Are waterways with willows wider?

Lizzie Pope[1], Brian Finlayson[2] and Ian Rutherfurd[3]

1 Earth Tech, 71 Queens Rd, VIC 3004. Email: elizabeth.pope@earthtech.com.au.
2 School of Anthropology, Geography and Environmental Studies, University of Melbourne, 221 Bouverie Street, Carlton, 3010. Web: http://www.sages.unimelb.edu.au/, Email: brianlf@unimelb.edu.au
3 School of Anthropology, Geography and Environmental Studies, University of Melbourne, 221 Bouverie Street, Carlton, 3010. Web: http://www.sages.unimelb.edu.au/, Email: idruth@unimelb.edu.au

Abstract

Planting native vegetation on stream banks is the most common stream restoration activity in Australia, because it is relatively low cost, and is widely believed to provide multiple benefits for the stream. However, there are few scientific studies that can be applied in the Australian context on how riparian vegetation affects stream channel form. The purpose of this paper is to present the current scientific evidence on the association between vegetation and stream channel width, and supplement existing information with data from Victorian streams. This data indicates that different types of vegetation are associated with stream channels of different widths. Measurements of Victorian streams suggest that there is little difference between the width of streams lined with native trees and those lined with pasture grasses. However, where exotic willows invade the stream bed (usually in small streams) channels tend to be wider than those lined with native vegetation. In contrast, where the willows colonise the banks of the stream (because the channel is too deep for them to invade the bed), the stream width is similar to a corresponding stream with native trees or grass. Thus the effect of vegetation on stream morphology is dependent on scale.

Keywords

Stream width, vegetation, south-eastern Australia, *Salix spp*.

Introduction

The cross-sectional geometry (width, depth, area and general shape) of river channels is a central preoccupation of both fluvial geomorphologists and river managers. The size of a channel is often used as an indication of the rates of erosion and deposition within a stream, it has direct ecological relevance (Davies-Colley, 1997; Sweeney *et al.*, 2004) and is important for land management. Un-natural widening of the river can lead to substantial losses of arable land and increase the sediment input to rivers, a topical management issue in Australia. Numerous downstream hydraulic geometry studies demonstrate that, in general, the larger the mean annual discharge, the larger the channel cross-sectional area (Park, 1977; Hey, 1978). However, there is wide variation in this relationship. One factor that contributes to this variation is riparian vegetation.

Although a number of studies have researched the effect that vegetation has on channel size, no clear pattern has emerged. Of 12 studies reported in the literature and reviewed for this paper, six have found that reaches with woody vegetation have narrower bankfull channels compared to those without, five have observed the reverse and one found that there was no difference between the two. While a comprehensive literature review found that there are many possible explanations for the conflicting results (Pope, 2005), it may be that the contradictions are due to a lack of consideration of the species of woody vegetation and the size of the river being studied.

In terms of Australian river management, riparian re-vegetation is currently the most common form of stream restoration (Anderson *et al.*, 2004). Exotic willow trees were widely used in the past because of their ease of establishment, high survival rate and thick root mat which was thought to protect the bank. Re-vegetation with native trees has more recently become the norm due to the undeniable benefits for aquatic and riparian ecology. However, the effect of this re-vegetation on the size/shape of stream channels has received less attention.

In this study we aimed to increase understanding of how vegetation affects channel width by asking two central questions:

- Are the individual characteristics of trees, as well as their presence or absence, important in determining how they affect channel width? i.e. Are streams with willow trees wider than comparable streams with native trees or only grass?
- Is the effect of vegetation on channel width mediated by catchment scale, i.e. is the effect of vegetation the same on small streams with small discharges/catchment areas, as it is on larger streams, with higher discharges, draining larger catchments?

The three vegetation types investigated within our study include: sites with a predominately grass cover, sites with a dense cover of native Australian riparian trees (mainly *Eucalyptus sp*. and *Acacia sp*.) or sites dominated by exotic willow trees (*Salix x. fragilis*).

We expected that streams lined with native trees would be narrower than those lined with grass, as tree roots would stabilise the bank. Conversely, we expected that streams lined with willows would be wider than those lined with grass as the increased blockage ratios from the in-stream trees and branches would contribute to stream bank erosion.

Methods

Thirty-five river reaches located in central Victoria were selected for study. Potential sites were chosen using maps available from www.vicwaterdata.gov.au, visited, and then assessed for suitability. In order of priority, sites had to have:

- A high (>80 percent) cover of mature trees directly adjacent to the stream (either native Australian species (*Eucalyptus sp.* or *Acacia sp*.) or introduced willow trees (*Salix x fragilis*)) or a minimal (<5 percent) cover of woody vegetation. Sites where recent willow removal had occurred were also included as willow sites and sites with recent revegetation were included as pasture sites.
- a similar cover of vegetation for a length of at least 14 channel widths
- mainly alluvial banks
- no artificial structures such as bridges, culverts or weirs

At each site, bankfull width measurements were taken at approximately 20 points along the reach. Distances between measurements were selected at random points, using values from random number tables. Measurements were a minimum of 4m and a maximum of 15m apart. At sites with small to medium sized channels (<15m wide), two people held a tape measure across the stream to determine bankfull and base width. On larger rivers (>15m wide), a rangefinder (Accuracy +/- 1m) was used to measure channel width.

The channel width of each site was then plotted against catchment area. Catchment area was used as a substitute for discharge as information on mean annual flow and other hydrologic variables was not available for all study sites.

Results

As expected, the mean bankfull width of streams appears to vary markedly in response to the type of riparian vegetation on the bank at small catchment areas (Figure 1). A cover of riparian willow trees was associated with the widest stream channels for all catchment areas while a cover of native trees was associated with the narrowest channels at small catchment areas (<60km^2). Streams lined with grass appear to be narrower than streams with native trees at catchment areas above approximately 60km^2 (Figure 1).

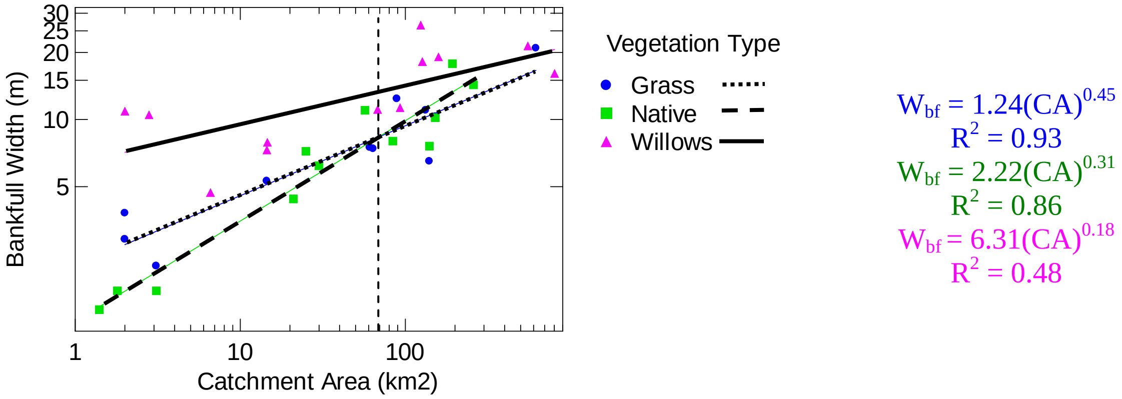

Figure 1. Scatter plot and regression equations showing the relationship between vegetation type (willows, natives or grass), bankfull width and catchment area (log-log scale). The vertical dashed line indicates the point at which sites with natives become narrower than those with grass (~60km^2).

The 95 percent confidence intervals of the mean bankfull width for sites with grass and sites with native trees overlap by more than a quarter at all catchment areas (Figure 2). This means that the differences in mean bankfull width between them are not significant (P>0.05). In contrast, the 95 percent confidence interval for the mean bankfull width of sites with willows is significantly above that for sites with native trees or grass at the lower catchment areas (Figure 2). Above a catchment area of approximately 70km^2, the confidence intervals of all three types of vegetation overlap by more than a quarter. This means that for catchments larger than ~70 km^2, the mean bankfull widths of sites with different vegetation types are not significantly different (P>0.05).

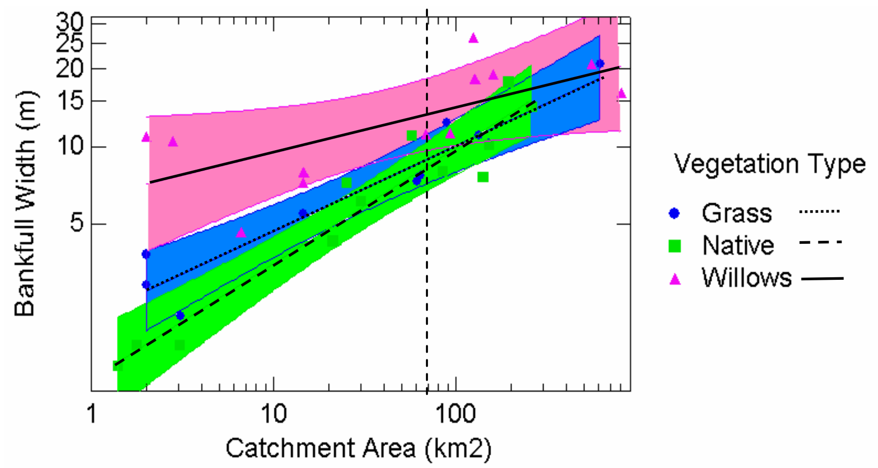

Figure 2. Scatter plot showing the relationship between vegetation type, bankfull width and catchment area (log-log scale). The shaded sections refer to the 95 percent confidence intervals around each regression line. The vertical dotted line indicates the point at which the confidence intervals of all three vegetation type overlap by more than a quarter (~70km^2).

An analysis of co-variance (ANCOVA) conducted on the effect of catchment area and riparian vegetation type on the mean bankfull width of streams revealed that the slope of the regression lines of each vegetation type were significantly different from each other (Table 1). This means that the association between vegetation type and bankfull width was dependent on the catchment area of the study site.

Table 1. Results of ANCOVA conducted on the effect of catchment area and riparian vegetation type on the mean bankfull width of streams. Dependent variable is bankfull width, sample size = 35, R^2 = 0.62.

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*	*P*
Catchment Area (CA)	483	1	483	28.4	**<0.001**
Vegetation	290	2	145	8.5	**0.001**
Vegetation *CA	138	2	69	4.1	**0.028**
Error	492	29	17		

Discussion

Native trees and grass

Previous studies have found that both tree roots and grass appear to enhance the stability of river banks and reduce rates of erosion (Thorne, 1990; Abernethy & Rutherfurd, 2000; Simon & Collison, 2002). This increased stability, in turn, has been associated with the formation of narrower stream channels in some studies (Millar & Quick, 1993; Huang & Nanson, 1998). However, in this study, the width of streams lined with native trees was statistically indistinguishable from those lined with grass. This suggests that the reinforcement and protection of stream banks by tree roots, and/or by grass is not able to account for the variations in channel width observed between field sites with different vegetation. Note, however that our data cover a larger range of stream sizes ($2km^2$ to $600km^2$) than other studies which have commonly focused on streams draining catchment areas less than $200km^2$. Another issue is that a wider channel may not necessarily relate to a channel experiencing a lot of erosion. For example, a study by Allmendinger *et al.*, (2005) found that streams lined with grass were narrower than those lined with trees but they experienced much higher rates of lateral migration, i.e. a high erosion rate was coupled with a high deposition rate.

Why are willow-lined channels wider?

During field sampling it was noted that willows tended to colonise the lower bank and in the bed of the stream, while native trees were generally only established at the top of the bank. Large accumulations of sediment tended to be located on the downstream side of the trunks of in-channel willows and considerable amounts of debris were also often trapped within the branches. In many cases there was evidence of bank scour around these blockages (Figure 3). Sites with native trees did have some Large Woody Debris (LWD) in the channel but the quantities were modest compared to the blockages and obstructions caused by in-channel willows.

Trees growing within the stream channel are considered to be a special case of LWD. According to Keller and Swanson (1979), fallen trees and branches often protect the bank because moving water re-positions them parallel to the flow. In contrast, trees living in the channel are securely rooted in position and generally cannot be relocated by flow (Keller & Swanson, 1979). They also provide a firm base for sediment and other debris to get caught on. This means that they can provide a much greater obstruction, and contribute to even higher levels of flow resistance. During peak flows, water ponds behind obstructions caused by in-channel trees and eventually flows around the side, causing bank scour (Figure 3). This can cause significant erosion and enlargement of the channel (Thorne, 1990; Trimble, 2004).

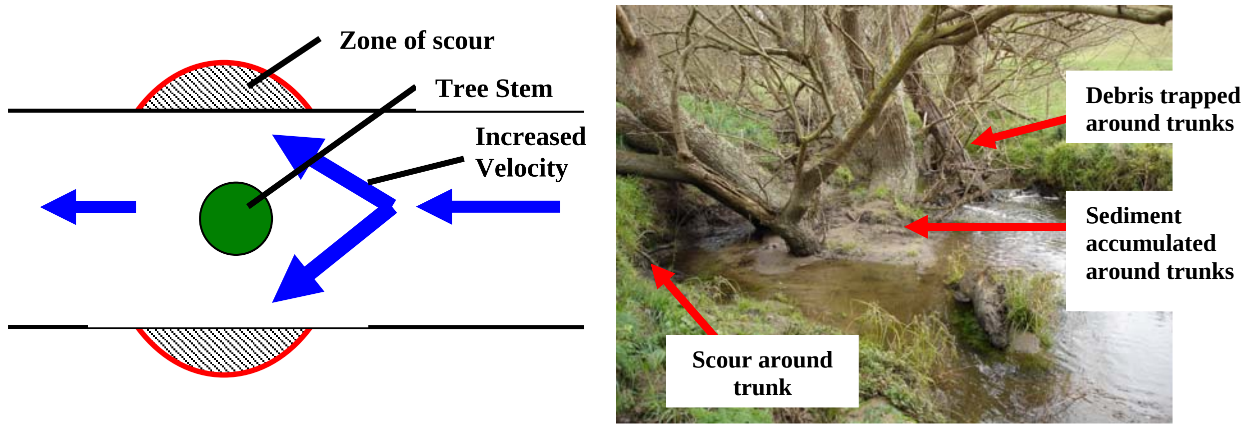

Figure 3. (a) Diagram showing how flow accelerates around mid-channel vegetation leading to bank scour (Diagram adapted from Trimble, 2004, p.155), and (b) a typical in-channel bed willow from one of the field sites (Coal Creek). Note the considerable blockage of the channel by the willow tree and the associated trapped sediment and debris.

The decreasing influence of vegetation with increasing catchment area is further evidence that flow roughness created by mid-stream vegetation is a major factor contributing to wider channels. While the channel capacity of the stream increases with increasing catchment area, the size of trees remain the same, regardless of the dimensions of the channel they are occupying (Abernethy & Rutherfurd, 1998). This means that an in-stream tree and its associated accumulation of debris and sediment, positioned within the bed of a small stream, can almost entirely block the channel and is likely to cause bank scour and channel widening. However, a tree of the same size, growing within a much larger channel may cause some disruption to the flow, but the effect on channel size tends to be much lower.

Within this study we also observed an interaction effect between catchment size and the position of trees in the channel. It appeared that the frequency of willows in the stream bed decreased with increasing channel size. This may be because, in larger rivers, with higher discharge, the flow is too strong, or the river is too deep for broken branches or seeds to lodge and grow in the bed of the channel. The lack of willows in the bed of larger rivers would decrease the levels of flow deflection and therefore bank scour leading to a reduced effect of willows on channel dimensions. The reduced incidence of trees in the bed, may, therefore, be another factor that explains why the width of channels lined with willows are not significantly different from the width of sites with native trees or grass at larger catchment areas.

Conclusion

As with several international studies, we have provided evidence that riparian vegetation influences the width of stream channels in catchments with areas of between 2 km^2 and 600 km^2. However, our results do not support other findings that channels lined with grass tend to be narrower than banks lined with native trees (Huang & Nanson, 1997). This suggests that although native trees contribute a significant amount to ecological values, their impact on channel width on small to medium sized alluvial streams in Victoria may be limited. The most obvious effect of vegetation on channel width is the effect of willows. Up to catchment areas of ~70km2 the invasion of willows into the stream bed and lower banks means that streams lined with willows are significantly wider than streams lined with grass or native trees. The effect of willows on stream width appears to decline as catchment area increases, most likely because willows are unable to colonize and survive within the channel bed at higher discharges.

Over the past decade, several scientific studies have highlighted the negative ecological effects of introduced willow trees (Read & Barmuta, 1999; Serena *et al.*, 2001; Greenwood *et al.*, 2004). Assuming that in this study, sites with native trees represented the 'natural' geomorphological state of Victorian streams, the results show that willows are also associated with streams that are significantly wider than the natural state, especially at small catchment areas. This finding presents further evidence in support of the case for removing willows from Victorian streams. It also suggests that removal would be more beneficial on small streams, where their geomorphic impact appears to be greatest. A note of caution is that the results of this study do not predict whether removing willows will lead to channel narrowing and a return to a ‘natural’ state.

Acknowledgments

Special thanks to the Co-operative Research Centre for Australian Weed Management who provided funding for the Honours year and all those who helped out with field work: Kent Alexander, Penny Clark, Este Darin-Cooper, Ronan Magaharan, Mark Stacey, Llew Thomas, Georgie Tucker, Geoff Vietz, Elisa Zavadil.

References

Abernethy, B., & Rutherfurd, I. D. (1998). Where along a river's length will vegetation most effectively stabilise stream banks? *Geomorphology, 23*(1), 55-75.

Abernethy, B., & Rutherfurd, I. D. (2000). The effect of riparian tree roots on the mass-stability of riverbanks. *Earth Surface Processes and Landforms, 25*(9), 921-937.

Allmendinger, N. E., Pizzuto, J. E., Potter, N., Johnson, T. E., & Hession, W. C. (2005). The influence of riparian vegetation on stream width, eastern Pennsylvania, USA. *Geological Society of America Bulletin, 117*(1-2), 229-243.

Anderson, B., Reich, P., Lake, P. S., Rutherfurd, I. D., Quinn, G. P., & Stewardson, M. (2004). *The Riparian Rehabilitation Experiment: Evolution of a Practical Methodology.* Paper presented at the 4th Australian Stream Management Conference, Launceston.

Davies-Colley, R. J. (1997). Stream channels are narrower in pasture than in forest. *New Zealand Journal of Marine and Freshwater Research, 31*(5), 599-608.

Greenwood, H., O'Dowd, D. J., & Lake, P. S. (2004). Willow (Salix x rubens) invasion of the riparian zone in south-eastern Australia: reduced abundance and altered composition of terrestrial arthropods. *Diversity and Distributions, 10*(5-6), 485-492.

Hey, R. D. (1978). Determinate Hydraulic Geometry of River Channels. *Journal of the Hydraulics division, ASCE, 104*(6), 869-885.

Huang, H. Q., & Nanson, G. C. (1997). Vegetation and channel variation: A case study of four small streams in southeastern Australia. *Geomorphology, 18*(3-4), 237-249.

Huang, H. Q., & Nanson, G. C. (1998). The influence of bank strength on channel geometry: An integrated analysis of some observations. *Earth Surface Processes and Landforms, 23*(10), 865-876.

Keller, E. A., & Swanson, F. J. (1979). Effects of large organic material on channel form and fluvial processes. *Earth Surface Processes and Landforms, 4*(4), 361-380.

Millar, R. G., & Quick, M. C. (1993). Effect of bank stability on geometry of gravel rivers. *Journal of Hydraulic Engineering, 119*(12), 1343-1363.

Park, C. C. (1977). World-wide variations in hydraulic geometry exponents of stream channels - Analysis and some observations. *Journal of Hydrology, 33*(1-2), 133-146.

Pope, L. (2005). *The Geomorphic Effect of Vegetation on Streams - A comparative Study on the Effect of Grass, Australian Native Trees and Introduced Willows on Stream Channel Width in Southeastern Australia* Unpublished BSc (Honours) Thesis, University of Melbourne, Melbourne.

Read, M. G., & Barmuta, L. A. (1999). Comparisons of benthic communities adjacent to riparian native eucalypt and introduced willow vegetation. *Freshwater Biology, 42*(2), 359-374.

Serena, M., Worley, M., Swinnerton, M., & Williams, G. A. (2001). Effect of food availability and habitat on the distribution of platypus (*Ornithorhynchus anatinus*) foraging activity. *Australian Journal of Zoology, 49*(3), 263-277.

Simon, A., & Collison, A. J. C. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms, 27*(5), 527-546.

Sweeney, B. W., Bott, T. L., Jackson, J. K., Kaplan, L. A., Newbold, J. D., Standley, L. J., *et al.* (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America, 101*(39), 14132-14137.

Thorne, C. R. (1990). Effects of vegetation on riverbank erosion and stability. In J. Thornes (Ed.), *Vegetation and Erosion: Processes and Environments* (pp. 125-144). Chichester, England: J. Wiley & Sons.

Trimble, S. W. (2004). Effects of riparian vegetation on stream channel stability and sediment budgets. In S. J. Bennett & A. Simon (Eds.), *Riparian Vegetation and Fluvial Geomorphology* (Vol. Water Science and Application 8, pp. 153-169). Washington, DC: American Geophysical Union.