

# Managing riparian ecosystems

for ecosystem services and biodiversity



**A handbook  
for the cotton  
industry**



**CRDC**  
COTTON RESEARCH AND  
DEVELOPMENT CORPORATION





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# Introduction

Riparian ecosystems are highly valuable components of the landscape. They support a diverse range of critical ecological functions, harbour high levels of biodiversity and provide many important ecosystem services to people.

Riparian ecosystems are particularly important in settings where there is a distinctive difference between riparian vegetation and vegetation of the surrounding landscape. This is generally the case in semi-arid and arid regions where riparian vegetation tends to be the most diverse and complex vegetation in the landscape. Additionally, riparian vegetation often comprises the most significant remnant (and regrowth) vegetation in agricultural landscapes.

In rural settings, riparian zones are multifunctional spaces that support many human activities (e.g. cropping, grazing, water supply, recreation etc.) in addition to crucial ecological functions. As well as providing significant habitat for terrestrial biodiversity, riparian ecosystems play a major role in determining river health by providing an important buffer that protects aquatic ecosystems from disturbances and pollution from human activities in the surrounding landscape.

Vegetation condition is typically the single most important factor determining the ecological function and value of riparian ecosystems.

Modified and degraded riparian vegetation is associated with many environmental problems including bank erosion, water quality deterioration and biodiversity loss. Effective management of riparian ecosystems is therefore vital in semi-arid agricultural landscapes to conserve biodiversity, maintain ecological functions, promote ecosystem services and limit environmental degradation. The value of riparian ecosystems can also be expected to grow as the climate changes (Capon et al. 2013).

## Purpose of this handbook

A significant proportion of cotton farms in Australia are situated in lowland, floodplain areas of semi-arid inland catchments, especially in the northern Murray-Darling Basin straddling the Queensland and New South Wales border. Riparian ecosystems comprise large areas of most cotton properties in these regions as well as representing substantial proportions of remnant vegetation in these landscapes. Consequently, protecting and effectively managing riparian ecosystems for ecosystem services and biodiversity are important objectives contributing to the sustainability of the Australian cotton industry.

This handbook provides an overview of riparian ecosystems and their management in relation to cotton farms in inland semi-arid lowland regions of eastern Australia. The first part synthesises current understanding of riparian ecosystems, their functions and ecosystem services and the main factors influencing these. Major threats to riparian ecosystems in cotton growing regions are also considered.

The second part of the handbook provides information concerning management of riparian ecosystems including setting management goals and priorities as well as approaches to protecting and restoring riparian ecosystems. Guidelines for monitoring and evaluation of riparian ecosystem management are also included.

**Part 1.**

**Understanding riparian ecosystems**



# What are riparian ecosystems?

Riparian zones are most simply defined as areas of land adjacent to watercourses or waterbodies (Naiman et al. 2008). Consequently, riparian zones can be viewed as interfaces, transition zones or 'ecotones' between neighbouring terrestrial and aquatic ecosystems (Naiman et al. 1998).

Because of their position in the landscape, riparian ecosystems are characterised by gradients in environmental conditions (e.g. elevation or flooding). These environmental gradients tend to be reflected by 'zonation' in ecological processes and the occurrence of organisms. More aquatic and amphibious species, for instance, generally occur in the lower, wetter parts of riparian zones with more terrestrial species occurring as you move further away from the waterbody.

In the semi-arid lowland regions of the Murray-Darling Basin, common riparian vegetation zones often include river red gums on the immediate river banks which grade into coolibahs at higher elevations. Low-lying swampy riparian areas in the region often support lignum shrubland.

## A functional definition of riparian ecosystems

A riparian zone can also be defined from a functional perspective as an area of land that adjoins and directly influences, and is directly influenced by, a body of water, even if this only flows occasionally (Price & Tubman 2007).

Riparian ecosystems are therefore those which both exert a direct influence on adjacent watercourses or waterbodies and are themselves influenced by the hydrology and geomorphology of these aquatic systems.

Consequently, riparian ecosystems can include:

- river banks
- dry river beds and creeks
- dry lake beds
- floodplains
- floodplain wetlands

Common riparian ecosystems of cotton farms in the northern Murray-Darling Basin dominated by river red gum (top), coolibah (middle) and shrubs including tangled lignum and *Eremophila* species (bottom).









# Riparian ecosystem functions

Riparian ecosystems support many critical ecological functions (Figure 1) which fall broadly into seven major categories (Capon and Pettit 2018):

## 1. Microclimatic regulation

Plants growing on the edge of watercourses, especially trees and shrubs, shade aquatic ecosystems, reducing in-stream light and water temperatures (Bayley & Williams 1981; Bunn 1993, Davies et al. 2008). Shading by riparian plants is particularly important for limiting algal growth in streams, especially where there are high nutrient inputs from surface and groundwater flows (Peterjohn & Correll 1984; Chauvet & Decamps 1989). Where riparian vegetation has been disturbed, increased light and water temperature, along with elevated nutrients, can stimulate excessive algal growth, reducing oxygen levels and altering habitats in streams with detrimental effects on other aquatic organisms. As growth of most aquatic plants, including green algae, is controlled by light availability more than nutrient levels, riparian shading can be a major driver of aquatic primary productivity (Davies et al. 2008). At sites with high nutrient levels, shading can therefore ameliorate the effects of nutrient enrichment and restrict plant and algal growth.

Riparian canopy cover can also influence in-stream water temperatures. This is particularly important

for aquatic fauna that are sensitive to high water temperatures (Stewart et al. 2015). Where most riparian vegetation has been removed from stream banks, water temperatures can exceed the lethal limits of many aquatic organisms which, without shade, have no areas of lower water temperature to escape to during hotter parts of the day. Even partial shading created by riparian vegetation can create refuges of lower water temperature for aquatic fauna in the summer.

## 2. Nutrient filtration and cycling

Riparian vegetation can limit the amount of nutrients entering streams via surface and groundwater flows (Peterjohn and Correll 1984, Weaver & Reed 1998) as the riparian interface is where most surface and shallow subsurface flows of water enter the stream. Biological processes, including nutrient uptake by plants and microbial processes (e.g. denitrification), influence the retention of nutrients in the riparian zone and reduce nutrient concentrations entering waterways.

Riparian ecosystems can also absorb nutrients from the stream as water continually exchanges between the streambed and bank sediments. Phosphorus can be adsorbed to sediment particle surfaces and nitrogen can be utilised or transformed via microbial activities.

## 3. Sediment trapping

Riparian vegetation plays an important role trapping sediments from the catchment and reducing sediment inputs entering watercourses and waterbodies. This is particularly critical in headwater streams which can drain around 70 % of the catchment and are a major source of sediment. Sediment loads and nitrate concentrations in a river in the United States, for example, were reduced by up to 90 % in water flowing through naturally vegetated riparian headwater areas (Gilliam 1994).

In lower reaches of a catchment, riparian vegetation within and fringing the stream channel can reduce stream flow and allow deposition of sediments. This natural process is important for the maintenance of channel landforms as well as riparian vegetation condition by providing areas for regeneration of riparian plants (Nanson & Beach 1977).

Riparian vegetation also provides a source of wood that can accumulate within channels and on floodplains, further reducing flow rates and promoting deposition of sediments (Abbe et al. 2003). This is particularly important in channels with sandy beds that lack other hard surfaces, such as rocks and boulders, to reduce the mobilisation and increase the entrapment of sediments (Beesley 1996).

#### 4. Landform stabilisation

Rivers are naturally high-energy systems, especially in periods of high flows and floods, and consequently some erosion is a natural occurrence. Without riparian vegetation, however, increased erosion of bank and stream bed sediments can lead to the transport of more sediment downstream, reducing water quality and potentially burying important aquatic habitats. Stream banks with little or degraded vegetation can also become unstable with erosion during high flow events leading to greater flooding of surrounding land (Thorne 1990) and widening, shallowing and simplification of stream channels.

Riparian vegetation can limit channel erosion and down-cutting by reducing the force of flowing water, protecting banks from its direct impacts and by inducing sediment desposition (Malanson 1993). Without perennial vegetation, subsidence of banks can occur, particularly if the soil is wet and the bank can collapse under its own weight (Thorne 1990).

Bank stability is maintained by the roots of perennial vegetation, especially trees and shrubs, which provide a stable base for binding the soil and holding the bank in place (Pen 1999). Accumulation of sediments promotes establishment of riparian vegetation that, in turn, reduces near-bank flow velocities and tractive forces, reducing erosion and increasing deposition of sediment (Thorne 1990). Large tree roots anchor river banks while roots and rhizomes of perennial understorey vegetation (e.g. shrubs and sedges) hold surface soil in place between these larger roots.



Riparian trees and fallen timber play an important role in stabilising river banks.

Vegetation is particularly important for stabilising landforms when rivers are in flood. During flooding, riparian vegetation reduces the velocity and spread of floodwaters and reduces bank wetness via evapotranspiration, (Pen 1999). River bends are major sites of erosion and deposition as material is eroded from the outside of the bend and deposited on the inside. In many rivers, these depositional areas (i.e. point bars) provide a major substrate on which primary succession of riparian vegetation communities can take place (Malanson 1993).

#### 5. Food-web subsidies

Significant flows of energy and materials occur between riparian zones and adjacent aquatic ecosystems (Polis et al. 1997). Organic matter inputs (e.g. leaf litter) are crucial to aquatic foodwebs. The abundance and diversity of aquatic macroinvertebrates, for example, tend to be greatly reduced when streams are deprived of leaf litter inputs (Davies 1994; Wallace et al. 1997). Riparian ecosystems also contribute many invertebrate organisms to aquatic foodwebs (Nakano & Murakami 2001). Terrestrial invertebrates can provide up to half the annual energy budget for fish, especially in closed-canopy riparian zones (Baxter et al. 2005).

Many Australian riparian trees are from the Myrtaceae family (e.g. Eucalyptus, Melaleuca) and have tough leaves that are high in tannins and volatile oils and are not readily broken down in the stream. Tannins contained in these leaves can stain the water, reducing penetration of light and limiting photosynthesis, further limiting algal growth in streams with elevated nutrients.



## 6. Aquatic habitat

Riparian vegetation plays an important role in generating a diversity of habitats for in-stream organisms which can have an important influence on the maintenance of aquatic biodiversity.

Overhanging roots and branches from riparian plants introduce physical habitat structure to channels. Leaf litter and fallen branches from riparian vegetation provide substrates and habitat for aquatic organisms while fallen trees can create 'riffle' zones and step-pools (Malanson 1993). As well as influencing flows and channel morphology, large woody debris also affects the colonisation and establishment of many riparian plant species in river channels and on floodplains, further promoting in-stream habitat diversity (Naiman et al. 1998; Pen 1999, Lovett & Price 1999).



Overhanging branches and roots, as well as fallen leaves and wood provide aquatic habitat.

## 7. Terrestrial habitat

The diversity and dynamics of riparian vegetation contribute to higher species diversity and abundance of plants in riparian ecosystems as well in the surrounding catchment. Riparian zones are generally considered hotspots of diversity as they form a transition zone between the different plant communities of terrestrial and aquatic systems (Wissmar & Swanson 1990; Nilsson et al. 1993; Naiman & Decamps 1997).

Intact riparian vegetation often comprises a range of taxonomic groups of plants of various life forms and functions. Riparian plants typically display a variety of adaptations that enable them to persist in an environment with a high frequency of natural disturbances (e.g. flooding and drought). This provides riparian vegetation with a relatively high degree of resilience to other disturbances in the river environment.

Riparian vegetation also offers many different habitats for terrestrial fauna, especially animals that prefer the moist, productive riparian habitat to adjacent upland areas (Leach & Edge 1994). Riparian zones can provide terrestrial 'corridors' that connect remnant patches of vegetation (Watson 1991) in modified catchments, allowing animals and plants to disperse throughout the landscape (Knopf & Samson 1994). The great diversity of habitat formed by these corridors of natural riparian vegetation makes them very important for regional biodiversity (Naiman et al. 1993). Species diversity and abundance of birds and mammals is often greater in riparian corridors than in the surrounding landscape (Decamps et al. 1987; Crome et al. 1994).

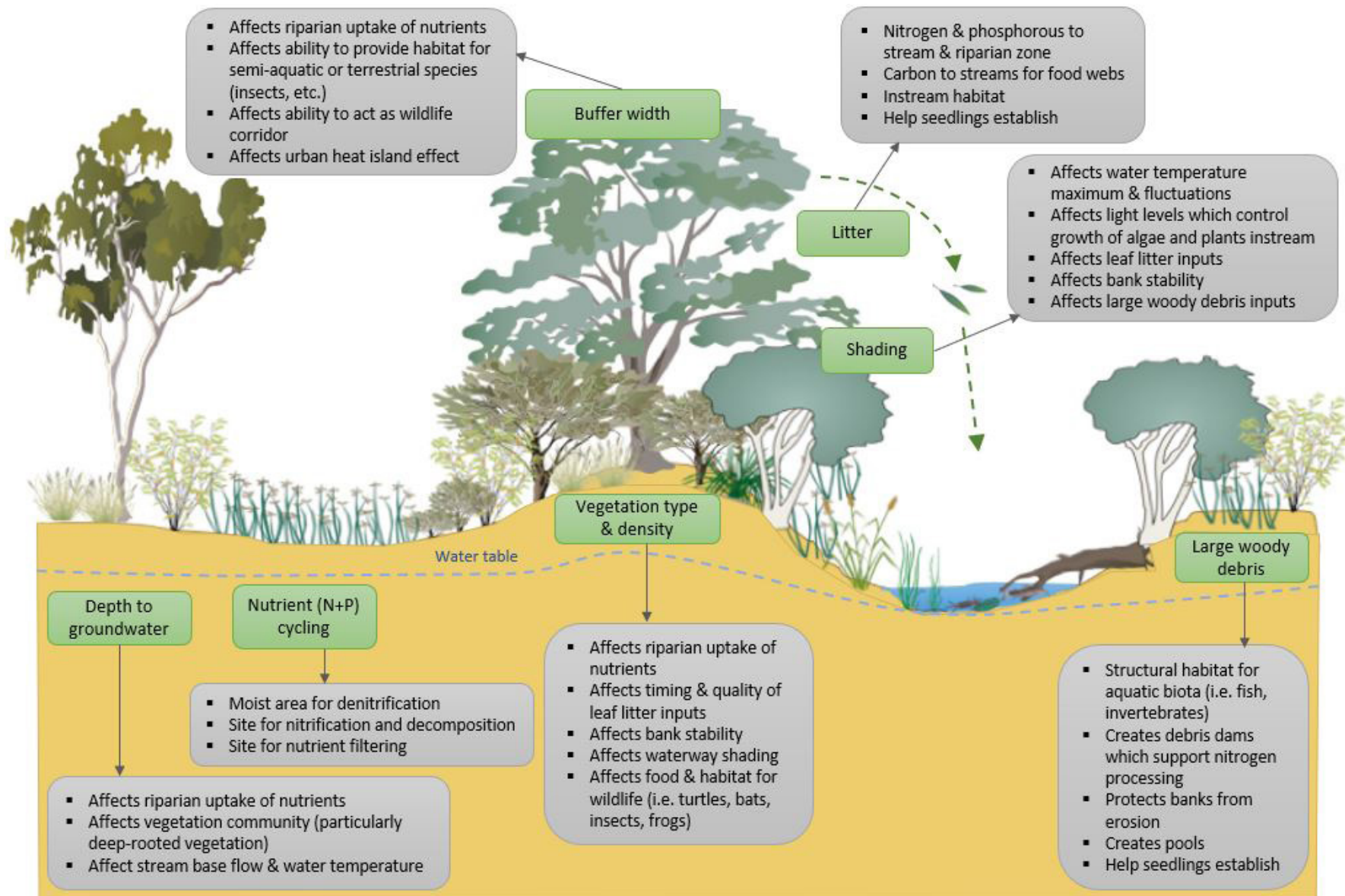
## Gwydir case study

Of 90 species observed during terrestrial vertebrate fauna studies on cotton farms in the Gwydir River catchment, 26 species were only observed in riparian (i.e. channel bank) habitats including peaceful dove (*Geopelia placida*), white-plumed honeyeater (*Ptilotula penicillata*), little friarbird (*Philemon citreogularis*), willie wagtail (*Rhipidura leucophrys*) and inland freetail bat (*Mormopterus* species 3).



Peaceful dove (*Geopelia placida*)

Additionally, the number of bird species recorded in riparian habitats was nearly twice that recorded in floodplain habitats. Similarly, the number of bat species was about 30 % lower in floodplain habitats compared with riparian (channel bank) habitats.



**Figure 1. Major ecological functions supported by riparian ecosystems and their effects on terrestrial and aquatic ecosystems.**



# Riparian ecosystem services

In addition to supporting healthy and resilient aquatic and terrestrial ecosystems, riparian ecosystem functions provide many benefits to people (Table 1). These 'ecosystem services' fall into three broad types:

1. production services, i.e. provision of goods such as pasture, timber, food, fibre etc.
2. regulating and supporting services, i.e. services that regulate and support healthy ecosystem function such as water filtration, nutrient cycling, micro-climate regulation; and
3. cultural services, e.g. recreation and historical, social, spiritual values.

Reid et al. (2003) identified major ecosystem services provided by natural areas on Australian cotton farms:

1. natural pest control,
2. maintenance of soil health,
3. water filtration,
4. prevention of soil erosion,
5. water absorption and breakdown,
6. maintenance of river flows,
7. maintenance of groundwater levels and groundwater quality,
8. maintenance and regeneration of habitat,
9. maintenance and provision of genetic resources,
10. regulation of climate, and provision of shade, shelter and barrier effect.

All of these ecosystem services are supported by riparian ecosystem functions either directly, as in the case of water filtration and shading, or more indirectly as in the case of natural pest control. For natural pest control, the most important feature is simply cover of native plants, particularly in the understorey (Cate Paull (CSIRO) pers. comm.). Insectivorous birds sheltering and nesting in riparian vegetation, for example, can play a significant role controlling populations of insects that are potentially harmful to agriculture, horticulture, native plants or people (Loyn 1987).

Recent work suggests that riparian ecosystems on Australian cotton farms also have significant carbon sequestration potential (Smith and Reid 2013; Smith et al. 2017). Old growth river red gum forests in particular can store substantial amounts of carbon (Rhiannon Smith (UNE) pers. comm.). The sequestering of carbon by trees is important for reducing carbon dioxide in the atmosphere that would otherwise be contributing to warming of the Earth.

Riparian ecosystems also provide many cultural and social benefits as sites of significance for cultural heritage, recreation and tourism, science and education, and aesthetic and spiritual values.

Riparian ecosystems can be sites of cultural and social significance. Balonne River near St George, 1917 (top), and Brewarrina fish traps, Barwon River (bottom).



**Table 1. Major ecological functions and related ecosystem services of riparian ecosystems and their key drivers.**

Ecological functions	Key ecosystem services	Key drivers	
		Vegetation traits	Other factors
Light and temperature control	Shading, drought refuge	Canopy cover, canopy height	Channel width, channel orientation, ground-water influence, instream nutrient levels
Nutrient filtration	Water quality regulation	Buffer width, continuity, groundcover, leaf litter density, composition, below-ground microbial interactions, rooting depth	Topography (slope), hydrology (depth to water table, water residence time, ground/soil water interactions), soil type
Sediment trapping	Water quality regulation	Buffer width, continuity, stem density, root structure (density and depth profile), community composition of different functional groups (i.e. trees, shrubs and herbs)	Topography (slope), soil moisture (depth to water table), soil type, hydrology, hydraulics, diversity of other substrates
Bank/bed stabilisation	Water quality regulation, land stability		
Food-web subsidies	Biodiversity	Composition (e.g. leaf traits), temporal dynamics	Flooding, water quality, nutrients
Aquatic habitat	Biodiversity, fish	Composition, temporal dynamics, spatial heterogeneity	Hydrology, hydraulics, water quality, nutrients
Terrestrial habitat	Natural pest control, pasture, timber, biodiversity, salinity mitigation, erosion control	Canopy cover, composition, temporal dynamics, floral diversity, buffer width, longitudinal connectivity	Hydrology, other disturbances (e.g. grazing, fire), regional climate, surrounding land cover
	Carbon storage and sequestration	Abundance of mature trees, tree recruitment and regrowth	Soil type
	Cultural values; recreation & tourism; science & education; aesthetic, spiritual & wilderness values	Composition and structure	



# Factors influencing riparian ecosystems

The capacity of riparian ecosystems to provide ecosystem services is determined mainly by the structure and composition of riparian vegetation (Table 1). Important characteristics of riparian vegetation encompass its composition (i.e. number and type of species) and structure (e.g. canopy height, canopy cover, root depth and density, groundcover including leaf litter and wood cover).

The effectiveness of riparian vegetation in supporting ecosystem services can also be modified by many other factors such as topography, soil/sediment characteristics, climate and hydrology and surrounding land use (Table 1). The amount and impact of shade created by riparian vegetation, for example, is influenced by several factors, including canopy height and foliage density as well as channel width and orientation (Bunn et al. 2007; Davies et al. 2008).

The capacity of riparian ecosystems to retain nutrients, and thereby regulate water quality, is controlled by hydrologic characteristics such as water table depth, water residence time and groundwater interactions with soil water. The relative influence of biological nutrient cycling processes will depend on water (and nutrient) input rates, soil characteristics and vegetation type.

Riparian vegetation is generally considered to be a good short-term filter for removing N, P, Ca and Mg from runoff flowing from upland areas (Lowrance et al. 1984). Wet riparian soils, together

with riparian vegetation, can provide an effective nitrate buffering capacity with a 30-50 metre wide buffer reported as being sufficient to remove all nitrates seeping through in the groundwater (Pinay & Decamps 1988; Pinay et al. 1993). These processes are most effective if the gradient of riparian land is low enough (<5%), and the distance through the riparian land is long enough (>50m), to allow sufficient time for the chemical reactions to take place.

The capacity of riparian ecosystems to regulate water quality by trapping sediments is also influenced by a combination of vegetation structure, soil type and topography (Table 1). Dense vegetation cover; deep, organic, permeable soils and low gradients combine to form a buffer which moderates the delivery of sediment to streams.

Other ecosystem services of particular benefit to farmers are governed by relatively straightforward drivers. Natural pest control on cotton farms, for example, appears to be promoted mainly by an abundance of native flowering plants (pers comm. Cate Paull, CSIRO). Similarly, carbon storage in riparian landscapes of Australia's semi-arid cotton growing regions is strongly associated with the abundance of mature trees, especially river red gum (pers comm. Rhiannon Smith, University of New England). Riparian vegetation also aids in reducing bank erosion and mitigating salinisation of soil (pers comm. Rhiannon Smith, University of New England).

At a landscape scale, the spatial characteristics of riparian vegetation will also influence its capacity to provide ecosystem services, including its width, longitudinal continuity along watercourses and lateral connectivity with upland ecosystems.

## Case Study: Shade & leaf litter determine plant establishment from soil seed banks

Experiments were conducted using soils collected from riparian zones across the northern Murray-Darling Basin to investigate understorey vegetation responses to a range of leaf litter, shading and hydrological treatments. Shade increased the abundance, species richness and reproduction of germinating plant communities under dry, but not wet, conditions. In contrast, leaf litter reduced the establishment and growth of understorey plants under dry and wet conditions. The results emphasise the importance of the riparian canopy in shaping understorey vegetation responses to wetting or drying. In particular, the findings suggest that leaf litter is likely to suppress the establishment and reproduction of weeds residing in the soil seed banks of these riparian zones.

(Source: Capon et al., 2017)

# Threats to riparian ecosystems

Riparian ecosystems face many threats in modified landscapes, especially in relation to land use and land cover change in catchments as well as alteration to hydrological regimes.

Changes to riparian ecosystems in rural landscapes are generally related to the loss of riparian vegetation and an increase in weed invasion. Flow-on effects to native wildlife (e.g. birds) are typical and can have cascading effects on ecosystem function and resilience by affecting their role in pollination, seed dispersal and insectivory.

Some of the more immediate and serious threats to riparian ecosystems in agricultural landscapes include:

## **Vegetation clearing and change**

Fragmentation of riparian vegetation isolates remnant patches, leading to the loss of continuity along watercourses and connectivity within the riparian zone and between the riparian zone and upland areas. Both continuity and connectivity are essential for ecological processes and the resilience of the broader stream network and their loss can lead to the general degradation of the riparian vegetation. With less available foliage for native grazers like wallabies, remaining vegetation is at greater risk of overgrazing.

Clearing of land adjacent to the riparian zone can also result in rising watertables, causing stress and even death of the vegetation through permanent waterlogging and/or salinity (Peck 1978; Busch & Smith 1993). Loss of mature trees particularly from riparian zones will lead to a decline in shade and leaf litter available in the system. Shade has been shown to be particularly important for establishing seedlings in dry areas (Capon et al. 2017). Leaf litter often benefits understorey plants in arid areas by providing a microclimate that protects against desiccation (Capon et al. 2017). A reduction in leaf litter has the potential to inhibit the growth of understorey vegetation.

## **High nutrient levels**

Surface water flows from rural catchments can carry nutrients into the riparian zone, particularly where this land has been fertilised or carries livestock (Lowrance et al. 1984; Weaver & Reed 1998).

Elevated inputs of nitrates may result in eutrophication (i.e. excessive nutrients leading to dense algae/plant growth) and acidification of waterways, impacting on in-stream macroinvertebrates and other fauna (Jeffries & Mills 1990).

## **Channelisation and levees**

Clearing within riparian and catchment areas affects infiltration and transport of water through the catchment and can lead to significant flooding, particularly in low reaches of streams. Increased frequency and magnitude of peak flows can also occur, resulting in erosion of stream banks and beds. Bank erosion, in particular, will lead to channel widening and deepening, which can cause fringing riparian vegetation to collapse into the river, reducing the width of the riparian buffer. Such flooding also has the potential to destroy riparian plant communities, with altered conditions affecting their ability to naturally regenerate.

In some situations, past management solutions to mitigate flooding have included engineering approaches, such as channelization of the stream network, to improve the conveyance of high flows, and the building of levees to reduce overbank flow. Such solutions can, themselves, however lead to bigger problems for the stream and riparian area. Channelisation will simplify both the structural (i.e. removal of woody debris) and hydraulic (i.e. loss of riffles, pools and backwaters) diversity that supports ecological processes and biodiversity. The construction of levees will disconnect the river from its floodplain and reduce flood frequency leading to the degradation of riparian vegetation communities.



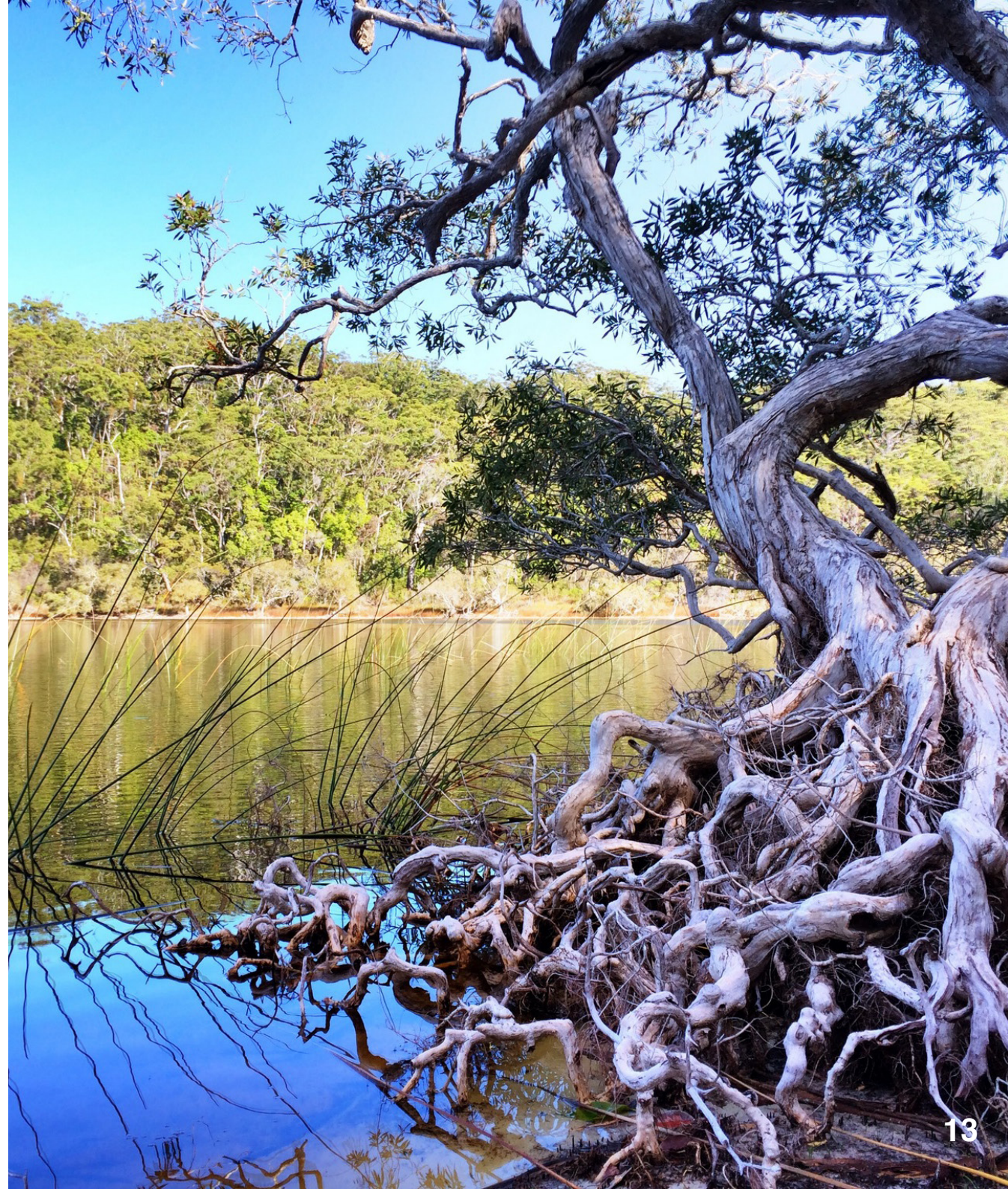
## Introduced weed species

Loss of native plants, disturbance and a high edge to area ratio of riparian zones makes them particularly vulnerable to invasion by exotic plants. Weed infestations are often the result of disturbance or the build-up of excessive nutrients caused by increased run-off. Invasive plants can increase competition for space and resources amongst native species and may result in further loss of local plant diversity.

Many exotic plants have soft leaves that break down quickly, adding nutrient and labile carbon to waterways, that can drastically alter in-stream ecology (Pidgeon & Cairns 1981; Pen 1999). These soft-leaved exotic plants can therefore supply a ready source of carbon which, in combination with high nutrient levels, can lead to rapid growth of in-stream algae with the potential to cause detrimental algal blooms.

Leaf fall into streams from exotic plants is also likely to affect aquatic food webs as organisms in most Australian streams are adapted to Myrtaceous leaves (i.e. from Eucalyptus and Melaleuca species) which are high in tannins and other volatile chemicals so that they breakdown very slowly. Because of these characteristics of native riparian tree leaves, leaf shredding macroinvertebrates are not common in Australian streams.

Exotic perennial grasses can also dominate riparian areas, reducing light and trapping sediment, reducing the channel competence to convey high water flows (Bunn et al. 2003), leading to increased potential for flooding of surrounding areas.





## Removal of large woody debris

Logs are often removed from watercourses to reduce the risk of flooding or to improve ease of transportation. However, large woody debris (LWD) provides many functions to the stream and riparian zone and its importance is well known (Gregory et al. 1991, Abbe et al. 2003). LWD provides habitat to both aquatic and terrestrial organisms, alters stream flow and geomorphology and re-enforces stream banks to protect against erosion.

Accumulation of woody debris in large rivers increases channel complexity and initiates riparian succession on alluvial surfaces (Gregory et al. 1991; Fetherston et al. 1995; Abbe & Montgomery 1996; Naiman et al. 2002; Gurnell et al. 2005). Wood within the active river channel promotes the formation of bars, pools and side channels, and provides a moist, nutrient-rich microenvironment for macroinvertebrates, and plant propagules (McBride & Strahan 1984; Jacobsen et al., 1999).

The removal and destruction of riparian trees will also lead to the eventual loss of LWD as there are no old and dead trees and branches replacing the natural attrition of LWD. Fires in the riparian zone are also a major source of loss of LWD (Pettit & Naiman 2007).

## Altered fire regimes

Fires in riparian zones are the result of interactions between fire characteristics and the biophysical characteristics of the riparian environment (Pettit & Naiman 2007). Altered fire regimes within riparian zones can have a detrimental affect on regeneration of vegetation.

Riparian zones can also act as a buffer against fire and therefore as a refuge for fire-sensitive species. However, under some circumstances, such as dry climatic conditions and the accumulation of dry fuel, riparian areas become corridors for fire movement. In areas of native vegetation, wildfires would probably have occurred historically from time to time and, as for upland vegetation, many plants in the riparian zone may require a disturbance such as fire for recruitment (Kellman & Tackaberry 1993) and to stimulate seed release (Lamont et al. 1991).

Secondary effects of riparian fire include altering nutrient fluxes and cycling, increasing sediment loads, and stimulating erosion. Some plants, e.g. sedges and rushes at the outer edge of the riparian buffer, can provide a natural firebreak and reduce the risk of riparian fires spreading to agricultural areas and vice versa.



Large woody debris in the Lachlan River at Booligal, NSW.



**Part 2.**

# **Managing riparian ecosystems**

# Management goals & priorities

Management goals and priorities for riparian zones should be designed to promote particular attributes that are important for the maintenance and resilience of riparian ecosystem functions (Table 2).

Replanting riparian vegetation can be effective for providing shade and maintaining channel attributes, however, the desired effects of replanting will be sensitive to channel width, tree height and stream orientation. Even on broad streams where trees cannot shade most of the stream, riparian trees will provide some areas of shade for aquatic animals in stream areas very near the bank (Davies et al. 2008). Most shading by riparian vegetation occurs on north-south orientated streams. For east-west flowing streams in Australia, planting on the north bank of channels should be prioritised for maximum shade effect (Bunn et al. 1999, Davies et al. 2007).

For bank stabilization, the effect of riparian trees depends upon the size of the tree and the size of the channel bank. Planting trees low on a stream bank will increase bank resistance to slumping and provide the most shade.

For nutrient filtration, areas of diffuse overland flow should be identified as hotspots of nutrients entering the riparian zone and the stream. Perennial grasses or sedges planted to cover contour banks or swales on the outer edge of the riparian buffer can be important for trapping

sediments and nutrients and biogeochemical processes such as denitrification (Hairsine 1996).

Woody debris is a critical element for the maintenance of ecosystem function with its complex structure (e.g. leaves, branches, trunk and roots) providing a number of different-sized spaces, including hollows, representing important habitat both instream and in the riparian zone (Pettit et al. 2012). Many freshwater fish species rely on stable woody debris, as well tree roots and aquatic vegetation, as their nurseries. Woody debris also plays an important role in bank stabilization (Abbe et al. 2003).

The goal of implementing on-ground management efforts to protect and restore the riparian area is to maintain or return this to a good condition so that it can provide the required functions and associated ecosystem services (Table 1). This can be achieved by determining the riparian functions that are most important at a given site (either naturally, or otherwise) and understanding which riparian functions are most under threat. The potential to repair the function (i.e. likelihood of success) should also be considered.

Promoting natural regeneration of vegetation is generally the easiest, most cost effective and most ecologically efficient approach to managing riparian areas, especially in agricultural landscapes. Preserving existing mature trees whilst planting more will also work to maintain and restore

appropriate leaf litter levels to provide a beneficial microclimate for new understorey growth. In addition, replanting or re-seeding of native plants can enhance and thicken natural riparian vegetation. This usually requires some site preparation such as soil amendment or weed and pest control. Where riparian areas are severely degraded, major site preparation may be required and may include earthworks to stabilize stream banks, weed and pest control, revegetation and protection from disturbance (e.g. fencing).

Whilst planting additional aquatic vegetation is not always possible or suitable, by concentrating on the other management strategies listed here, and maintaining a low density of invasive species, native aquatic plants will be given the best chance to thrive. This in turn enhances the nursery habitat for freshwater and estuarine fish, in turn supporting much of the trophic system.

When prioritizing riparian areas to maintain or rehabilitate it is usually easiest and most cost effective to work on the least damaged areas first (Rutherford et al. 2007).



**Table 2. Riparian ecosystem functional attributes and management guidelines**

Function	Attribute	Guideline	Reference
Shading	Vegetation height	Trees 5-20 m height	Sweeney & Newbold 2014
	Vegetation type	Local native trees, eg. Eucalyptus rudis, Melaleuca raphiophylla in the SW	Penn 1999
	Vegetation density	High density (75%), continuous cover with several layers (Trees, tall shrubs)	Bunn et al. 1999
	Buffer width	Ten to 30 m wide (2 to 3 tree width)	Sweeney & Newbold 2014
Bank stabilization & sediment filtration	Buffer width	Minimum 10 m width from the top of the bank	Rutherford et al. 2007
	Vegetation type	Include different plant structural types (trees, shrubs, grasses/sedges)	Malanson & Bultler 1990
	Root type & density	Replant across a potential bank failure plane	Brooks et al. 2003
	Position	Planting trees low on a stream bank to increase bank resistance to slumping	Rutherford 2007
Nutrient filtration	Vegetation type	Include different plant structural types (trees, shrubs, grasses/sedges)	Prosser et al. 1999
	Buffer width	Minimum 10 m width from the top of the bank. Grass/sedge buffer strip at the outer edge of riparian zone	Haycock et al. 1997
Terrestrial/ Aquatic Trophic subsidies	Vegetation type	Maintain native trees with overhanging branches that contribute leaves (C), flowers, fruits and terrestrial invertebrates to the stream whilst reducing erosion. Maintain aquatic vegetation for fish nurseries	Nakano & Murikami 2001, Bunn et al. 2003
	Ground cover	Reduce weeds, fire and other disturbances that reduce litter cover	Catford et al. 2011
	Vegetation structure	Maintain structure for terrestrial invertebrates and birds	Lynch & Catterell 1999
Aquatic habitat	Vegetation type	Encourage growth of aquatic plants and tree roots within the water column	Cadwallar et al. 1980
	Woody debris & leaf litter	Place LWD with different orientations to bank and flow (parallel, angled, perpendicular). Leave overhanging tree branches. Retain leaf litter in pools and backwaters	Treadwell 1999; Pusey & Arthington 2003, Pettit et al. 2012
Terrestrial habitat	Vegetation type	Retain native vegetation or local species, including plants with a range of food sources. Retain old trees with nesting hollows	Lynch & Catterell 1999
	Vegetation structure	Include different plant structural types (trees, shrubs, grasses/sedges)	Loney & Hobbs 1991
	Woody debris & leaf litter	Retain leaf litter, and retain or add woody debris as microhabitat for fauna	MacNally et al. 1990, Pettit et al. 2007
	Fire	Reduce fire frequency, maintain fire suppressant buffers (30m at creeks, 50m at rivers)	2Rog Consulting 2019, Pettit & Naiman 2007
	Weeds	Weed removal, encourage or plant natives. Fence to reduce disturbances (fire, recreational)	Catford et al. 2011

## *Establishing a restoration framework*

There are many on-ground actions that can be implemented to repair riparian areas. However, certain actions will be more important than others given the particular environmental setting or the ecological functions requiring attention (Figure 2).

Furthermore, some actions may not be possible given current riparian conditions or relevant given the management objectives for the site. Consequently, we suggest that managers undertake a prioritization process to determine which actions they should implement at a given restoration site.

A management framework for the protection and restoration of riparian lands requires particular guidelines that include:

- a common understanding in the community and managing agencies of the importance of riparian land;
- a set of goals and objectives that are specific for the particular stream and riparian area to be managed, including clear priorities, tools to provide guidance and measurement of progress towards objectives and targets;
- mechanisms to encourage and facilitate riparian management in accordance with the stated goals and objectives; and
- clear responsibilities for riparian management and monitoring.

Management should prioritise key processes that affect ecological condition and the capacity of riparian ecosystems to support critical functions and ecosystem services. This includes managing flooding, stream erosion, sediment & nutrient delivery, riparian vegetation condition and disturbance, particularly human activity.

*Eucalyptus coolabah* ssp *arida* woodland, 2013.





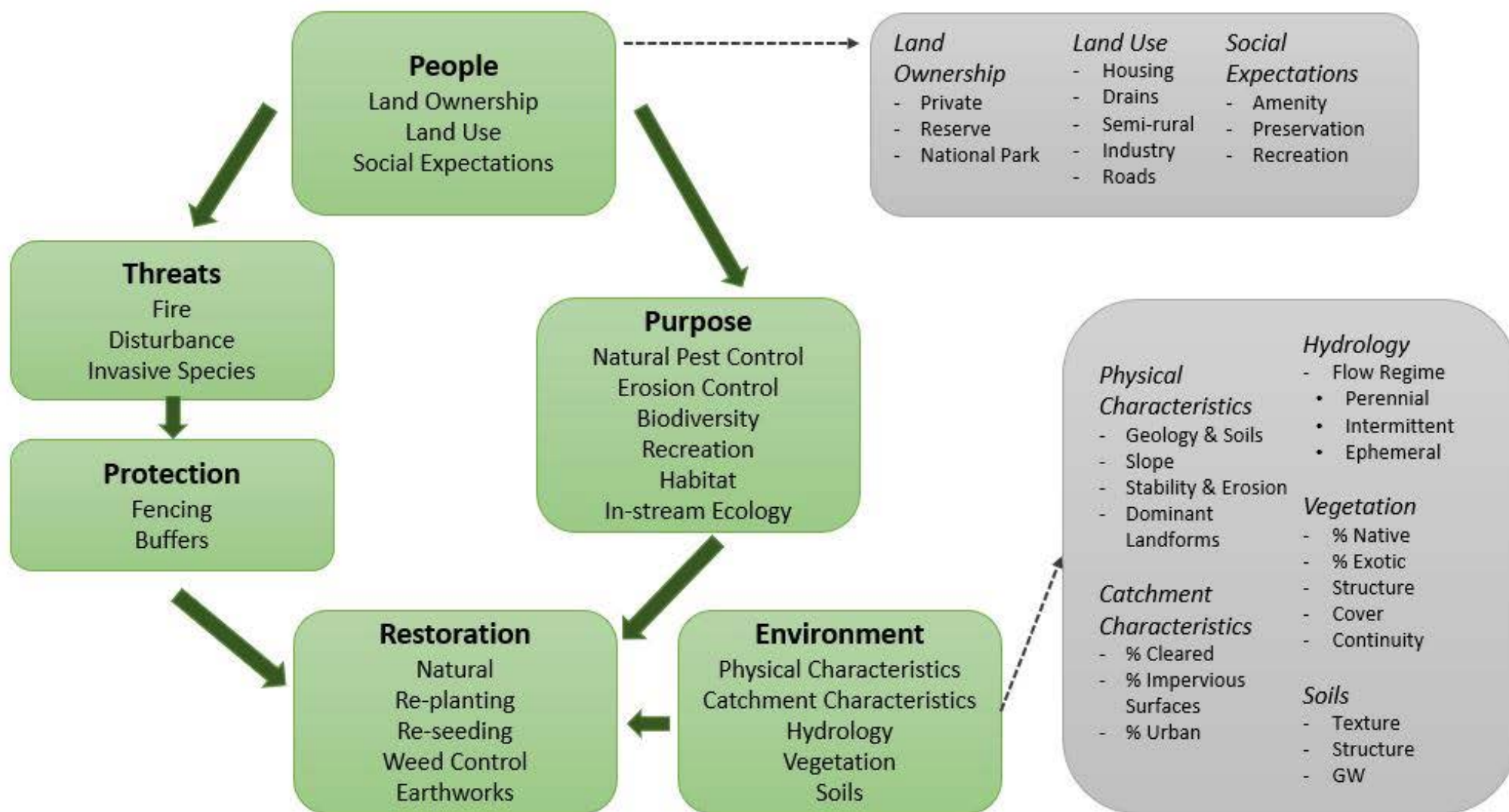


Figure 2. Conceptual diagram of keys to preparation of management plan for riparian areas.

The initial steps for the successful management of riparian buffers include consideration of the particular features of the environment to be managed, including the physical and catchment characteristics, as well as hydrology, vegetation and soils. Social and physical aspects of the human environment are also important in the evaluation of threats and purpose that, along with the type of environment, will inform the type and level of restoration and protection required.

# Protecting and restoring riparian ecosystems

## **To improve water quality**

Management practices should firstly preserve and improve existing native riparian vegetation to provide a minimum 10 metre width upslope from top of riparian bank. In most cases, it is better to replant with native species where possible (especially groundcovers) and ideally, include a grass (or dense sedge) strip to maximize nutrient stripping capacity.

Sediment is deposited from overland surface flows when the flow is slowed down. This effectively traps the sediment, absorbs nitrogen and phosphorus, as well as other solid particles and contaminants within the filter vegetation. The optimum riparian buffer width will be based on site characteristics such as slope, soil type, and rainfall intensity, etc. Other considerations will include the type of existing vegetation, landform shape, upslope development, the type and quantity of pollutants and the intensity of run-off (Sweeney & Newbold 2014).

## **To reduce bank erosion**

The key erosion processes for rivers include sub-aerial loosening, fluvial scour and mass failure and the major factors influencing these are bank materials, geometry and hydrology. Riparian vegetation generally has a second order impact on bank erosion processes, but this can still be important in slowing erosion to an acceptable rate.

Riparian vegetation protects banks from surface erosion by rain, water flow or other disturbances. The roots of riparian vegetation can help to dry and reinforce bank soils to prevent cracking and slumping.

The existing native riparian vegetation should provide a minimum width upslope from the top of the bank of 5 metres, plus the height of the bank, plus an additional width if the bank is actively eroding (Rutherford et al. 2007). The erosion allowance is calculated as the rate of bank erosion in metres per year, multiplied by the number of years it will take for replanted vegetation to reach a height of 10 metres.

On larger streams, the natural process of channel migration is usually around 1% of the channel width per year so that around half a channel width is the distance on each side of a river for the riparian buffer. The key principle in preventing or reducing erosion is to maintain a good covering of perennial vegetation across the soil surface. This should include relatively shallow rooted grasses and sedges and deeper-rooted shrubs and trees to reduce or prevent surface erosion as well as bank slumping and scouring.

A major outcome of removing riparian vegetation and wood from streams has been the changes in channel form (widening, deepening and straightening). Revegetating riparian zones, or adding large wood to stream channels, increases

the stage of floods (Rutherford et al. 2007). For downstream reaches, riparian vegetation will reduce the depth of flooding, however it is important to keep in mind that the decreased flow depth created by riparian vegetation comes at the cost of slightly longer flood durations. For revegetation in the stream zone careful consideration needs to be made of the effects on stream flow and in particular flooding. When restoring LWD to a river, they should be placed at a variety of locations, generally on the outside and downstream of a bend to reduce bank erosion. For a comprehensive discussion on managing the effects of riparian vegetation on stream flooding and bank erosion see Rutherford et al. (2007).

## **To reduce light and temperature to the stream**

The shade provided by the canopy of riparian trees reduces the effects of sunlight, reducing water temperature and light for photosynthesis, critical for in-stream biota and processes. The aim for restoration should be to have 75% riparian cover across the stream (for a sub-catchment >1000 ha, or the active channel >10 m). This requires tall trees in high density, at the top of the bank to provide maximum shading of the stream.

Where preserving or replanting riparian buffers for improved canopy cover, 2 to 3 tree widths is ideal. Riparian buffers may therefore vary from between 5–20 metres in width depending on the tree species used and the site.



### **To provide habitat and food for in-stream and riparian biota**

Native riparian vegetation provides inputs of leaves, woody debris, fruits, and insects which provide a subsidy for aquatic food webs and ecosystem processes. Two to three tree widths (10–20 m) is ideal, with a number of different vertical layers including groundcover plants, shrub layers and a canopy layer.

A minimum of one tree or tall shrub width (5–10 m) will still provide inputs if it has a healthy crown overhanging the stream. Leaves that fall into the stream provide the base sources of carbon for in-stream foodwebs, particularly in highly shaded, low nutrient conditions. Leaf chemistry and aquatic micro-organisms can play an important role in the degradation of this OM which can subsequently support aquatic consumers (Pettit et al. 2012b).

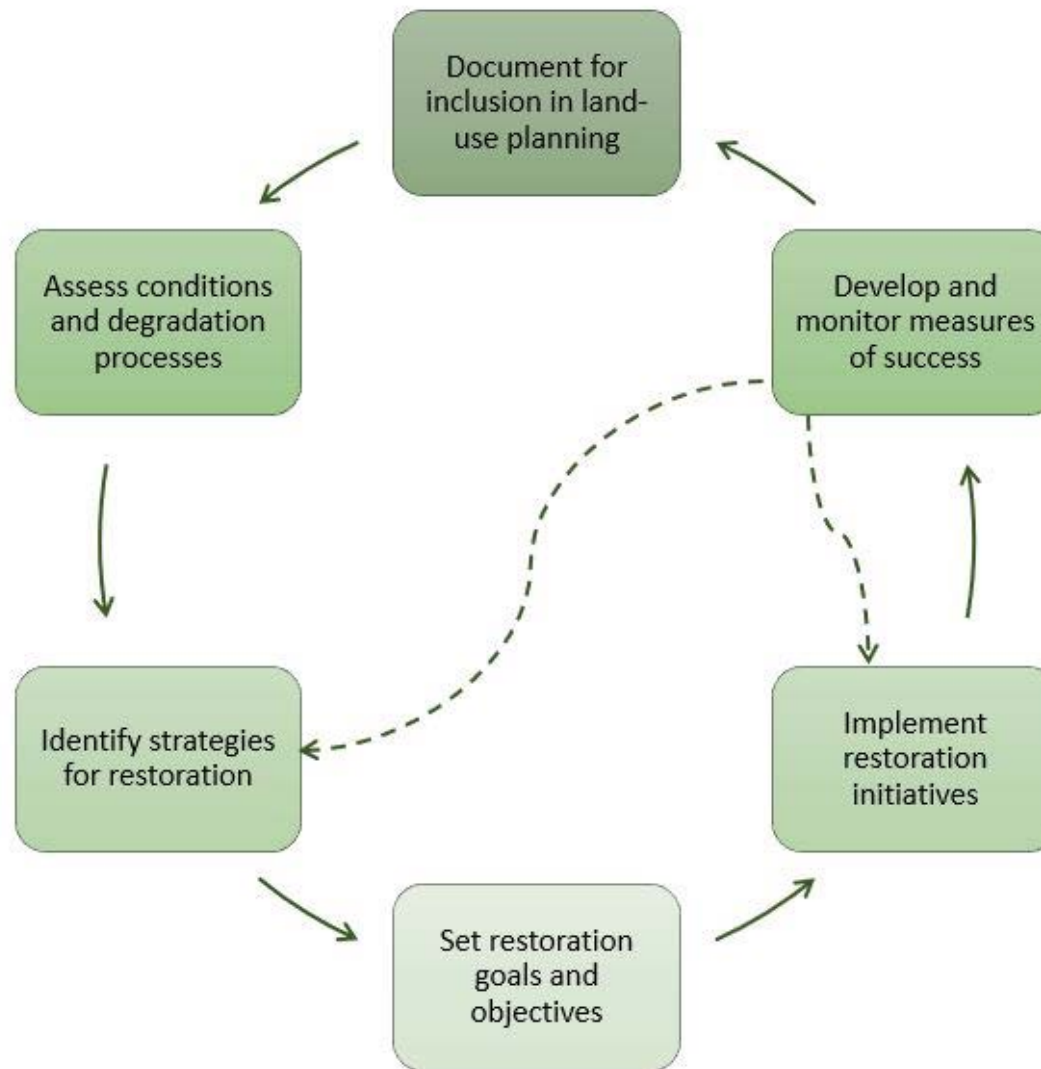
Branches and whole trees that fall on the ground and into the stream (LWD) also provide critical habitat for terrestrial and aquatic organisms, as well as altering flow velocities to produce different habitat conditions for in-stream animals.

A riparian width of at least 10 m will also provide habitat and corridors for small animals including riparian birds. Due to detrimental edge effects

riparian corridors suitable for terrestrial animals may need to be much wider to adequately fulfill this management objective. Recommended riparian buffer widths are 30m for creeks and 50m for rivers (2Rog Consulting 2019). It should also be noted that retention of dead standing trees or trees with large dead limbs is recommended as the tree hollows are important nesting sites for birds (e.g. galahs, cockatoos).

Talbragar River in Cobbora NSW, one month prior to flooding, 2009.





**Figure 3. Pathway to successful restoration of riparian buffers starts with an imperative to assess the conditions of the riparian zone under focus. Questions that need to be kept in mind include: What is needed to reverse the causes of ecosystem degradation? Can we achieve restoration by simply removing the stressors or will further action be needed? We then need to identify strategies that focus on abiotic manipulations such as removing degrading factors (stress) and repair physical/chemical environment, before biotic manipulations such as replanting.**



# How to maintain & rebuild a riparian buffer

Characteristics of the natural ecosystem that need to be considered in restoration ecology include composition, structure, pattern, heterogeneity, function and resilience (Hobbs & Norton 1996). The likely success of natural regeneration following the removal of degrading factors will depend on how they have affected these ecosystem functions (Brown & Lugo 1994).

If degradation of the riparian zone has affected only biotic components of the ecosystem, such as through the removal of the vegetation, then removal of this stress can result in fairly rapid recovery without further management intervention (Allen et al. 1994). However, if the degradation has affected the resource base or ecosystem processes, such as the soil or hydrology, restoration may require more complicated and costly intervention (Milchunas & Laurenroth 1995).

The restoration of degraded systems to some desired state (whatever this may be) in ecological terms requires the re-initiation of successional processes by accelerating biotic change (Luken 1990). Six key steps in achieving this outcome are (see also Figure 3):

1. identify natural ecological, physical and social values;
2. identify degrading processes / threats;
3. develop methods to reverse the degradation;
4. determine realistic goals;
5. develop observable measures of success; and
6. develop practical techniques and communicate results.

There is wide variation in the condition of riparian zones of streams in Australia. These can include streams with relatively intact riparian buffers, to heavily degraded streams with little cover from riparian trees and invasion of the stream by exotic plants, so that they have little ecological value and require extensive work and high cost to rehabilitate.

The first step in managing riparian buffers is to properly identify the extent and variability of the riparian zone. This includes the stream channel, natural flooded area, floodway and flood zone.

There should also be a provision for a further buffer strip that extends into the area of terrestrial vegetation (verge). In general, high gradient streams have narrow riparian strips where as low gradient streams have diffuse, wide riparian areas. While there are general principles that apply across all riparian areas, each will require specific management needs. Therefore as each watercourse is unique, it is best to assess the area of the riparian zone that requires active management on a case-by-case basis and the effectiveness of riparian buffer system depends on factors that can only be addressed at the local scale (Naiman et al. 2005).





## Riparian buffer widths

Although there is a broad consistency about the general widths recommended for riparian areas, there are differences depending on the purpose of riparian protection, types of stressors, physical attributes of a particular stream and position within the catchment. For example the clearing of the upstream catchment will increase stream flow and cause the river channel to widen downstream, causing the riparian zone to be degraded or eroded away altogether.

Provisions for future protection may need to be made in catchments with low disturbance but forecast to undergo intensive development. This could be in the form of setting wider buffer strips to compensate for losses that occur as the riparian buffer falls into the channel (Vietz et al. 2014).

Overall, buffers  $\geq 30$  m wide are needed to protect the physical, chemical, and biological integrity of small streams ( $<100$  km<sup>2</sup>). The buffer zone should also include a small additional area to minimise edge effects and to accommodate successive degradation of the buffer edge, effectively protecting native riparian vegetation and habitat at the streamside. This could be in the form of planted grassy or low shrub areas that can absorb water and nutrient run-off and create a barrier against weeds moving into the riparian areas.

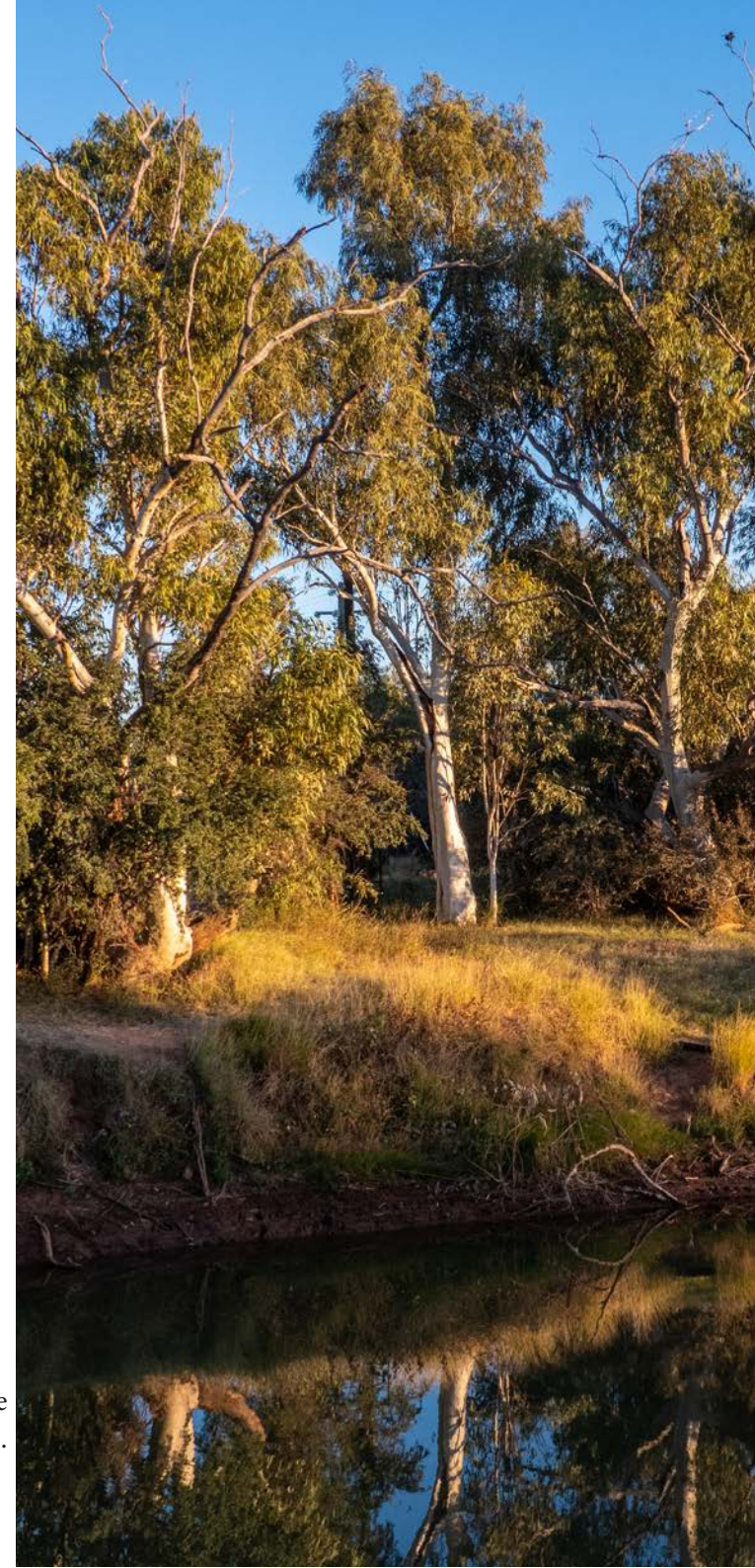
Adequate riparian buffer zones perform the following functions:

- Reduce water runoff from surrounding land into the wetland.
- Reduce the amount of sediments, contaminants and nutrients in this runoff.
- Prevent invasion of exotic plants.
- Provide corridors for wildlife movement.
- Provide a transition between upland and lowland habitats.

By enhancing the ability for riparian zones to perform their key ecological functions, in turn ecosystem services will also be enhanced.

- Natural pest control as insectivores are offered more habitat to roost in
- Regulation of water quality
- Denitrification of the soil
- Land stability
- Shading & drought refuge
- Enhanced timber and pasture production
- Enhanced diversity of native flora and fauna

*Eucalyptus camaldulensis* on the banks of the Burke River, Boulia, Queensland, 2019.





## Protecting and revegetating riparian zones

To protect intact or replanted riparian vegetation requires firstly the elimination or reduction of the disturbing element such as flooding, fire, pests or human use. Some type of fencing and the creation of buffer strips is a minimal requirement in most cases. Where some intact vegetation exists the easiest, most cost effective management is to encourage natural regeneration. The active replanting of riparian areas requires:

- Careful planning and plant selection;
- Site stabilization using earthworks, riprap, LWD, commercial matting;
- Extremely important to control weeds and pests;
- Soil preparation such as ripping;
- Soil amelioration such as gypsum or mulch;
- Correct seedling planting time and densities;
- Decide whether to replant seedlings or use direct seeding;
- In some cases watering in the first summer may be necessary; and
- Fencing to protect the newly replanted areas from stock and native grazers (e.g. wallabies).

The conservation and management of riparian buffers should include considerations of immediate and short term needs but also with sufficient planning and thought into the effects for the future is required. Therefore management should consider both short and long term aims and objectives for riparian management and could include:

### Short-term objectives

1. Develop priorities for restoration of riparian vegetation through river and catchment planning processes, regardless of land tenure and jointly with other remnant vegetation management.
2. Actively manage and restore healthy native riparian vegetation in priority areas.
3. Protect remnant native riparian vegetation through existing statutory and planning processes.

### Long-term objectives

1. Wherever possible protect and establish continuous corridors of native riparian vegetation, of suitable width, structure and composition to ensure maintenance of ecological processes, along all streams.
2. Re-establish ecological processes and biodiversity in riparian areas along streams.

In many cases we can combine the recommended management operations so that they can meet different objectives. For example, a 10–20 metre wide grass filter strip could be combined with the replanting of native vegetation immediately adjacent to a stream or creek to meet the multiple objectives of trapping sediment and nutrients, while also providing shade to the stream.

Protection and repair of riparian areas should also include:

- Ensure an adequate fertiliser action plan is in place (particularly important for poor sandy soils);
- Use soil remediation methods to improve the nutrient holding capacity of soils;
- Maintain or improve the stores of carbon within riparian soils by limiting disturbance and planting native vegetation; and
- Native riparian vegetation, providing a complex community of trees, understorey, groundcover and streamside sedges, should be planted where it is lacking.



Balonne River in St George, during drought, 2003.

It should be kept in mind that there are several levels of management intervention that can be undertaken and they each have different costs and benefits that need to be weighed up. Choosing which level of intervention is required will depend to a large extent on costs and ambition. In ecological terms, full restoration of a disturbed site is almost impossible because loss of species, processes and changed conditions make full re-establishment highly unlikely. Also, the costs and time needed to fully restore a site are prohibitively high in most cases.

Most interventions are likely to be at the level of rehabilitation or reclamation:

- Restoration - re-establishment of former functions and characteristic species and communities. Generally not possible at landscape scale because of conflicting land-use, public support and high costs;
- Rehabilitation - Restore selected ecosystem functions in part of the landscape. Does not necessarily lead to significant increase in biodiversity in the whole landscape. Practical at an intermediate scale;
- Reclamation- Increasing biodiversity per se, E.g. making land fit for cultivation. Appropriate at landscape scale.

Pathways to successful restoration of riparian buffers are summarized in Figure 3. This starts with the assessment of the local conditions and questions that need to be kept in mind which include:

- What are the unique features of the ecosystem to be managed?
- What are the major stressors and their sources?
- What is needed to reverse the causes of ecosystem degradation?
- Can we achieve restoration by simply removing the stressors or will further action be needed?

We then need to identify strategies that focus on biotic manipulations such as removing degrading factor (stress) and repair physical/chemical environment, before undertaking biotic manipulations such as replanting. When setting goals we need to consider the particular attributes of the system to be restored and how the stressors are leading to degradation. This will determine the types of actions that are required.

When setting restoration goals we need to focus on both potential short- and long-term outcomes and where possible use reference systems. There should also be a focus on desired goals for the future, rather than on the past societal desires and economic constraints. Finally, monitoring, assessment and reporting is an essential requirement for the management and rehabilitation projects for riparian areas. This should detail steps in decision-making processes, methods of active management undertaken and detailed assessment of what worked, what didn't and why.

The Balonne River at St George, 2008.





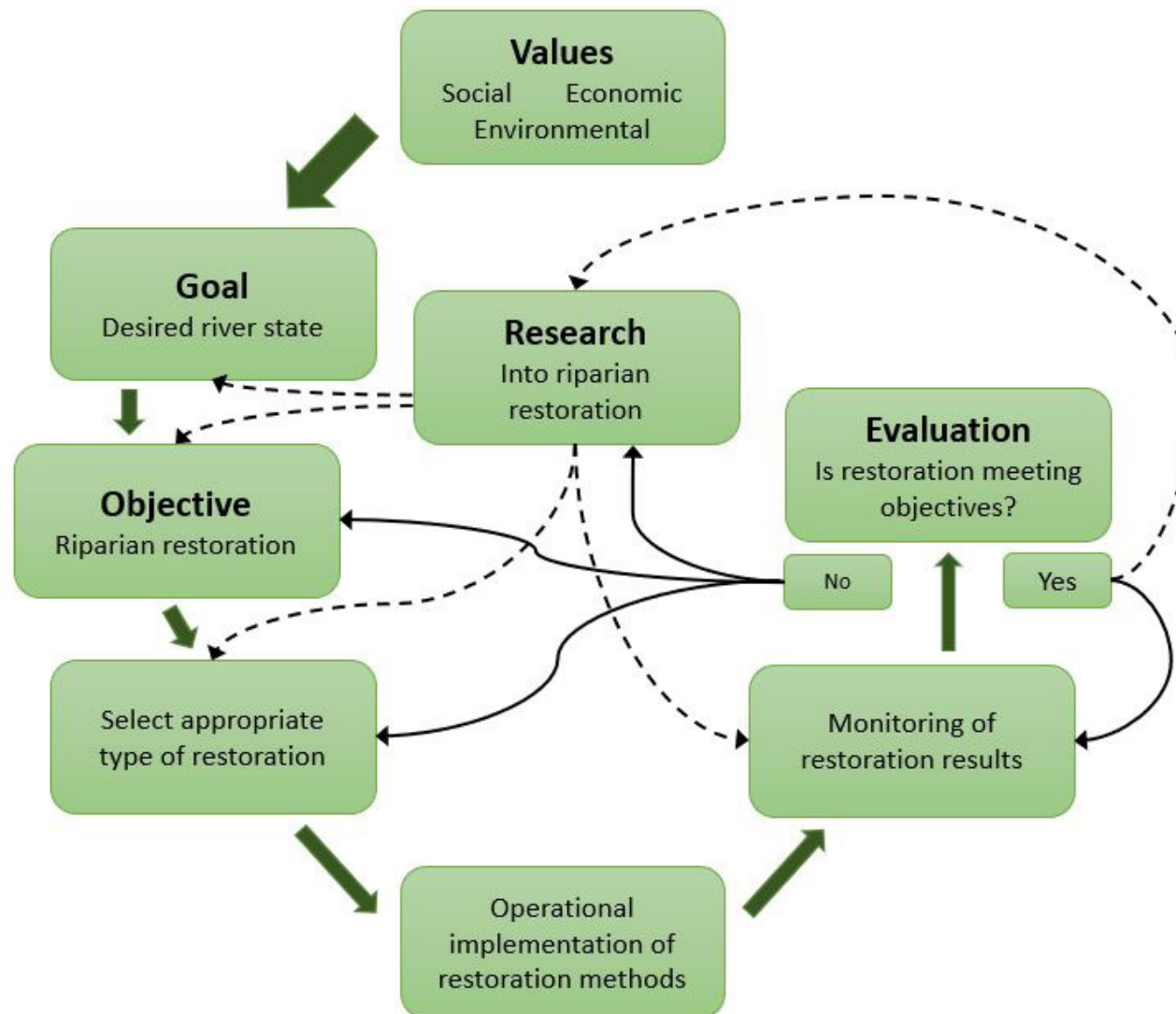


Figure 4. Adaptive management of riparian management whereby defining goals is the critical first step in riparian management and restoration. The conceptual diagram emphasises flow of decision sequence and feedback mechanisms that allow assessment and linkages to make appropriate and timely adjustments (adapted from Davies et al. 2014).

# Monitoring & evaluation

The before and after monitoring, assessment and evaluation should be seen as an integral part of the management of riparian land (Figures 2 and 3). Developing an appropriate monitoring plan is critical and should consider what to monitor, and could include particular key species, populations or processes. Other possibilities for monitoring could include level of recruitment, age structure, taxonomic assemblages or communities. Surrogate measures can also be used such as habitat variables, indicator or umbrella, sensitive and representative species. It is therefore important to identify potential indicator species. For example, umbrella species represent a range of ecological needs and population responses. Community metrics such as species richness and composition, colonisation rates or ratio of native to exotic species are also commonly used.

The appropriate indicator chosen should be:

- directly linked to a key aspect or condition, function or pressures (stressors);
- detect change at the required spatial and temporal scales;
- unambiguous and sensitive to changes anticipated.
- easily and cheaply measured using existing methods, with a high degree of accuracy and repeatability.

Monitoring ecosystem processes provides a direct measure of whether functions have been restored. This can include measuring nutrient cycling, animal migration, hydrological flows or plant recruitment. Where possible it can be very useful to select a range of reference sites to assess the natural variation in local riparian areas and define boundary conditions for parameters to be monitored.



Judging success needs adequate measures of progress toward agreed-upon goals and objectives. We need to monitor and evaluate these measures to understand why some projects succeed and others fail. Adequate reporting is essential but

often poorly done, with either no documentation or not freely available. Published documentation is required to communicate all success and failures and should also include documenting all decisions and steps taken in the process. Effective monitoring and documentation of results of riparian management and restoration will feedback into adjusting and refining the setting of goals and implementation of management actions (Figures 2 and 3).

Evaluation of restoration or management programs should be more than reporting on whether the action is following the agreed schedule and milestone. Monitoring and evaluation must involve measuring over time whether the required changes in condition (e.g. less bank erosion, lowered water temperature, increased in-stream habitat) have been achieved as a result of the management action.

Key elements to proper evaluation should include:

- Selection of appropriate indicators,
- Consideration of appropriate spatial and temporal scales,
- Consideration of frequency of measurement,
- Collection of baseline data at the commencement of a monitoring program,
- The use of multiple reference sites with which to compare the rehabilitated site.



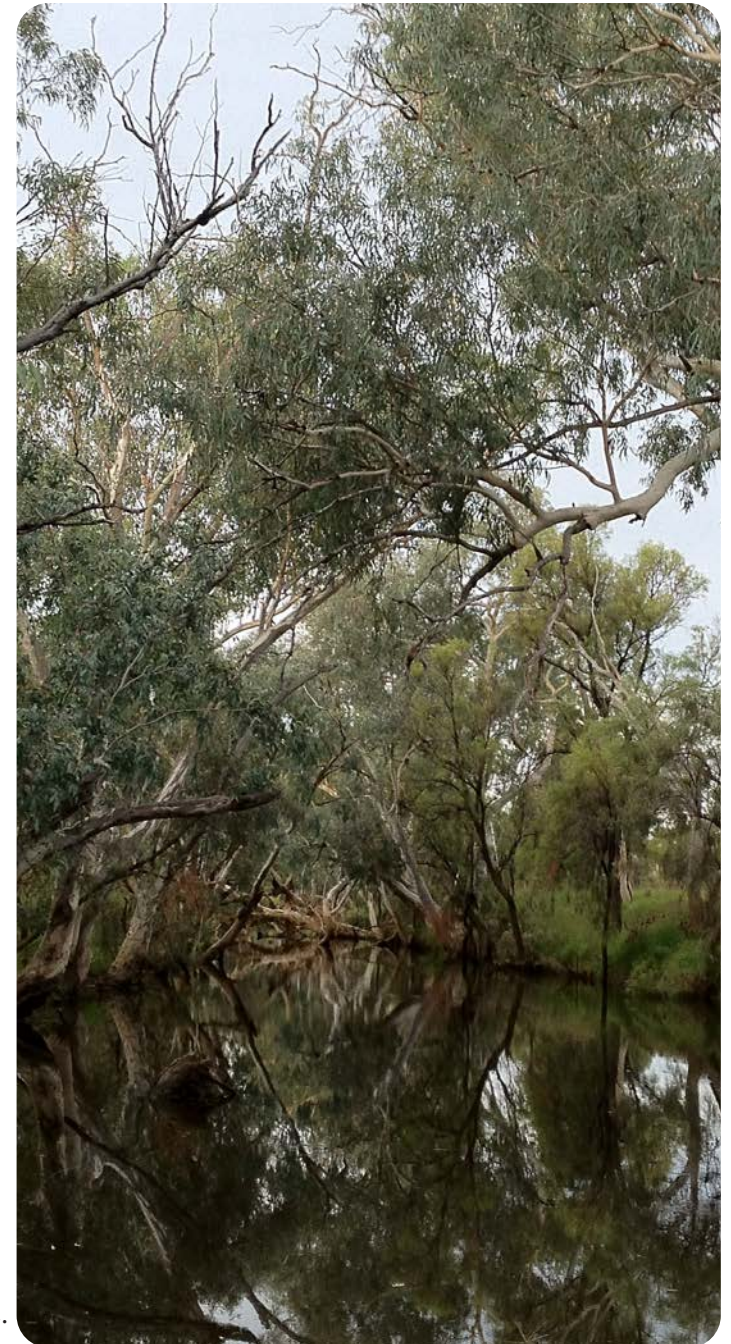
Where no comparison with other sites is possible, the collection of adequate baseline data from the treated site becomes very important. Effective evaluation requires consideration of the scale and frequency of measurement, and potential difficulties of separating treatment effects from natural variability. Comparison with reference sites is the preferred, but is not always possible. Selection of indicators for monitoring programs should reflect the questions being asked in the evaluation. Develop appropriate performance indicators for this threatening process to assist land and water management authorities in environmental audit and condition of catchment requirements.

Several methods have been developed for appraisals of environmental condition of waterways. These are especially valuable where repeated assessments are required, using non-technical assessors, and over a large number of sites. They often use surrogate indicators for ease and speed, and are suitable for situations where trends over time are more important than absolute measures. Two rapid appraisal methods suitable for riparian zones on rivers in southern (Jansen et al. 2005) and northern Australia (Dixon et al. 2006) have been widely tested and applied and provide useful information on the current condition of riparian areas. In Western Australia an index of river condition has been developed to assist in the management of waterways (<http://water.wa.gov.au/water-topics/waterways/assessing-waterway-health/south-west-index-of-river-condition>). This uses a range of standardized indicators to assess riparian condition.

Proper monitoring and evaluation procedures also provide a basis for adaptive management and continued improvement, and can assist in identifying priorities when resources are limited. Adaptive management applied to riparian buffers whereby defining management or restoration goals is the critical first step, which must take into account society as well as ecological values. Particularly in rural and urban settings, people form part of the ecosystem in their use of this resource and providing feedbacks onto riparian condition is important to initiate appropriate responses (Groffman et al. 2003).

There are primary and other possible feedback mechanisms that allow assessment of riparian management actions and the linkages required to make appropriate and timely adjustments and, as well, the importance of suitable research on riparian and stream ecology relationships (Fig. 4). When adaptive management is embedded into the operational management of riparian zones, the monitoring and evaluation of outcomes for species and processes can be used to assess the effectiveness of management to refine and adapt practices (Fig. 4). Adaptive management also needs to be forward thinking and allow for unexpected results.

Barcoo River, near Tambo, Queensland, 2012.



# Glossary

**Acidification** - The process of a substance increasing in acidity. In soils, this occurs when hydrogen cations build up after the addition of an acid, such as nitric, carbonic or sulfuric acids.

**Adsorb** - The adhesion of particles from a substance to the surface of a solid particle. For example, organic compounds can adsorb on to the surface of soil particles.

**Aridity** - A lack of moisture. An area is arid when it is severely deficient in available water.

**Biodiversity** - A measure of the variety and variability of all life on Earth, at a genetic, species and ecosystem level.

**Buffer zone** - A strip or area of vegetation or land between two zones. I.e. riparian vegetation offers a buffer zone to the water body from farmland or urbanisation.

**Carbon sequestration** - The act of carbon dioxide being taken from the atmosphere and held in liquid or solid form.

**Corridor** - Wildlife, habitat or green corridors are stretches of habitat that connect larger areas of quality habitat, allowing fauna to travel between patches safely.

**Denitrification** - A process in soil where bacteria utilises nitrates for respiration in place of oxygen, resulting in a loss or reduction of available nitrogen.

**Ecological function** - An ecosystem's potential to deliver ecosystem services.

**Ecosystem services** - The outputs or processes of natural systems that can benefit humankind, either directly or through the provision of other goods and services.

**Ecotone** - An area of transition between two distinct biological communities.

**Erosion** - The result of surface processes that remove soil, rock or other material away from their original position.

**Eutrophication** - When a body of water becomes inundated with excess nutrients, generally resulting in an overgrowth of algae.

**Fluvial scour** - The erosion of river beds or banks, occurring gradually or periodically as in the event of flooding.

**Food-web subsidy** - The addition of resources, such as nutrients, detritus or prey, to one system from another.

**Fragmentation** - Refers to the splitting into smaller sections or fragments of a whole.

**Heterogeneity** - The state of being diverse in content or character.

**Hydraulics** - The way water moves; often describing surface flow or variation.

**Hydrology** - The study of the distribution, movement and management of water.

**Levee** - An embankment or ridge of sediment at the edge of a river. Can form naturally through sediment deposition, or can be artificially designed to prevent river overflow.

**Large woody debris (LWD)** - Dropped tree branches or dead tree trunks, for example, that contribute to the riparian ecosystem.

**Mass failure (erosion)** - Also known as collapse or slumping, mass failure occurs when whole sections of riverbank erode and slide into the stream.

**Nitrification** - The addition of oxygen molecules to ammonia to form nitrite, then nitrite to form nitrate.

**Primary succession** - The growth of vegetation in an otherwise previously lifeless area.

**Propagule** - A plant structure that can detach from the parent plant to grow as a new plant, such as a bud or spore.

**Regrowth vegetation** - The vegetation growing in an area that had previously been cleared.

**Remnant vegetation** - Vegetation remaining in its original form or state without human disturbance.

**Riffle zone** - A shallow stream segment where water flow is affected by rocks.

**Riparian** - Relating to the banks of a river.

**Riprap** - Loose stone forming the foundation of a streambed or breakwater.

**Semi-arid** - Receives little rain, but not as low as a desert.

**Subsidence** - The sudden or gradual sinking or caving in of land.

**Substrate** - The surface on which something lives or grows.

**Sub-aerial loosening** - The loosening of soil or rock from below the surface.

**Sustainability** - Avoidance of natural resource depletion to ensure an ecologically balanced system.

**Swale** - A shallow channel for water catching with gently sloped sides.

**Terrestrial** - Of or pertaining to the land or ground.

**Trophic** - Relating to feeding or nutrition. Trophic level refers to position in the food chain.

**Urban heat island effect** - The retention of heat in urban areas due to replacement of vegetation with hard surfaces.

**Water table** - The boundary between surface soil and the upper level of underground soil or rocks that are saturated with water.



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Tangled lignum (*Meuhlenbeckia florulenta*) habit (p. 3, bottom photo). From tangled lignum, by Mark Marathon, 2013 (<https://commons.wikimedia.org/wiki/File:Lignum.jpg>). CC BY-3.0.

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Talbragar River, at Cobbora NSW, November 2009, one month prior to flooding (p. 21). From Talbragar River, by Eregli bob, 2009 ([https://commons.wikimedia.org/wiki/File:Talbragar\\_River\\_at\\_Cobbora\\_NSW\\_November\\_2009.jpg](https://commons.wikimedia.org/wiki/File:Talbragar_River_at_Cobbora_NSW_November_2009.jpg)). CC BY-SA-3.0.

Belyando riverbank in central Queensland. From Central Queensland: Galilee Basin (p. 23), by Lock the Gate Alliance, 2012 (<https://www.flickr.com/photos/lockthegatealliance/8353582422/in/set-72157632603956115>). CC BY-SA-2.0.

Eucalyptus camaldulensis on the banks of the Burke River, Boulia, Queensland (p. 24). From Eucalyptus camaldulensis, by John Robert McPherson, 2019 ([https://commons.wikimedia.org/wiki/File:Eucalyptus\\_camaldulensis\\_Burke\\_River\\_Boulia\\_Queensland\\_P1060517.jpg](https://commons.wikimedia.org/wiki/File:Eucalyptus_camaldulensis_Burke_River_Boulia_Queensland_P1060517.jpg)). CC BY-SA-4.0.

Balonne River in St George, Queensland, during drought (p. 25). From St George, Queensland, by Vinko Rajic, 2003 ([https://commons.wikimedia.org/wiki/File:St\\_George\\_-\\_Baloone\\_River\\_drought\\_-\\_panoramio.jpg](https://commons.wikimedia.org/wiki/File:St_George_-_Baloone_River_drought_-_panoramio.jpg)). CC BY-SA-3.0.

The Balonne River at St George, Queensland (p. 26). From St George, Queensland, by Mattinbgn, 2008 (<https://commons.wikimedia.org/wiki/File:StGeorgeBalonneRiver.JPG>). CC BY-SA-3.0.

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Barcoo River, near Tambo, Queensland (p. 29). From Queensland riverbanks, by Wittylama, 2012 ([https://commons.wikimedia.org/wiki/File:Barcoo\\_river,\\_Tambo.JPG](https://commons.wikimedia.org/wiki/File:Barcoo_river,_Tambo.JPG)). CC BY-SA-3.0.

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