be shown to be almost universally preferable to cleared streams in those zones. I would also suggest that even relatively low-disturbance eucalypt-*Acacia* dominated riparian vegetation may not have compelling benefits over willows under many circumstances. Willow invasion of pristine, rare or clearly self-repairing native ecosystems can be dealt with through well-accepted bush regeneration techniques.

However, our current willow management strategies advocate clearing willow-lined streams. The evidence presented in this paper suggests that would be catastrophic. It is possible that clearing willows makes room for planting of native trees and shrubs, but I can foresee no other immediate or even medium term benefits. In all the streams we have studied, clearing will mobilise sediment, nutrients and organic matter, will make heterotrophic streams more autotrophic, will threatening habitat values for invertebrates and fish and will threaten pool-riffle sequences. Native vegetation planted where willows are cleared will take many decades if not hundreds of years to mature, for the canopy to close over and for significant limb fall to occur.

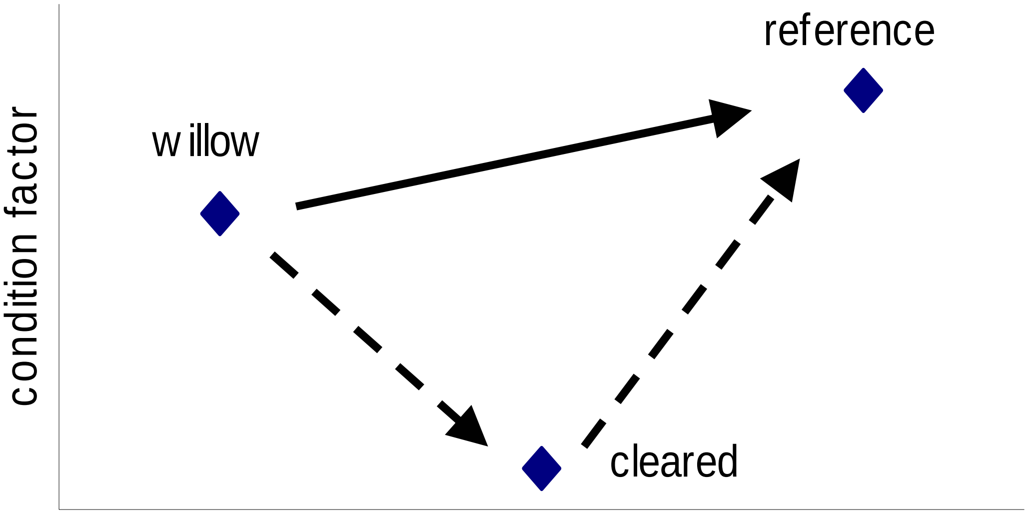

Figure 11. A diagrammatic representation of succession (the solid arrow) that is demonstrably preferably to willow clearing and revegetation.

Clearly a better way is needed and that is succession (Figure 11). There is no need to clear willows – I contend that it is the absence of complex vegetation across our landscape that is the problem, not the presence of willows. Willows can be left to continue to restore the channel and we can plant a native forest (or whatever species mix is required for production, aesthetic and habitat values) next to and under the willows. This strategy can be immediately implemented under current funding arrangements for riparian fencing and restoration. Willows are intolerant of shade and will be displaced over time, as is observed already in old stands.

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