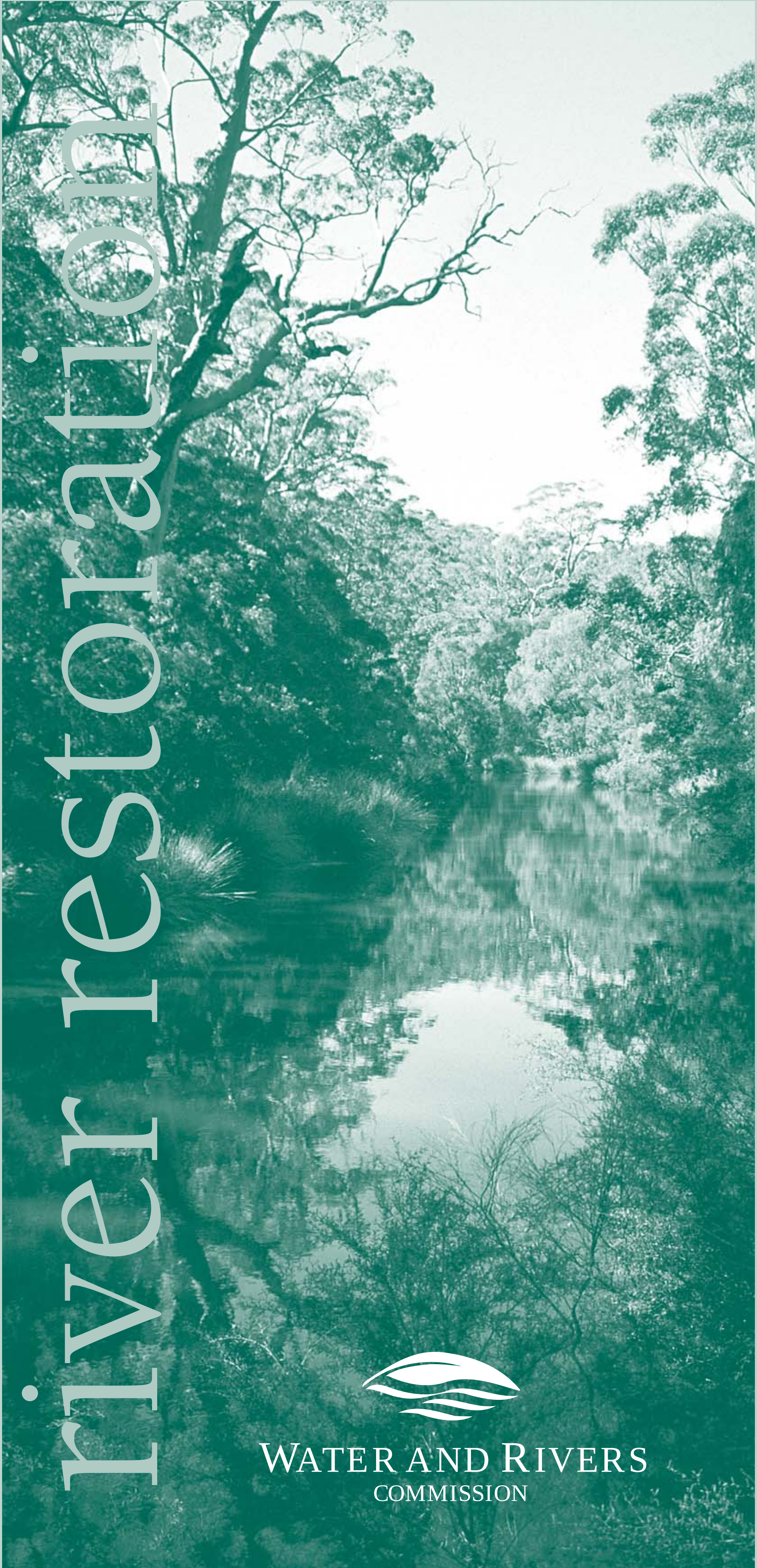

Revegetation

Revegetating riparian zones in south-west Western Australia

August 1999
Report No. RR 4

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REVEGETATION

Revegetating riparian zone in south-west Western Australia

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Jointly funded by

Natural Heritage Trust

WATER AND RIVERS COMMISSION

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Foreword

Many Western Australian rivers are becoming degraded as a result of human activity within and along waterways and through the off-site effects of catchment land uses. The erosion of foreshores and invasion of weeds and feral animals are some of the more pressing problems. Water quality in our rivers is declining with many carrying excessive loads of nutrients and sediment and in some cases contaminated with synthetic chemicals and other pollutants. Many rivers in the south-west region are also becoming increasingly saline.

The Water and Rivers Commission is responsible for coordinating the management of the state's waterways. Given that Western Australia has some 208 major rivers with a combined length of over 25 000 km, management can only be achieved through the development of partnerships between business, landowners, community groups, local governments and the Western Australian and Commonwealth Governments.

The Water and Rivers Commission is the lead agency for the Waterways WA Program which is aimed at the protection and enhancement of Western Australia's waterways through support for on-ground action. One of these support functions is the development of river restoration literature that will assist Local Government, community groups and landholders to restore, protect and manage waterways.

This document is part of an ongoing series of river restoration literature aimed at providing a guide to the nature, rehabilitation and long-term management of waterways in Western Australia. It is intended that the series will undergo continuous development and review. As part of this process any feedback on the series is welcomed and may be directed to the Catchment and Waterways Management Branch of the Water and Rivers Commission.

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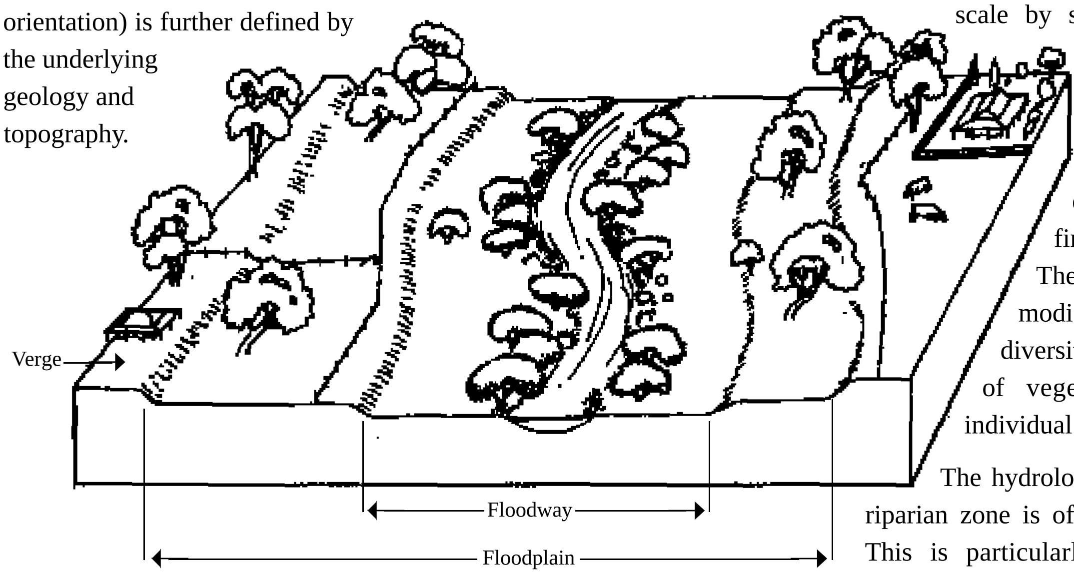
1. Introduction

1.1 The Riparian Zone

Successful river revegetation projects develop from a fundamental understanding of the physical framework of the river system and the processes that influence that system. This means understanding why a river has a certain shape and size, what the main components are, how soil types and wetting characteristics vary spatially, and how seasonal, annual and longer term cycles influence the system.

The major components of the 'riparian zone' in cross section can be defined as (i) verge or upland, (ii) floodplain - seasonally inundated flats bordering a watercourse, and (iii) floodway - seasonally or permanently flooded zone comprising the embankment and channel-bed. These broad zones are defined by hydrology ie. the depth of water, period of inundation, and velocity of flow. Their morphometry (width, length, orientation) is further defined by the underlying geology and topography.



Vegetation patterns in the riparian system reflect these hydro-geomorphic zones, ie. there are noticeable changes in vegetation composition from the upland to the floodway. These usually distinctive vegetation sequences are defined by the hydroperiod (wetting cycle). A typical southwest floodway will have submergent aquatics, such as water ribbons (*Triglochin spp.*) in the channel bed, emergent macrophytes (sedges and rushes such as *Juncus, Baumea)* or saltmarsh plants on the lower embankment, flooded gums, *Melaleucas*, river *Banksias* and other shrubs on the mid to upper embankment.

Climatic setting and the underlying geology influence differences in the composition of vegetation between similar riparian zones at a broad scale. Flooded gum (*Eucalyptus rudis*) defines the floodway in most south-west watercourses, with paperbark (*Melaleuca rhaphiophylla*) and swamp sheoak (*Casuarina obesa*) key floodplain species. Yate, *Eucalyptus occidentalis* is a key upper floodway species in the south-eastern Province, and *Melaleuca* heath the main floodplain community. In the wheatbelt and northern rivers a common floodway species is river gum (*Eucalyptus camaldulensis)*.

Vegetation patterns are also influenced at a finer scale by soil characteristics, hydrological gradients, and secondary factors such as salinity, excessive nutrients, fire and weeds. These latter factors modify the distribution, diversity and abundance of vegetation types and individual species.

The hydrological regime in the riparian zone is often quite dynamic. This is particularly so in southern Western Australia since most channel wetlands are groundwater-fed and dependent on rainfall. This means that subtle shifts in both the boundary of hydrological zones and wetland vegetation boundaries occur over time, contracting and expanding in response to water level changes. This is most noticeable within the floodplain. Understanding the dynamic nature of riparian ecosystems is essential in restoration.

1.2 Importance of Riparian Vegetation

Vegetation plays important structural and functional roles in the riparian zone. Structural diversity, (varying heights, shapes and orientation of species) contributes to habitat value and largely dictates the diversity of associated vertebrate and invertebrate communities. Plant structure also provides water shading resulting in temperature attenuation and reduced algal blooms/midge outbreaks. As well as diversity in stem structure, root architecture is extremely relevant to the stability and functioning of riparian systems. Shallow-rooted sedges and rushes stabilise surface sediments and intercept shallow subsurface flows to 1 m depths, the surface root mats of many woody trees and shrubs intercept surface run-off and stabilise sediments at depth. Structural diversity is also directly linked to the functional diversity of watercourses.

Riparian vegetation contributes a highly complex set of functions to wetland dynamics which can be viewed broadly as (i). hydrologic; (ii). biogeochemical; (iii). biodiversity and (iv). landscape.

Hydrologic

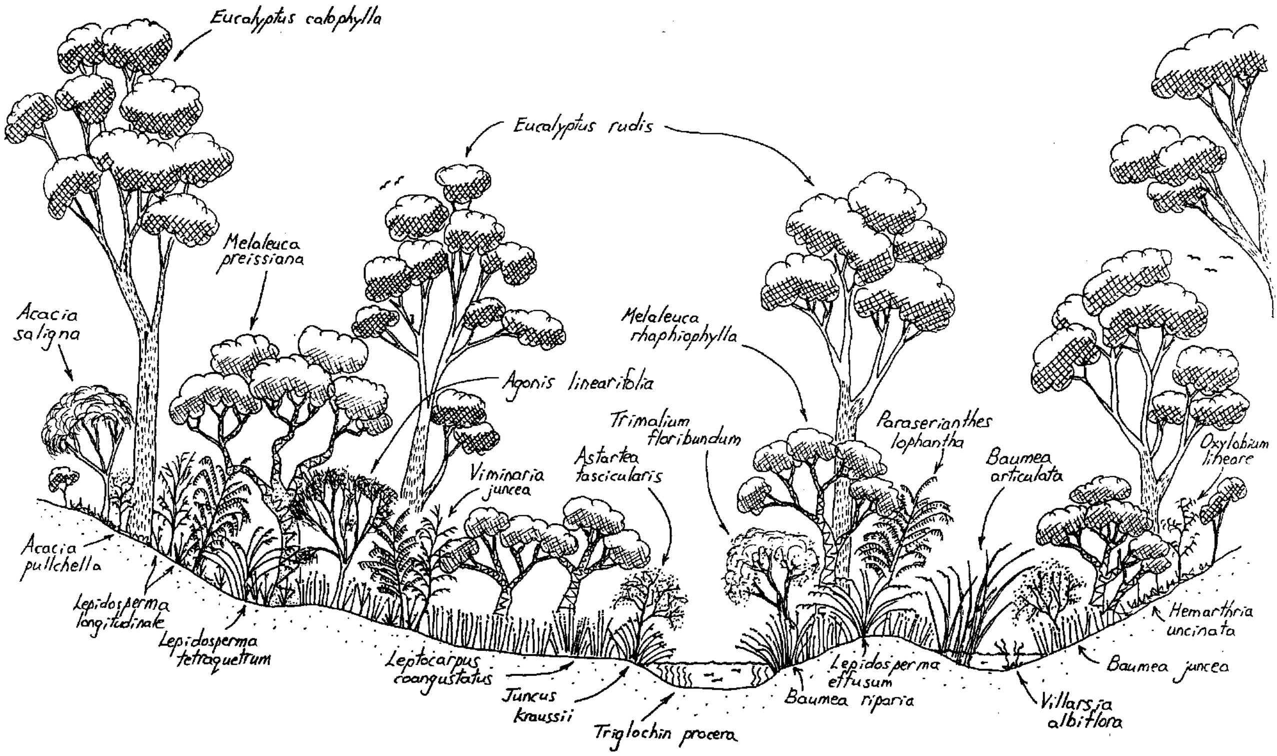
Transpiration is vital in water usage and moderation of groundwater flow or discharge. This is particularly significant for agricultural regions where excessive clearing has resulted in rising, saline groundwater levels.

Biogeochemical

Vegetation is fundamental to nutrient cycling, the uptake and transformation of pollutants, the retention of particulates and sediment trapping, organic carbon production and export, and tannin production. Leaf litter and woody debris represents the major energy source to south-west streams. These biogeochemical interactions in turn determine the water quality and biodiversity of riparian systems.

Biodiversity

Biodiversity as a function means the ability of an ecosystem to persist and reproduce in time and space, preserving rare or significant species and the genetic composition and diversity of flora and fauna. Plant community composition and structure determine resilience of both plant and animal community functions.



A typical cross section of native plant species of the lower south-west of Western Australian.

Landscape

Riparian vegetation provides a linkage with upstream, downstream and adjacent habitats providing fauna corridor values, buffer values and genetic exchange.

Vegetation also contributes to the regional conservation significance of wetlands and their aesthetic, recreational and cultural values.

Individual species can be further classed into specific functional groups, such as salt-tolerant, soil stabilisers, nutrient-strippers etc. Knowledge of these specialist species is important, particularly where the watercourse has been permanently altered, eg. due to salinity.

1.3 Objectives of Revegetation

The incentive for river restoration needs to be thought out in terms of the outcomes that are expected, ie. clean water, stabilised banks etc. The most common objectives for revegetation are outlined below:

Erosion Control

Loss of vegetation cover in riparian zones is one of the major causes of surface and in-stream erosion. The root system of all vegetation strata plays an important role in reducing soil erosion through the provision of a root matrix, which effectively binds the soil. Shallow-rooted perennials, such as rushes and sedges, are effective at surface soil binding, and deeper rooted perennials for stabilising at depth.

Biodiversity Enhancement

Weed control and re-establishment of floristic and faunal diversity are central to biodiversity enhancement. Weed control is necessary for long-term sustainability of the riparian system, and recovery of native vegetation functions. Native fauna is dependent on the native vegetation for energy and habitat. The irregular high inputs from deciduous exotics are not utilised effectively by aquatic fauna, with organisms likely to suffer food shortages for most of the year (Barling & Moore 1993). Most exotic trees do not produce hollows that are often vital habitat for fauna spawning and shelter (Barling & Moore 1993).

Revegetation for biodiversity objectives needs to consider desired outcomes in terms of diversity, density and cover of species, spatial boundaries of particular community types, and use of local genetic provenance. It is essential to utilise a healthy reference site nearby to determine these specific outcomes.

Water Quality Improvement

Riparian vegetation improves water quality by retaining incoming nutrients and sediment. The vegetation increases the infiltration capacity of the soil by effectively improving soil structure and by providing more efficient infiltration routes through soil macropores created by the roots (Thorne 1990). Increased infiltration reduces the amount of surface runoff and hence the amount of soluble pollutants which are transported through the riparian zone (Vought *et al.* 1994). In addition, the increased surface roughness created by the vegetation slows the surface flow velocity, effectively increasing sediment deposition and therefore limiting its export to receiving waterbodies (Muscutt *et al*. 1993).

Nutrient assimilation in riparian buffer strips in surface runoff occurs via sediment deposition and the exchange of dissolved nutrients with the soil/litter interface. The efficiency of these mechanisms is dependent on the vegetation and soil/sediment moisture and composition (Vought *et al.*, 1995).

Certain species are known high nutrient assimilators, and at least several are likely to be present or native to most watercourses. Emergent aquatics such as *Schoenoplectus validus*, *Juncus kraussii*, *Eleocharis sphacelatus* and *Baumea articulata* and submergent aquatics such as *Potomogeton, Ruppia, Triglochin,* are common nutrient assimilators. These species are often good substitutes for high nutrient-responsive weeds, such as kikuyu and watercress.

Salinity

The role of revegetation in saline river systems may be to reclaim denuded areas, ie. to achieve an altered state using species adapted to the new environment, or for control (reduction) of the impact and spread of salt through transpiration loss. Riparian buffers are important salinity control zones in Western Australia, where the groundwater of moderate salinity is at or close to the streambed (Borg *et al* 1987). Riparian buffer strips with deep rooted perennial vegetation assist in lowering the water table and reducing the flow of salt into streams from sub-surface flow. The difficulty in revegetating saline affected areas is the complication of waterlogging that accompanies groundwater rise. Therefore, revegetation planning for saline areas must invariably consider waterlogging tolerance when determining species selection and planting densities.

Aesthetics/Recreation

Many river restoration projects are undertaken with the central goal of improving the aesthetics of the river for recreational purposes. In virtually all cases, this objective can be readily linked to other revegetation objectives, such as biodiversity enhancement. Care should be taken not to degrade existing functions of the riparian system through use of plants requiring fertilising, or exotic species.

2. Site Planning and Prioritisation

2.1 Site Selection

The importance of selecting an appropriate site for river restoration cannot be overstated. The chosen site must reflect the objectives needing to be achieved and must be at a scale that is feasible for achieving such objectives, taking into account cost and time constraints. If the key objective is biodiversity enhancement, the best approach is to begin in areas where the remnant vegetation is relatively intact and weed problems minimal. If the objective is blackberrry control, the scale will need to be at least one linear kilometre, maintained over a two to three year period, to ensure the rate of re-invasion does not exceed the rate of control. Similarly, if the goal is water quality improvement within a catchment, site selection will need to take into account: (i) the existing quality of watercourses within the catchment, (ii) the nature of the pollutants and contributing factors, (iii) location of major point source pollutants, and (iii) an evaluation of the likelihood of success in achieving the desired outcomes.

The suggested framework for selecting sites is to begin at the catchment level and work down to the local scale, ie. the specific stretch of watercourse:

a) Prioritise key objectives at the catchment level

This enables better selection of the watercourses which, once restored, will contribute relatively more to the overall management objectives in the catchment than others.

b) Select subcatchment

Subcatchment selection should be based at a primary level on its relative contribution toward water quality deterioration in the final waterbody, or toward impacts on other biodiversity functions. The final receiving water body in the southwest drainage districts will usually be an estuarine or oceanic outfall or a major permanent river. In inland agricultural regions the final receiving waterbody is more likely to be basin wetland ('lake') or seasonal or permanent channel wetlands. A suggested selection method for prioritising the subcatchment is as follows:

- identify relative nutrient export contributions from each river subcatchment at the final receiving waterbody;
- identify other catchment restoration activities which may be enhanced by restoration works in a particular subcatchment (e.g. restoration already proceeding in a receiving river);
- identify other management opportunities and constraints (e.g. high or low level of community support).
- evaluate costs and benefits of each subcatchment and rank according to priority.

(*c) Select watercourse*

Once a subcatchment has been selected, differentiate the upper, middle and lower order branches of the main watercourse. Selecting a watercourse or section of a watercourse to be revegetated must be done with a good understanding of its spatial setting. In particular, the zonational setting needs to be defined, ie: is it at the headwaters in the erosional zone, or in an intermediate zone with lower gradients, higher volumes, or in a mature depositional zone with slow flow rates? The following site characteristics should be assessed:

1. *Where the watercourse sits in the river system defined above and in the overall catchment;*
2. *How it relates to upstream, downstream and adjacent landuses, e.g. Does it feed directly into a high conservation wetland? Does it receive point source discharge such as a dairy wastewater? What is the type of surrounding agriculture? Is it more or less vegetated than other rivers in the catchment? etc.*
3. *What its condition is relative to other watercourses in the catchment.*

In most cases, a good selection approach is to target the upper order (minor) watercourses first, and any others that are known to be key point-sources of pollution. Once these 'target' watercourses have been identified, undertake a generic cost:benefit evaluation to determine which watercourse is best to begin with, what length of watercourse should be restored, and what time-frame will be required. The following selection method may be used (Regeneration Technology 1999):

- Identify and eliminate any watercourse with difficult social/political constraints, e.g. regulated by adjacent land-use (perhaps flood arrangements for potato growing);
- Complete an overall evaluation of the following broad watercourse characteristics, using aerial photos, or by ground survey:
  - % vegetation cover
  - length of branch
  - morphometry (ie. meandering or straight, approximate width of riparian zones)
  - location of erosion/deposition zones
- Identify **time** and **budget** requirements and/or constraints in general terms, and make a first pass assessment of the relative **benefits** of doing each of the target watercourse sections. The costs of watercourse restoration will increase with length of watercourse, if there is little or no vegetation cover, and if the watercourse does not have a meandering pattern.
- Undertake a detailed classification of the **condition** of each of the target watercourse, using either the Pen and Scott (1995) classification scheme for farming areas or the method developed by Shepherd and Siemon for urban and semi-rural areas (Water and Rivers Commission, 1999). Note any impact of modified processes such as salinity and grazing.

2.2 Setting Objectives and Constraints

Whilst broad objectives, such as biodiversity enhancement, water quality improvement etc. are essential, river restoration will not be effective unless specific, achievable, measurable goals are set. This should be done by thoroughly reviewing the constraints operating in the selected site, which may include weeds, salt, flood frequency, flow, sediment loads, nutrient loads and/or grazing.

2.3 Revegetation Plan

A basic revegetation plan is an essential tool for determining the areas to be rehabilitated, the range of soil types and riparian zones present, the number of plants/seeds required, and timing schedules. A preliminary revegetation plan should include the following:

(a) Define area (m^2) of verge, floodplain, embankment, and channel-bed requiring revegetation.

(b) Characterise water quality - salinity, nutrients (N,P), turbidity

(c) Identify existing soil types and vegetation (community types and species) in each riparian zone.

(d) Map river morphometry (plan and cross-section) and indicate annual flood line and points of erosion and deposition.

3. Site preparation and weed control

3.1 Site Stabilisation

In many cases, the embankment of the floodway will require re-grading where erosion has caused excessive slumping, or steepening of the natural gradients. This may require use of machinery to batter slopes. Before any re-engineering is undertaken, the natural erosion and deposition points along the river need to be identified and 'river training' undertaken in accordance with the natural meandering morphology of the river. If this is not taken into account, plantings are likely to be washed away.

Where re-grading is not possible, steep embankments should be 'benched' or terraced, secured with a roll-out organic fibremulch such as Jutemat, and planted into. In-stream revegetation projects may need to provide temporary deflection of flows until plants are properly rooted. This can be done by installing deflectors or dissipators. Organic products on the market include fibremulch rolls (Ecologs), which are secured at an angle upstream of the planted area. Rocks can be used in shallow streams to disperse and slow the flow of water.

3.2 Protection

Revegetation sites may need immediate protection from feral animals, livestock grazing or vehicle movement. Fencing is essential to successful revegetation. Where rabbits are in serious numbers, planting may have to be undertaken in stages using temporary enclosures. If this is not possible, mature plants rather than seedlings should be used. An additional technique is to plant highly palatable species, such as fleshy monocots, under prickly or less palatable species such as *Acacia pulchella*.

3.3 Weed Control

Appropriate weed control is pivotal to successful revegetation of riparian systems and in degraded environments, will require an ongoing maintenance commitment to succeed. Methods of control will vary depending on the extent of the problem and the types of weeds present. Control is usually most demanding in the first two to three years when native vegetation is establishing, and if conducted correctly during this period, future maintenance should be minimised.

Due to the sensitivity of water environments, herbicide use should be treated with caution, and only low-toxic herbicides should be used. Care should be taken to avoid over-spray into open water. Burning for the purposes of weed control or fire management should be avoided. Burning on a regular basis favours weeds over natives, resulting in a diminished native vegetation cover and seed bank.

Whatever the method of control, there are several basic principals which should be adhered to:

(1) Start at the upstream end of the weed infestation. This may require extending weed control beyond the actual area designated for revegetation.

(2) Minimise disturbance of substrate and any existing native vegetation.

(3) The rate of regeneration of native plants should determine the rate of weed removal.

(4) Undertake weed control one season before planting is undertaken to allow at least one follow-up treatment.

The competition created by weeds for light, nutrients and water can in many instances limit the development of native seedlings. Therefore those areas with excessive amounts of weeds will require follow-up control to ensure native seedlings survive. It is important to remember that weed control will not be a once only management strategy, as often conditions that caused the initial weed invasion will continue to prevail after the initial weed control process. Added to this will be the inevitable disturbance of soil, despite the utmost care being taken. Therefore weed control must be viewed as a staged program that incorporates initial control, secondary follow-up and long-term ongoing maintenance. The main weed control techniques are as follows:

(i) Physical Removal

Physical removal is the most environmentally friendly method of weed control. This method is very labour intensive but can be applied to relatively small areas where volunteer groups or other bodies are available.

(ii) Solarisation

Solarisation to kill weeds and as a method for soil sterilisation can be achieved by laying good quality clear or black plastic sheeting over weeds areas or newly turned soil and leaving undisturbed for 2 - 3 weeks. For best results the plastic should be in direct sunlight and the soil should be damp. This encourages the weed seeds to germinate, which then die due to the high temperatures under the plastic. The best success is achieved during summer and early autumn. This is often a good technique following slashing and/or spraying of above-ground biomass.

(iii). Herbicide Control

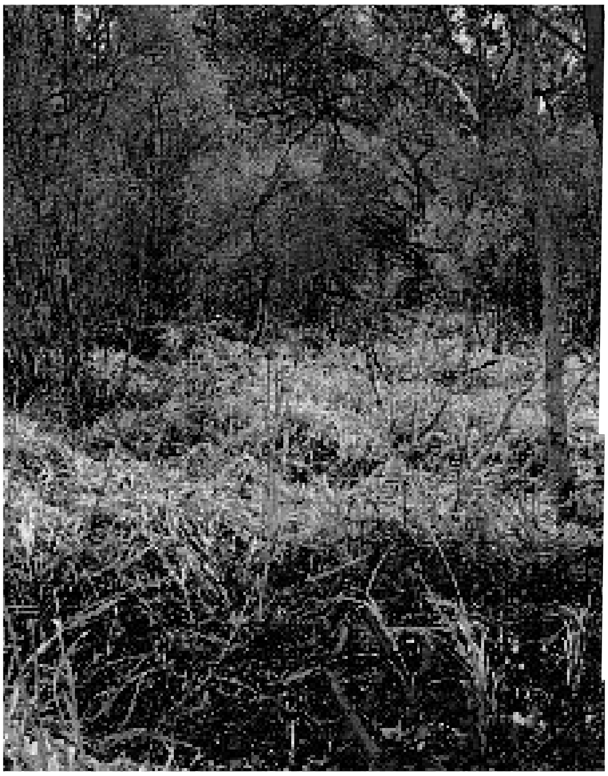
Use of herbicides in wet areas must be undertaken with great care, using only low toxicity herbicides approved for use in such areas. The most effective herbicides are Brush-Off (metsulfuron methyl) (e.g. for bridal creeper, watsonia and blackberry), glyphosate, (e.g. for most weeds), and Fusilade for exotic grasses. Extreme care must be taken to avoid direct spraying into water. Use of surfactants should be avoided due to toxic effects on aquatic fauna.

3.3.1 Control Measures for Key Weed Species

Appropriate weed control measures for specific weeds can be found in Scheltema and Harris (1995). One of the key inland weeds is a South African rush called *Juncus acutus*, which is an aggressive, salt-tolerant coloniser of seasonal channel wetlands and flats. This species should be replaced with the native analogues, *Juncus kraussii* and *Gahnia trifida*. However, removal of this weed is only recommended in conjunction with revegetation works, since the species is fulfilling an important function in these salinised environments.

3.4 Site Mark-Out

Once all revegetation areas have been defined on the revegetation plan, it will be necessary to undertake clear site mark-out of each riparian zone to be planted/seeded, using stakes or flagging etc. If any engineering works are required, a proper survey will be necessary to ensure correct grades are achieved.



Infestation of Watsonia bulbiliferum *at Helena River. This species is a severe fire hazard in summer.*

Table 1. Control strategies for key riparian weeds in southern Western Australia.

COMMON NAME	SCIENTIFIC NAME	DESCRIPTION	CONTROL
Bridal creeper	*Asparagus asparagoides*	Extremely invasive weed that has become one of Western Australia's most urgent environmental weed problems (Hussey *et al*., 1997). The creeper smothers small plants by climbing or trailing over the ground. The seed is rapidly dispersed by birds which feast on its succulent fruit.	(i) Mats of bridle creeper can be rolled up and destroyed Regrowth should be sprayed (spot or herbicide wipe) with Ally, Brushoff ("Metsulfuron methyl") at a rate of 10g/100L of water (a wetting agent such as "Pulse" should be added at 1 part per 400 mixture), during the growing season May-July. Repeat application may be necessary. (ii) Young plants can be removed by hand, ensuring that the bulbous base is completely removed.
Watsonia	*Watsonia spp.*	There are six species of Watsonia in Australia, all of which rise from corms, and form clumps of stiff, sword-shaped, upright leaves (Hussey *et al*., 1995). They are highly invasive and most species are considered serious weeds, particularly in disturbed regions. The plants rapidly spread after fire.	(i) Hand removal is recommended in small infestations. Care must be taken to ensure the corm is removed, or that the stem is broken close to the corm which facilitates rotting. Ensure that any bulbil/seed heads are also removed to limit reinfestation. (ii) In larger infestations plants can be sprayed with Glyph. 360 or Roundup. Highly successful results can be obtained by wiping the leaves with herbicide using a sprayer with foam fitting attached. Ideally spraying should be conducted from September to November when the plants are flowering, however control has been achieved between July and December (Dixon & Keighery, 1995).
Arum Lily	*Zantedeschia aethiopica*	A widespread and conspicuous weed that proliferates in wet swampy habitats and grows from a bulbous root. It is toxic to stock, especially cattle (Hussey *et al*., 1997).	(i) In wet areas Glyphosate without a surfacant should be used. The herbicide should be applied so as to form a pool at the base of the leaf to facilitate absorption. Application should occur between June and October and several applications may be necessary.

COMMON NAME	SCIENTIFIC NAME	DESCRIPTION	CONTROL
Nut sedges	*Cyperus spp. (C. eragrostis, C. congestus, C. tenuiflorus, C. polystachyos)*	These are nuisance perennial weeds which compete with native plants and proliferate in disturbed wetland habitats (Hussey *et al.*, 1997).	(i) Hand pulling is ideal if feasible. Roundup can be applied in summer in larger infestations either as a wipe or as a spot spray.
Blackberry	*Rubus spp.*	Serious riparian weeds that are a declared plant in many south-western shires (Dixon & Keighery, 1995). The plant is spread by birds and foxes, which eat the succulent fruit.	(i) Brushcut brambles and hand remove stumps removing as many connected roots as possible, this is particularly successful in waterlogged sites. Alternatively the stump can be brushed with a herbicide such as Glyphosate or Roundup®. Control is most effective if undertaken between early December and late March. (ii) The entire plant may also be sprayed with either Ally, Brushoff at 10g per 100L of water, with an added wetting agent such as "Pulse" at 1 part per 400 mixture. Or alternatively Roundup Bi-active 360g/L (1 part per 80 parts of water) can be sprayed with 1 part "Pulse Penetrant" to 400 parts of mixture. Monitor annually for germination.
Narrow Cotton Bush or Swan Plant	*Gomphocarpus fruticosus*	Proliferates in disturbed areas and will form dense thickets. The species is a declared weed in some areas (Dixon & Keighery, 1995).	(i) Hand pull small populations by cutting at or slightly below the soil surface. Remove any seed heads and wear gloves to avoid skin contact with the sap. (ii) Alternatively spray with Glyph./Roundup® between September and December before fruit forms.
Budding Club Rush	*Isolepis prolifera*	Invasive naturalised weed, which out-competesnatives and reduces biodiversity.	(i). Difficult to control. Best to slash and spray with Glyphosate (ii). Dense infestations can be excavated and regrowth sprayed.
Juncus	*Juncus acutus, effusum, bufonius, capitatus, microcephalus*	These introduced rushes out-compete natives and favour disturbed riparian areas.	(i). Slash taller species in winter and spray regrowth with Glyphosate, 1 part to 2 parts water. (ii). Hand remove small species (*J. bufonius, J. capitatus, J. microcephalus*) and spray or wipe with Glyphosate. (iii) Repeat spraying of new germinants for several seasons due to large seed bank.

COMMON NAME	SCIENTIFIC NAME	DESCRIPTION	CONTROL
Water Couch	*Paspalum distichum*	A stoloniferous and rhizomatous semi-aquatic perennial (Hussey *et al.*, 1997). The species is found in disturbed wetland areas where it competes with native species forming large smothering colonies (Dixon & Keighery, 1995)	(i) Can be controlled through handweeding, however will require several seasons of removal to ensure complete removal. (ii) Larger areas can be sprayed with Fusilade® (approved for use in wetland areas by Swan River Trust) at a rate of 4L/ ha. Spraying should be conducted in spring-autumn when the species is actively growing and not under stress (Dixon & Keighery, 1995).
Kikuyu Buffalo Couch	*Pennisetum clandestinum* *Stenotaphrum secundatum* *Cynodon dactylon*	These grasses spread by stolons, above ground stems which form roots at the nodes. Couch is also rhizomatous.	(i) Spray grass in late spring or early summer when actively growing, and remove dead grass in autumn before undertaking revegetation. Use Roundup® if no native vegetation is present or if the native plants can be protected, otherwise use Fusilade® at a rate of 4L per ha. Monitor growth and respray where necessary.
Cape Lilac	*Melia azedarach*	Deciduous tree with bird-dispersed berries; spreading throughout the south-west.	(i). Plants should be removed by hand. Great care must be taken to remove all cuttings as they readily take root in moist conditions. Stumps should be wiped or injected with a herbicide such as Glyphosate.
Castor Oil Plant	*Ricinus communis*	Common in disturbed areas, and spreads rapidly once established from seed.	(i) Remove small populations by hand (ii) Slash prior to flowering (iii) Cut stump and wipe with glyphosate (iv) Spot spray seedlings with glyphosate
Taylorina	*Psoralea pinnata*	A small shrub or tree which has become dominant in wetland areas in the Albany region (Hussey *et al.*, 1995).	(i) Seedlings can be remove by hand, mature trees can be lopped below the lower branches and the exposed stem painted with Access mixed in a distillate 1 part per 60 distillate. (ii) Larger infestations can be selectively sprayed. Spray with Ally, Brushoff at a rate of 10g/100L of water with a wetting agent such as "Pulse" added at 1 part per 400 mixture. Monitor annually for seedlings.

COMMON NAME	SCIENTIFIC NAME	DESCRIPTION	CONTROL
Victorian Tea tree	*Leptospermum laevigatum*	Out-competes native species and produces large amounts of seed. Trees are killed by fire; thickets readily regenerate from seed.	(i) Hand-pull small seedlings. Spot spray small plants. Large trees if cut at ground level do not resprout and there is no need for herbicide treatment.
Wild Fig	*Ficus carica*	This commonly known species has spread along river and stream margins throughout	(i) Trees should be cut to base. Stumps should be wiped or injected with a herbicide such as Glyphosate.
Willow	*Salix babylonica*	A deciduous tree which is beginning to spread prolifically throughout southern Western Australia.	(i) Plants should be removed by hand. Great care must be taken to remove all cuttings as they readily take root in moist conditions. Stumps should be wiped or injected with a herbicide such as Glyphosate.

4. Species Selection

4.1 Key Habitat Variables

4.1.1 Botanic Province

The type of species used in revegetation should reflect those that are native to the botanic region within which the river is located, and preferably within the same local provenance. This is because such species are better adapted to local conditions, it avoids contaminating and possibly degrading the gene pool, and avoids the possibility of generating new weedy species or variants. It is difficult to define how far 'local' extends since this will vary with different species, and has not been researched for most of our native taxa. As a minimum, select species and collect propagation material from similar ecotypes (ie. same soil systems and hydrological regimes). Even where the specific objective is salt or nutrient management, there is often no need to import non-local species.

4.1.2 Soil Type

It is essential to know the limits of the species you are dealing with. Most species prefer either sandy or clay soils, and will fail if planted in the wrong environment. Basic horticultural knowledge should be sought on each species used in revegetation. The simplest approach is to take soil and depth to water measurements for each community and associated species in a nearby reference site.

4.1.3 Hydroperiod/Flow Velocity

This is a key parameter in plant survival. Wetland species can be defined as permanent, or seasonal inundation tolerant. Their ability to withstand flooding depends on the amount and distribution of air cells (aerenchyma) present in the roots, rhizomes and stems and physiological attributes. Planting species in an area with the wrong hydrological regime may not show up for several years, since many species can tolerate excessive inundation periodically. Species should be selected according to each riparian zone, ie. in-stream floodway, lower embankment, upper embankment, floodplain, upland. If hydroperiod has altered, or is likely to continue to alter due to groundwater rise or increased/decreased run-off, this will need to be taken into account.

4.1.4 Salinity/Waterlogging

The selection of plants for salt affected areas will usually require specialist advice from appropriate agencies. A useful guide for appropriate tree species is given in a publication entitled 'Trees for Saltland' (CSIRO 1995). Deep-rooted trees can pump between 50 and 170 L/hour from the groundwater. Successful revegetation of salt-degraded/waterlogged areas must also incorporate shallow-rooted species to 'mop-up' excessive surface water. If this aspect is ignored, many trees will die from waterlogging of their feeder roots. Appropriate salt-tolerant, shallow-rooted species include *Juncus kraussii, Baumea juncea*, *Hopkinsia anoectocolea*, *Hopkinsia adscendens, Isolepis nodosa, Gahnia trifida,* and *Gahnia decomposita.*

4.2 Other Factors

Other factors influencing species selection for revegetation may include commercial agricultural considerations, such as a desire for grazing of the floodplain, use of species with commercial floriculture potential etc. Riparian species such as ti-tree, banksias, boronia and many native rushes and sedges are of commercial value as cut flowers or foliage.

5. Plant Establishment

5.1 Common Species

Once a species list has been defined, the next step is to understand the propagation and establishment biology of each species. This section outlines information on the more common riparian genera and species in relation to:

• their functional roles

• how they naturally regenerate

• problems in propagation

• new research.

5.1.1. Sedges and Rushes

Wetland sedges and rushes are usually referred to as emergent macrophytes and belong to the families Cyperaceae (sedges), Juncaceae (rushes), Restionaceae (southern rushes) and Typhaceae (bulrushes). These groups are vital components of the channel bed and lower-to-mid sections of the embankment within the riparian floodway. They are shallow-rooted (usually to 1 m), are characteristic of permanently wet to seasonally wet zones, with the distribution of individual species defined by water regime. They are excellent in slope stabilisation, and important in interception and capture of both surface and subsurface nutrients from lateral flow, and in-stream nutrients. In-stream species provide critical habitat for fauna, assist in slowing water flow rates and encourage sedimentation. Certain species are salt-tolerant.

Typhaceae - Bulrushes

There is only one native bulrush in WA, *Typha domingensis,* which differs from the introduced *T. orientalis* by narrower, paler inflorescences. *Typha domingensis* inhabits permanently wet or moist sections within the channel bed of minor watercourses, but is more common in basin wetlands. It is found in scattered locations in the south-west and south-east, and is common in the north of the state. This species tolerates brackish conditions and reproduces by underground rhizomes and sexually from a massive annual seed set. Seeds require light to promote germination.

Juncaceae - Rushes

Some of the most widespread macrophytes belong to the rush genus *Juncus* (shore rushes). Common riparian species include *Juncus krausii* on lower embankments and the outer channel bed in saline areas, *Juncus holoschoenus, J. subsecundus* and *J. pauciflorus* on lower embankments in freshwater watercourses, and *J. pallidus* in mid-upper embankment zones in freshwater watercourses. *Juncus holoschoenus* and *J. subsecundus* will grow in winter wet areas of the floodplain. All species of Juncaceae are easy to propagate from seed. They contain from several to more than 50 seeds in each capsule, and readily germinate in light. Most perennial species also reproduce vegetatively from tufted rhizomes.

*The salt-tolerant Shore rush (*Juncus kraussi*) along the Swan River.*

Cyperaceae - Sedges

The sedges are probably the most abundant riparian macrophytes in southern Western Australia, the most common genera being *Baumea, Lepidosperma, Schoenoplectus* and *Gahnia.* As a general rule, species of *Schoenoplectus, Isolepis, Cyperus,* and *Scirpus* are quite easy to germinate, but require full light and very warm temperatures (>28˚C), which corresponds to their natural summer germination conditions. Other genera, such as *Baumea, Lepidosperma,* and *Gahnia* are notoriously difficult to propagate using conventional means, due to low seed set, low viability of seed, and complex dormancy mechanisms. Propagation of many species in these groups (e.g. *Baumea juncea, B. rubiginosa, B. vaginalis, Lepidosperma gladiatum*) is now possible using tissue culture of seed embryos, and plants are available at under $1/plant in most wetland nurseries. *Baumea juncea*, *Gahnia trifida* and *Isolepis nodosa* are good species for salt-affected areas.

*Sword sedge, (*Lepidosperma effusum*), common sedge along river banks in the south-west.*

*Twig sedge (*Baumea juncea*) lining the river banks at Jane Brook.*

Restionaceae - Southern Rushes

The Restionaceae are probably the least familiar of the wetland macrophytes, partly due to their notoriously difficult taxonomy. Identification and knowledge of these species will be assisted by a recent publication on this family (Meney and Pate 1999). The most common riparian species in this group belong to the genera *Meeboldina (M. coangustatus, crassipes, roycei, thysananthus),* all common in the south-west. Other common southwest taxa include *Anarthria prolifera, Desmocladus flexuosus, Empodisma gracillimum, Leptocarpus tenax, Lepyrodia riparia, Platychorda applanatus, Sporadanthus rivularis* and *Taraxis grossa*. In inland areas, the two main species are *Hopkinsia anoectocolea* and *Hopkinsia adscendens,* both of which have become restricted due to clearing and weed encroachment. Both are salt-tolerant.

Propagation of the Southern Rushes is difficult; most require tissue culture techniques, and some species rarely set seed. However, some success can be achieved by cutting the upper stems when seeds are mature, and securing the brush along the embankments during spring/summer. Seeds require light and fluctuating conditions to break dormancy. Don't expect germination until the second season.

*One of the southern rushes, (*Leptocarpus tenax*), common throughout the south-west.*

5.1.2 Submergents

Submergent aquatics grow in the channel bed and root in the substrate, usually emerging to the surface during flowering and seed development. These species are critical in slowing stream flow, encouraging sediment deposition and as a key food and habitat resource for aquatic fauna. Most species can be grown from seed in full light conditions, however they are often difficult to establish due to their sensitivity to water level changes and turbidity during their early establishment phase. This is a current topic of research. The main species belong to the genera *Triglochin* (water ribbons), *Potomogeton* (pond weed), *Otelia* (native lily), *Villarsia* (marshworts) and *Myriophyllum* (water fern). Because there are many weedy species, it is essential to correctly identify species before using them in revegetation. Submergent aquatics are often serious weed species in open sunlit shallow waters.

5.1.3 Shrubs and Trees

Most of the dominant riparian shrub and tree species in the southwest belong to the Myrtaceae (eg. *Astartea, Agonis, Pericalymma, Eucalyptus).* Other common species belong to the legume family, Fabaceae (*Oxylobium, Bossiaea, Viminaria)* or Proteaceae *(Banksia, Hakea)*. Establishment of most of these species is relatively easy. Most do not have complex seed dormancy mechanisms and set good quantities of seed. For bradysporous species (ie. those holding their seed on the plant in cones or capsules, such as banksias, melaleucas, eucalypts), direct establishment can be achieved by cutting and laying branches carrying mature seed direct to site. Geospores, ie. those dropping seed annually to form a seed bank, cannot be done as easily this way, and are best propagated by collecting and germinating seed. Apply the seed pre-treatments described below.

5.2 Techniques

5.2.1 Direct Seeding

Direct seeding is an excellent technique for the floodplain and upland zones. It is not advised on the embankment due to high seed losses from soil and water erosion. This technique is a good way of increasing the diversity of species used in revegetation, since many are unlikely to be available as tubestock. A common seed pre-treatment for legumes and hard-seeded species is the use of heat or mechanical scarification. Smoke (aerosol of smoke water) is now a standard pre-treatment for most native species (Dixon and Roche 1995). However, where there is likely to be a good native residual seed bank, smoke water can be applied as a post-treatment after direct seeding to encourage germination of dormant seeds.

Appropriate seeding densities and ratios of trees/shrubs/herbs/sedges should be determined either by surveying the existing vegetation or seed bank in an adjacent reference area. Where this is not possible, in the south-west a rule of thumb guide of 500:50:5 herbs/sedges to shrubs to trees should be used in each 100 m^2 section. To calculate the appropriate seeding rate to achieve the final ratios, determine the viability of seed collected, allow 50% mortality of seedlings, and weight the required seed lots accordingly. This service is available from some commercial seed operators.

Direct seeding should be undertaken in late summer/early autumn.

5.2.2 Planting

Planting is the appropriate technique for embankment and in-stream revegetation, and where direct seeding is difficult due to insufficient seed, excessive weed competition etc. Densities for trees/shrubs/herbs/sedges should be determined as outlined above. Planting should be undertaken in spring/summer along the lower embankment and within the channel, and in autumn elsewhere. Appropriate site preparation should be undertaken as described above.

Commercially available species and approximate costs can be obtained from the following wetland nurseries: Apace, Ecosystem Management Services, Native Environmental Systems, Regeneration Technology Pty Ltd and Wild Australia Nurseries. Many tree and shrub species are also available from general nurseries. The cost of tubestock or bare-rooted stock ranges from $0.30 to $2 for difficult species. If labour is available, clonal sedges and rushes can be purchased as ‘stock plants’and vegetatively divided every six to eight weeks to increase plant numbers and reduce individual plant cost.

5.2.3 Transplanting

Transplanting is only a good technique if an appropriate donor site is available, or where engineering works requires removal of native species that can be transplanted later to the restored site. It is not recommended if it involves degrading one site to assist another. Care must also be taken to avoid transfer of weed propagules and/or diseased soil. The technique is labour intensive and therefore expensive. Transplanting is usually successful for species with vegetative growth and fairly shallow roots (e.g. sedges and rushes). Transplanting should be undertaken in winter to early spring to minimise plant shock. Timing is particularly critical for species of *Lepidosperma, Desmocladus* and *Gahnia.*

5.2.4 Pre-seeded Matting

Pre-seeded matting involves spreading seeds onto an appropriate fibremulch, and laying the mat on-site in early winter after germination. This technique is excellent for steep embankments, since it provides erosion control and revegetation in a single stage. It is usually only suitable for seeding with rushes and sedges and other monocots, since matting usually requires rolling (similar to roll on lawn) for transport to site. However, if the matting is transported to site before seeding, any species can be used and the matting simply dragged in place and secured once seedlings have germinated.

5.2.5 Brush

The use of brush of bradysporous species is an excellent technique in all zones apart from the channel bed. Brush should be collected by harvesting from plants at seed maturity and laid immediately on to the revegetation site. Brush along the embankments should be secured using upright timber pieces. This technique is particularly useful for myrtaceous species *(Agonis, Astartea, Melaleuca, Pericalymma).*

6. Monitoring and Maintenance

6.1 Fire

Fire is a risk wherever there is vegetation. However, control of weed biomass and revegetation using native species will greatly reduce the amount of flammable material. Use fire-retardant species, such as *Jacksonia*, *Viminaria* and native herbaceous monocots, particularly at the boundary of the river restoration zone and adjacent agricultural areas. Maintain weed control by target slashing/spraying at least twice yearly. Ensure appropriate vehicle access points are maintained for fire control. Controlled burning is not recommended in riparian areas. Use of fire as a management tool will result in temporary reduction of fuel loads, and will need to be undertaken at greater frequencies due to its effects in favouring weeds over native species.

6.2 Weeds

Ongoing weed control is essential to successful revegetation. The restoration site should be monitored and follow-up control undertaken at least twice yearly. In many cases, control of one species will result in proliferation of another, particularly in very degraded sites. Weed seeds and vegetative propagules will continue to emerge from the soil for many years after initial control, so it is important to target removal of seedlings and young plants each winter. Severe areas may require saturation planting of suppressant natives.

6.3 Feral Animals

Depending on location, ongoing control of feral animals may be necessary. Baiting, or long-term use of exclosures may be appropriate.

6.4 Monitoring Change

It is important to monitor the success of revegetation each year, in terms of the original objectives set for the site. Re-doing stream condition assessments, monitoring plant survival and growth, weed control success, and physical changes to the river zones (eg. erosion, deposition points) should be recorded. If water quality improvement is an objective, a regular sampling program should be undertaken. Preparation of progress reports give encouragement to those involved in the revegetation works, and is useful for others undertaking similar projects.

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