

Guidelines for the Rehabilitation of Riparian Vegetation in Southeastern Australia

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SUMMARY: Stream management authorities now recognise the many ecological and geomorphological benefits that indigenous riparian vegetation can provide. Observations of interactions between channel and floodplain geomorphology, the characteristics of riparian vegetation in undisturbed catchments and monitoring of different trial planting methods have enabled the development of a set of guidelines for riparian revegetation. The guidelines aim to restore riparian corridors as close as possible to their pre-disturbance state and recognise that riparian vegetation is an important component of complex stream ecosystems. Four methods of selecting species are proposed, to be used in combination in different situations. Many factors that should be considered in the rehabilitation of riparian vegetation are outlined. Standard methods of planting are discussed as well as experimental techniques that are cost-effective, reduce physical disturbance of the riparian corridor and reduce the need for irrigation and maintenance.

MAIN POINTS OF THE GUIDELINES:

- Genetic integrity and biodiversity should be maintained by the planting of indigenous vegetation species, not exotics.
- Species can be selected using a combination of remnant vegetation surveys, historical records, palynology and scientifically designed trial plantings.
- A mosaic of species should be planted taking into account the factors of vertical zonation and species succession that relate to flood disturbance and local geomorphic conditions.
- Vegetation should be planted using appropriate techniques at densities that take into account the natural attrition of seedlings, reduce weed competition and encourage the regeneration of planted species.
- The rehabilitated corridor should be fenced off from stock and should be of a width determined with respect to stream magnitude and the objectives of landowners.

1. INTRODUCTION

The values of indigenous riparian vegetation have, in the past, been poorly understood by stream management authorities. In New South Wales (NSW), an apparent pre-occupation with the large-scale removal of riparian vegetation and large woody debris (LWD) is easily understood when it is realised that many river management practices, such as river training, evolved from flood mitigation. One of the often stated aims of flood mitigation is to increase channel capacity by carrying out so-called "channel improvements" (for example, Reddoch and Milston, 1953; Whitehouse and Clarke, 1983). Improvements meant an increase in flow velocity or an increase in channel size and were achieved by all of the following:

- removal of trees from channels;
- removal of snags (LWD) or desnagging;
- removal of bars of sand and gravel;
- artificial cutoffs; and
- physical enlargement of the river channel (Reddoch and Milston, 1953).

In association with these practices, there was a widespread pre-occupation with the planting of exotic species such as willows (*Salix* species) and poplars (*Populus* species). An example of the management of

riparian vegetation and LWD in NSW has been compiled for the Williams and Chichester River catchments from NSW Department of Land and Water Conservation (DLWC) records (Table 1). The numbers in Table 1 are thought to be approximate and do not include many small *Casuarina cunninghamiana* (River She-oak) and *Callistemon viminalis* (Weeping Bottlebrush) plants that have been removed from bars.

Table 1. Details of some of the works undertaken as part of river training schemes on the Williams and Chichester Rivers, 1954-1991.

No. of Trees and Logs removed	No. of Willows planted	No. of Poplars planted	No. of Privet planted
8000	40000	8150	120

(Source: Erskine, 1998)

More recently there has been a growing appreciation by river management authorities of the many ecological and geomorphological values that indigenous species of riparian vegetation can provide (Howell *et al.*, 1994; Raine and Gardiner, 1995; Abernethy and Rutherford, 1998). The planting of willow species appears to have declined due to their apparent ability to spread both

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sexually (by seed) and vegetatively thereby posing a problem as a potential environmental weed (Cremer *et al.*, 1995). Indeed Ladson *et al.* (1997) recommended that existing mature willows be removed in certain catchments in Victoria.

Monitoring of trial revegetation techniques and observations of interactions between riparian vegetation communities' structure and the channel and floodplain geomorphology of 'undisturbed' streams have enabled the development of guidelines for the rehabilitation of riparian vegetation. The guidelines embrace the many values of riparian vegetation as an important component of a complex ecosystem and aim to provide information for use by river managers seeking to responsibly rehabilitate stream channels (see Erskine and Webb, this volume). While most of the work contributing to these guidelines has been carried out in New South Wales and Victoria, it is believed that the principles involved have wider application.

2. SPECIES SELECTION

In order to maintain the genetic integrity and biodiversity of rehabilitated bushland, it is important to plant locally indigenous species of vegetation (Benson, 1992). The term *rehabilitation* is preferred in the context of improving riparian ecosystems as terms such as *restoration* imply an exact reconstruction of original plant communities (Buchanan, 1989), an outcome that may not always be achievable in highly disturbed riparian corridors. There is also growing concern that planting activities, regardless of their indigenous floristic accuracy, are not representative of ecosystems that have developed in response to environmental conditions (McLoughlin, 1997).

Selecting appropriate indigenous species for planting in riparian vegetation rehabilitation programs is achievable by using a combination of the following techniques.

2.1 Remnant Vegetation Surveys

Field surveys of remnant riparian vegetation communities growing adjacent (or near) to areas requiring rehabilitation probably provide the most reliable method of selecting species appropriate for planting. Such surveys should aim to do more than provide a species list. They should provide information on the vegetation community, taking into account features such as the relative abundance and density of each species and interrelationships with changes in micro-topography, soils, aspect, flood frequency and disturbance regimes (McLoughlin, 1997).

The reliability of remnant vegetation surveys is very much dependent upon the skills and experience of those carrying out the survey. There are many methods of quantitatively sampling vegetation communities and different methods are appropriate for communities of varying structural complexity. It is therefore recommended that the advice of plant ecologists is

sought before undertaking such surveys. A useful starting reference is Walker and Hopkins (1990).

2.2 Historical Records

Often, in areas requiring riparian corridor rehabilitation, due primarily to land-use changes, very little remnant vegetation remains. This poses a considerable problem for species selection. Historical photographs and accounts of natural vegetation during early European settlement are a potential source of information. Caution must be exercised in the use of such records as descriptions are often qualitative, incomplete or inexact. However, when used in combination with other methods (as discussed below), historical records can assist stream managers deciding upon species to plant in regions where today very little remnant vegetation remains.

2.3 Palynology

Palynology is the scientific study of pollen contained within the preserved bottom sediments of relatively undisturbed, anaerobic, layered environments such as exist in swamps and lakes (Faegeri and Iverson, 1975). The analysis of pollen slides prepared from cores drilled through such sediments allows the reconstruction of pre-disturbance vegetation community species lists (for example, Kershaw *et al.*, 1991; Bennett, 1997).

This method has the potential to provide valuable information, to be used in conjunction with the other methods outlined, for determining species appropriate for planting. As with historical records, there are certain problems with this method that require it to be used with caution. These are associated with the identification of pollen, the under- or over-representation of different species in the pollen record and the limited number of appropriate sites of pollen deposition and preservation (Dodson, 1983). People with the appropriate experience and expertise should ideally conduct pollen analyses.

2.4 Trial Plantings

River metamorphosis, or the complete transformation of river morphology during historical time (Schumm, 1969), has been observed in many catchments in southeastern Australia. Often in these catchments, the only remnant vegetation to be found is in protected fragments, in environments that are incompatible with the area requiring revegetation. A typical example is Wollombi Brook in the Hunter Valley. Remnant vegetation communities exist in its upstream reaches where mean annual rainfall is in excess of 900 mm (Bridgman, 1984). However, downstream at sites like Broke (Plate 1) where mean annual rainfall is 650 mm, Wollombi Brook is an eroding bedload river that has aggraded and widened substantially in response to a catastrophic flood event (Erskine, 1996). It is therefore unclear whether the species known to grow upstream would be suited to planting in such a dissimilar environment. It is also believed that such situations may exist in very saline areas where indigenous species cannot tolerate such conditions.

In cases such as that described for Wollombi Brook, it is suggested that trial plantings of various species should be conducted to determine those species appropriate for planting. It is important that such trials are designed scientifically so that meaningful results can be obtained, interpreted and hence applied (Webb, 1997).



Plate 1. Wollombi Brook at Broke in the Hunter Valley, New South Wales.

3. FACTORS FOR CONSIDERATION

The riparian zone is one of the most dynamic regions of the landscape, being subjected to regimes of disturbance and change. Indigenous riparian vegetation has evolved to cope with the stresses associated with such regimes. Observations of some of the process-response interactions between riparian vegetation and channel and floodplain geomorphology in 'undisturbed' environments and problems associated with trial plantings have enabled the compilation of some important factors that require consideration in riparian revegetation programs. They are outlined below.

3.1 Flood Disturbance

Floods of varying frequency, magnitude and duration are experienced at varying elevations above the streambed. This concept is important for planting in riparian zones. It is well established that mature riparian vegetation species have evolved with varying degrees of tolerance to flood disturbance and waterlogging (for example, Melick, 1990). However, planted seedlings or germinating seeds, are vulnerable to flood disturbance and may be removed by surface scouring induced by even the smallest flood events. In a study of 10 trial planting sites in the Hunter Valley NSW, it was found that the survival rates of planted *Eucalyptus melliodora* (Yellow Box) and *Grevillea robusta* (Silky Oak) seedlings were negatively correlated with the total number of floods experienced between 1983 and 1997 (Webb *et al.*, *subm.*).

It is therefore recommended that before planting at a site, calculations of channel capacity and likely flood frequency, either at-a-station where streamflow gauges exist (Pilgrim and Doran, 1987) or using regional methods (for example, Boyd, 1978), should be conducted for varying elevations above the streambed. This allows the prediction of the likelihood of flood disturbance during the establishment phase of planted

vegetation. Funding can then more reliably be allocated for replanting to compensate for losses incurred during flood events.

3.2 Sediment Deposition

The deposition of sediment is a factor closely related to flood disturbance. Clearly, sediment is deposited on floodplains at varying elevations with respect to flood magnitude and flow competence (Richards, 1982). Planted riparian vegetation must contend with such flood deposition. Some species are more tolerant of such deposition than others. In order to achieve maximum survival rates at planted sites, vegetation species observed growing at sites of active sediment deposition (for example in-channel benches/bars) in remnant corridors, should be planted in sites of potential sediment deposition where possible.

3.3 Vertical Zonation

Vertical zonation refers to the vertical distribution of vegetation species across the riparian corridor in natural situations. The zonation of species is due to their relative tolerance of the varying frequency, magnitude and duration of, and sediment deposited by, flood events experienced at different elevations above the stream bed (see Sections 3.1 and 3.2).

In order to maximise structural and ecological integrity, the vertical zonation of species in adjacent sites should be documented during remnant vegetation surveys and replicated in revegetation programs. This involves identifying the relative spatial distributions of different species within the riparian corridor. More than a species list should be provided for each site. Vertical limits of the distribution of individual species can be determined by the use of randomly selected belt transects (A/Prof M. Fox, *pers. comm.*). Alternatively, all trees within a riparian corridor can be surveyed with respect to the stream bed elevation. Figure 1 shows the distribution of 2 plant species surveyed by the authors with respect to the thalweg of Mogo Creek NSW, a laterally-confined sand-bed tributary of the Macdonald River in Yengo National Park.

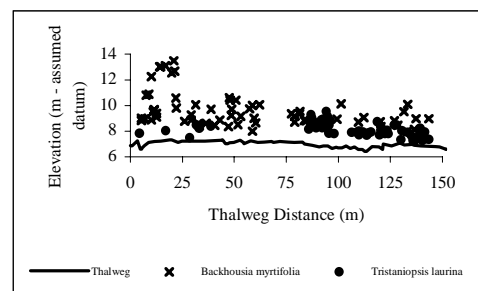


Figure 1. The distribution of 2 riparian vegetation species measured with respect to elevation above the thalweg and distance downstream, Mogo Creek, NSW.

In Figure 1 it is clear that the 2 plant species have different spatial distributions. *Backhousia myrtifolia* (Grey Myrtle) plants appear to grow at higher elevations

above the streambed than *Tristaniopsis laurina* (Water Gum) plants. Similarly it can be seen that there are longitudinal differences in the distribution of the 2 species. In this case, in only a small reach of river, *B. myrtifolia* seems to be the dominant species upstream, whereas *T. laurina* appears to be the dominant species downstream.

Maintaining the vertical (and longitudinal) zonation of riparian vegetation species is important not only for maintaining ecosystem structure but is likely to improve the success of planting schemes. Vegetation species should be identified, and hence planted, from the streambed (including submerged and emergent macrophytes), to the high floodplain.

3.4 Species Succession

Succession refers to temporal variations in the structure of vegetation communities. In a riparian context, primary succession is initiated by species that colonise landforms after flood disturbance. For example, *Casuarina cunninghamiana* (River she-oak) is adept at colonising recently disturbed landforms such as point bars. During their establishment colonising species, such as *Casuarina* and *Acacia* species, fix atmospheric nitrogen into the soil (being leguminous) and provide a microclimate conducive to the establishment of other riparian vegetation species.

Colonising species (and large woody debris) have often been cleared from stream channels on intuitive hydraulic grounds, though no quantitative evidence has been documented in Australia to prove that their presence significantly increases the frequency of overbank flooding (Gippel *et al.*, 1992). Such species should be included in revegetation programs as they are an integral component of riparian ecosystems. To accommodate species succession and maximise the success rate of vegetation planted on disturbed sites, plantings may be required subsequent to the initial planting. It is important to realise that colonising species are often short-lived and therefore may exhibit lower survival rates than other species 10-15 years after planting (Webb *et al.*, *subm.*).

3.5 Channel and Floodplain Material

The characteristics of the channel and floodplain material of a site requiring revegetation should be considered prior to planting. The bed material size will determine the type of macrophytes that are likely to grow. For example, species that grow on sand-bed streams may not grow on gravel-bed streams and so on. The pedologic characteristics of floodplain material will also vary between different stream types and hence influence the likely growth of different species. Webb *et al.* (*subm.*) found that for one species, *Melaleuca styphelioides* (Prickly Paperbark), its mean survival rate on in-channel benches in the Hunter Valley was 77% on sand-bed yet only 7% on gravel-bed sites some 14 years after planting. In this case the floodplain material was coarser textured and had better drainage on sand-bed sites relative to the gravel-bed sites.

Other soil characteristics, both physical and chemical (for example, pH and electrical conductivity), will influence the survival rates of different planted species. This is another reason why, in the absence of adjacent remnant vegetation, it is important to conduct scientifically designed trial plantings (see Section 2.4).

3.6 Corridor Planting Width

Howell *et al.* (1994) recommended that a 50 metre wide corridor of vegetation should be maintained on each bank of the Hawkesbury-Nepean River. Clearly, the recommended corridor width should vary with respect to stream magnitude and riparian landowner needs. In terms of reducing the likelihood of streambank erosion, it is recommended that the corridor should extend to at least the width of the stream banks and onto the adjacent floodplain. Historical bank erosion on the Williams River, for example, has resulted in up to 120 metres of bank retreat, highlighting the need for wide planting corridors (Erskine, 1998).

The planting corridor width is also important for the provision of habitat for terrestrial fauna, and the reduction of weed invasion. Riparian zones, being frequently disturbed, are ideal sites for invasion by exotic vegetation species. This invasion potential is increased when the ratio of corridor perimeter to area is at a maximum. So-called 'edge-effects' are reduced as corridor width is increased (Fox and Adamson, 1986). At the trial sites evaluated by Webb *et al.* (*subm.*) planting corridor widths ranged between 15 and 30 metres. In all cases it is believed that these narrow widths contributed to extensive weed invasion and low survival rates.

3.7 Planting Density

Though it may be perceived as expensive, planting vegetation at higher densities has long-term benefits. By making better use of available environmental resources, vegetation planted at higher densities is more resistant to invasion by weeds than vegetation planted at lower densities. The trials assessed by Webb *et al.* (*subm.*) were planted at 4 metre spacings. It is recognised that to reduce weed invasion and to account for natural attrition, vegetation may require planting at densities of one plant per square metre or greater (Raine and Gardiner, 1995).

3.8 Native Regeneration

The regeneration of planted species in rehabilitated corridors is desirable. As many species of native vegetation require a certain light intensity for germination (Ashton, 1981), conditions that maintain adequate ground level light intensities should be attempted. Of the 10 sites assessed in the Hunter Valley, native regeneration was evident at only 2 sites (Webb *et al.*, *subm.*). It is believed that regeneration was inhibited by low light intensities caused by the excessive growth of understorey weed species. Where this was not the case, ground disturbance by grazing stock is believed to have contributed to a lack of regeneration. At the 2 sites

where native vegetation had regenerated, seedlings had been damaged by grazing stock.

It is therefore recommended that corridors of riparian vegetation be fenced off from grazing stock. To maintain ground level light intensities and encourage the germination of native seeds, it is recommended that weed invasion be discouraged by the adoption of appropriate planting densities and an adequate corridor width (see Sections 3.6 and 3.7).

3.9 Large Woody Debris (LWD) Recruitment

Though it is not the aim of this paper to make recommendations for the reintroduction of LWD (snags) into stream channels, its natural recruitment is of importance for the rehabilitation of riparian corridors. Riparian vegetation is ultimately the source of the LWD found in stream channels. Given that planted riparian vegetation could take decades to fully mature, it is assumed that the natural rate of LWD recruitment would be significantly reduced in rehabilitated riparian corridors in comparison to remnant corridors. Research into the recruitment, residence times and volume of LWD in Australian streams has been virtually non-existent (Gippel *et al.*, 1992). As LWD is of hydraulic, geomorphic and ecological significance (Gippel *et al.*, 1992), its reintroduction into stream channels is an important factor to be considered in the rehabilitation of riparian vegetation and streams in general.

3.10 Maintenance

To ensure the long-term viability of revegetation programs, it is recommended that any funding include an allocation for site maintenance. This is to enable repairs to stock-proof fences, weed control, the planting of vegetation at different times within a species successional framework, to replant after flood damage and so on.

4. THE PLANTING METHOD

Having considered the above factors, it is essential to plant riparian vegetation species using appropriate methods. No one method can be recommended for use in all situations. The well-established method of standard tubestock planting is briefly discussed below, as well as the experimental methods of direct seeding and long-stem planting.

4.1 Standard Tubestock Planting

Standard tubestock planting is a well-established method used in riparian revegetation programs. Usually planted tubestock are protected, by some form of guard, from grazing eg. by rabbits, and from direct sunlight and/or frost damage. In some cases, such plantings may be ineffective due to excessive weed invasion and may require expensive irrigation (Webb *et al.*, *subm.*). Despite the numerous disadvantages of standard tubestock plantings, they should remain as one of the commonly used planting methods until experimental methods (see Sections 4.2 and 4.3 below) are proven to be viable.

4.2 Direct Seeding

In areas where standard tubestock plantings are impractical, for example where extremely large areas require revegetation, direct seeding is an appropriate method of planting. The method and its advantages have been outlined by Raine and Gardiner (1995) and Burston and Brown (1996) and so it will not be further discussed. This method can also be used in association with standard tubestock and long-stem plantings (see Section 4.3) as different species are best propagated using different methods.

4.3 Long-stem Planting

Traditionally, problems have been encountered with standard tubestock plantings in relation to flood disturbance, weed competition, drought conditions and cost-effectiveness (see Section 4.1 above). The 'long-stem' planting method, being developed by the Wollombi Landcare Group (namely Mr Bill Hicks) in association with DLWC, has the potential to overcome many of these problems (Raine and Gardiner, 1995).

Long-stem planting involves the growth of tubestock to a height of approximately 1.5 metres whilst maintaining a relatively small root mass. These long-stem seedlings are planted at depths of up to 1 metre using a water lancing jet which creates a narrow cavity in which the seedling is placed. Only the apex of the plant (top 30-50 cm) is left protruding above the soil surface following infilling of the planting cavity (Bill Hicks, *pers. comm.*, 1997) (Figure 2).

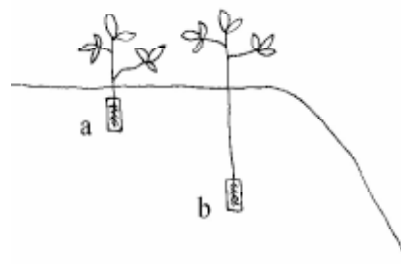


Figure 2. Diagrammatic representation of standard tubestock a); and long-stem b) plantings. (Not to scale).

This method has potential advantages over standard methods. If used adjacent to streams, it reduces the need for irrigation as root masses are located closer to the water table and hence have greater access to soil moisture. Long-stems also provide protection of roots from the hot surficial layers of soil in summer and allow access to the soil environment away from the competition of weed species. Being older than standard tubestock when planted and being rooted deeper in the soil, these plants are less likely to be washed away during minor flood events. This method is still being trialled on different species in the Hunter Valley, but will potentially provide a method of planting that requires minimal site preparation (though preparing the long-stems is time-consuming), is cost-effective and

results in reduced losses due to environmental factors (see also Raine, this volume).

5. CONCLUSIONS

As the rehabilitation of riparian corridors is receiving an increasing amount of attention, funding and community involvement, it is essential that stream management authorities, and Rivercare and Landcare groups are made aware of the many values that indigenous riparian vegetation can provide. To assist in the process of rehabilitation, many factors relating to the interactions between channel and floodplain geomorphology, riparian vegetation ecology and the implications of different planting methods need to be understood. The guidelines outlined in this paper have attempted to address these issues, thereby providing information of relevance to stream managers seeking to responsibly rehabilitate riparian corridors.

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