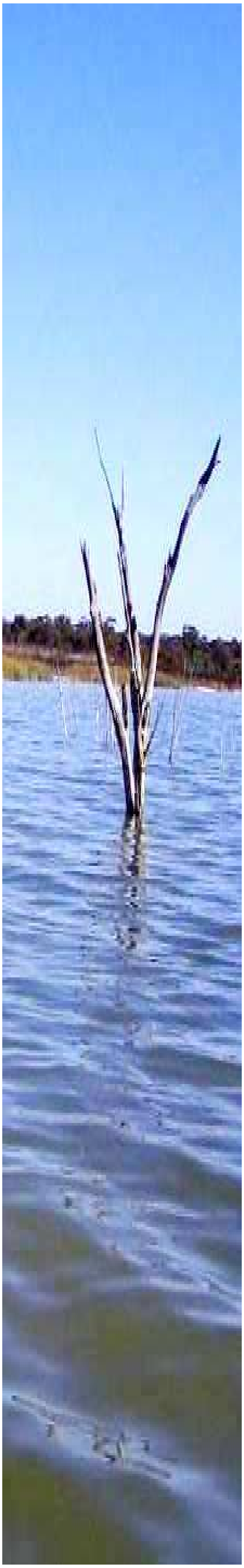

Potential Effects of Willow (*Salix* spp.) Removal on Freshwater Ecosystem Dynamics

A Literature Review

Sylvia Zukowski and Ben Gawne

June 2006

Report prepared for the
North East Catchment Management Authority

The Murray-Darling Freshwater Research Centre

NORTH EAST CATCHMENT MANAGEMENT AUTHORITY

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This report was produced by the **Murray-Darling Freshwater Research Centre**

The Murray-Darling Freshwater Research Centre is a joint venture between the Murray Darling Basin Commission and CSIRO Land and Water, which aims to answer locally relevant research questions to help guide water managers, and ultimately improve the health of our rivers, lakes and wetlands.

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This report may be cited as:

Zukowski, S. and Gawne, B. (2006). Potential Effects of Willow (*Salix* spp.) Removal on Freshwater Ecosystem Dynamics. A Literature Review. Report for the North East Catchment Management Authority. Murray-Darling Freshwater Research Centre, Wodonga.

Cover photograph: Willow leaf (Sylvia Zukowski).

Acknowledgements: A big thanks to Veronica Lanigan, Nick Whiterod, Bernard McCarthy and Catherine Hall for reviewing the report and to Shaun Meredith and Sue Gehrig for their valuable advice and input.

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1. INTRODUCTION

In March 2006, the Murray Darling Freshwater Research Centre was commissioned and funded by the North East Catchment Management Authority to develop a literature review detailing the effects of willow removal on freshwater aquatic systems. Anecdotal evidence suggests an overall increase in 'stream health' in the long term following willow removal. However, the lack of literature describing the effects of willow removal coupled with large knowledge gaps and opposing views in current literature specific to the effects of willows on Australian aquatic environments makes accurate predictions difficult.

This literature review summarises previous literature on willow effects and attempts to predict the potential short and long term effects of willow removal on aquatic ecosystems. It is part of a larger project that will develop a protocol for monitoring the effects of willow removal on stream ecology. The project will then apply the monitoring design to several willow removal sites to ascertain the effects of willow removal on aquatic systems.

2. BACKGROUND

2.1 Australian History of Willows

Willows *Salix* spp. (Salicaceae) have now been naturalised in North America, South Africa (Henderson 1991), New Zealand (Van Kraayenoord *et al*. 1995) and Australia (Glova and Sagar 1994; Lester *et al*. 1994a; Ladson *et al*. 1997). They have commonly been used for bank stabilisation, erosion control, boat navigation and as ornaments (Perkins 1903; Rodd 1982). In Australia, the cuttings from at least two willow species were introduced to the River Murray by 19th century European settlers e.g. (Schulze and Walker 1997), mainly to act as channel markers for river boats and as stabilising agents protecting reclaimed riparian swamplands (Perkins 1903; Ladson *et al.* 1997). Since then, more trees have been planted to stabilize riverbank levees and the margins of the weir pools constructed in 1922-1937 (Walker and Thoms 1993). Today more than 100 species, varieties, cultivars and hybrids of willows are present in Australia (Cremer 1995) with subsequent hybrids still arising (Ladson *et al.*

1997). One of the first species planted, the weeping willow (S. *babylinica*), now rivals the native river red gum (Myrtaceae: *Eucalyptus camaldulensis*) as the dominant riparian tree along some reaches of the River Murray (Walker *et al.* 1994).

The high invasion rate of willows in Australia arises from the trees remarkable ability to spread and the habitat created by river regulation. Willows grow best when they are near water (Schulze and Walker 1997) and this has facilitated their invasion with water acting as an ideal transport mechanism for branches and seeds. The brittle branches of willows allow them to spread freely and abundantly as the branches break easily and fall into the water, taking root downstream. This is exacerbated when branches are broken off to use as fishing line anchors (Albury/Wodonga Willow Management Working Group 1998) or ungathered branches are left on the banks or in the stream following a de-willowing operation.

Willows also have the ability to reproduce in enormous numbers by cross-pollinating seed germination (half a million seedlings were recorded at one site) (Albury/Wodonga Willow Management Working Group 1998). The ability to rapidly colonise available habitats allows willows to invade watercourses, as well as spreading along stream, wetland and river banks. The tree roots which spread into the bed of a watercourse, can potentially slow water movement, reduce aeration, encourage sedimentation and alter the shape of the stream bed, often making it broad and shallow (Bunn *et al.* 1993). The roots can also form thickets which divert water outside the main watercourse or channel, causing flooding and erosion where the creek banks are vulnerable (CRC for Australian Weed Management 2003; Upper Parramatta River Catchment 2003; Melbourne Water 2005).

The ability of willows to grow in permanently wet environments makes the altered hydrological regime in our now regulated river sections ideal for their colonisation, particularly as these sections may not be as suitable for native river red gums. Various authors have described changes in abundance and composition of riparian vegetation as a result of altered hydrologic regime, often consisting of declines in native species and establishment of exotic species such as willows (Johnson 1990; Carothers and Brown 1991; Stromberg and Patten 1991; Stromberg *et al.* 1993; Everitt 1995; Scott *et al.* 1996; Merigliano 1997; Patten 1998).

Victoria has experienced a strong willow invasion and willows currently represent a significant and potentially important component of many stream corridor ecosystems. The total river frontage in Victoria is 68,000 km, of which 30,000 km is dominated by willows (Ladson *et al.* 1997). The River Murray in South Australia has also been subjected to this invasive species, with the weeping willow now dominating over one-third of the 830 km river course from the Murray-Darling junction to the Murray mouth (Schulze and Walker 1997). The current extent of willow invasion in NSW is unknown (S. Holland-Clift 2006, National Willows Taskforce coordinator, pers. comm.). However the National Willows Taskforce is currently conducting a survey to quantify the levels of infestation across Australia, including NSW (see section 2.3).

In contrast to river red gums which drop leaves year-round and have relatively slow decomposition rates (Schulze and Walker 1997), willows are deciduous, with soft, fragile leaves that fall in late autumn (Schulze and Walker 1997) and provide a large flux (Gregory *et al.* 1991; Wilson 2001) of rapidly decomposing organic matter to aquatic systems (Baldy *et al*. 1995; Schulze and Walker 1997; Chergui *et al.* 1997; Janssen and Walker 1999; Legssyer *et al*. 2003). Branches and bark from willows also have a fast decomposition rate, whereas river red gums have a propensity to drop large limbs which decompose slowly, providing habitat for aquatic animals (Schulze and Walker 1997). This results in lower quantities of large woody debris in willow lined stretches as compared to river red gum dominated stretches of river. Also both the bark and leaves of willows leach cyanidins, delphinidins, leucoanthocyanidins and phenolglycosides into aquatic environments which have shown to deter herbivores (Binns *et al*., 1968; Rowell-Rahier, 1984).

The thick, overhanging canopy of willows crowds native plants and casts heavy shade which decreases the amount of solar radiation reaching the stream channel (Lester *et al*. 1994a; 1996). This can affect stream temperatures and primary production (Van Kirk and Benjamin 2001) and can alter growing conditions for native vegetation understorey. In contrast, the sparse, open canopy of river red gums favours a more diverse understorey of littoral macrophytes and terrestrial plants, (Schulze and Walker 1997) so that willow-lined river-banks are markedly different from places where the native river red gum still prevails (Schulze and Walker 1997).

Such differences between willow and native tree characteristics (Table 1), coupled with the willows strong invasive qualities has led to widespread concern regarding the possible ecological effects of willows on Australian freshwater ecosystems (Frankenberg 1995; Ladson *et al.* 1997; Schulze and Walker 1997). A widely accepted view has emerged that fundamental stream ecological processes may be affected by willow spread, causing a broad range of detrimental impacts to freshwater ecosystems (Campbell 1993; Frankenberg 1995; Ladson *et al.* 1997; Bobbi 1999; Smith and Star 1999). These, it is claimed, can be readily observed from field observation (Frankenberg 1995) however to date, few studies have demonstrated specific impacts and a number of studies comparing biota under native and willow vegetation have been inconclusive (Pidgeon 1978; Besley 1992; Hardwick *et al*. 1995; Schulze and Walker 1997).

Table 1. Willow characteristics and their associated possible environmental impacts. (Adapted from the North East and Murray Willow Management Working Group 1998)

Characteristic	Possible Environmental Impacts of Willows
Deciduous	Dense shade in spring and summer, followed by light shade and heavy leaf fall in autumn and winter, suppresses indigenous understorey and river fauna. Most leaves fall in autumn when natural stream flows are high and water temperatures low. This pattern is foreign to the Australian pattern to which local flora and fauna is adapted. The massive leaf drop in autumn can lead to high nutrient pulses within the system and to reduced water quality.
Dense shallow mat-forming roots	Roots and foliage trap silt build up on the ground surface and divert flows into banks. Eventually watercourses may change course to flow around willows, creating ‘braided’ streams with mid-stream islands. Streams with willows tend to become wider and shallower. This leads to increased flooding, until the channels have expanded. Roots generally suppress growth of indigenous plants, leaving bare ground beneath.
Bare banks beneath willows	Bare banks do not provide protection for frogs, water rats, snakes and lizards on the stream bank margin.
Dense canopy	Dense shade created by exotic tree canopies can decrease light availability and river/stream temperatures (especially during spring/summer). These modifications may cause a decline in in-stream primary production: limited regeneration of native flora and a decrease in dissolved oxygen concentrations.
Lack of predators or terrestrial willow-eating animals	Willows contribute little to the terrestrial food chain. Fewer insects results in fewer insectivorous birds. Few insects drop into the watercourse to provide food for fish etc. Lack of predators allows willows to grow faster than indigenous plants, and suppress indigenous understorey growth.
Monoculture-forming. Ability to dominate entire sections of the watercourses	Dominance of stream banks leads to marked reductions in natural diversity of flora and fauna and habitat/conservation values in the water and on the banks. Domination by willows severely alters the intrinsic Australian ‘sense of place’ created by the indigenous flora, and leads to landscapes vastly different from pre-European Australian landscapes. Watercourses dominated by willows may not be as accessible as typically indigenous watercourses.
Ability to spread	Willows can spread prolifically vegetatively (e.g. broken twigs rooting downstream) and by seeding between different willows. As such, they are highly invasive and have the potential to dominate watercourses. Such potential poses severe environmental risks to other areas, including intact ‘natural’ areas.
Tendency to grow into the centre of streams and cause erosion	Willows can grow in continually wet sediment and hence encroach towards the centre of watercourses. Such encroachment can create flow diversions which increases erosion potential, and can lead to complete stream blockages as the trees trap silt and debris. This increases flooding, and can cause streams to change course.
Tendency to accumulate debris	Willow debris deposited downstream can continue to grow causing further problems. Additionally, long overhanging willow branches or numerous trunks encourages the collection of debris, which increases stream blockages and redirects flows into banks where erosion may occur.
Few branches shed, and few hollows or snags formed	Willows are poor habitat for hollow-dependent mammals and birds, and snag dependent fish (many Australian fish depend on woody debris in the stream for habitat). Fallen branches that either rot quickly, reducing food resources for in stream invertebrates, or take root, spreading willows further.
Brief flowering season	Willow flowers only provide nectar for introduced honey bees, for a brief period. There are no records of use of flowers by nectar-feeding birds.
Water use	Willows can dry out streams and swamps by using more water than the herbaceous vegetation they replace, or have higher transpiration rates than indigenous species.

2.2 Listing as National Weed

In Australia, willows are generally seen as a serious weed threat to stream and wetland environments. The extensive spread of willows along Australian inland streams and rivers has triggered widespread concern over possible ecological effects to both riparian and stream zones. (Frankenberg 1995; Ladson *et al.* 1997; Schulze and Walker 1997; Ladson *et al.* 1999; DLWC 2001). Such concern has resulted in willows attracting national attention. In 1999 all but three willow *Salix* species were included on the 'Weeds of National Significance' (WONS) list which declares Australia's 20 worst weed species (ARMCANZ 2001). As part of this declaration, a National Strategy has been prepared to co-ordinate efforts in the management and control of willows throughout Australia (Farrell 2003). The Weeds of National Significance (Willow *Salix taxa, excluding S. babylonica, S. x calodendron and S. x reichardtii)* Strategic Plan was developed in 2000 with a vision to stop willows destroying waterways and wetlands. The strategy was developed in collaboration with government, catchment and conservation management agencies, industry groups, private consultants and community groups (Agriculture & Resource Management Council of Australia & New Zealand, Australian & New Zealand Environment & Conservation Council and Forestry Ministers 2000). The plan aims to deliver four primary outcomes:

1. Stop the further spread of willows.
2. Manage existing areas of willows.
3. Gain community support in the management of willows.
4. Prevent their importation.

The three species not included on the WONS list, the weeping willow S. *babylonica*, and two hybrid species of pussy willow S. x *calodendron* and S. x *reichardtii* (Cremer 2002), should not be excluded from management decision as they can hybridise with other willow species that would otherwise not produce seeds.

2.3 Victorian State Policy

In Victoria, willow removal and replacement projects are now part of many river restoration activities (DNRE 2002). The planting of exotic species on riparian land has also been strongly discouraged and actions to control or remove weed infestations have been implemented within the context of river restoration priorities (DNRE 2002).

In addition to the national listing of Willows on the WONS list (see section 2.2), Salix species, with the exception of S. *alba* var. *caerulea*, S. *alba* x *matsudana*, S. *babylonica*, S. x *calodendron*, S. *caprea* 'Pendula', S. *matsudana* 'Aurea', S. *matsudana* 'Tortuosa' S. *myrsinifolia* and S. x *reichardtii*, have also been proclaimed as noxious weeds (*restricted weeds) in Victoria under the *Catchment and Land Protection Act* (1994). (*Please refer to the *Catchment and Land Protection Act* (1994) Sections 63, 67 and 69). Eleven taxa of willows are also currently undergoing further assessment by Victorian Catchment Management Authorities to determine if their current level of classification should be revised. (Victorian review of noxious weeds - phase 3a - A. Hodges 2006, DSE, pers. comm.).

*(http://www.dms.dpc.vic.gov.au/Domino/Web_Notes/LDMS/PubLawToday.nsf/a12f6f60fbd56800ca256de500201e54/C14AAC42DB8B39C4CA25721700048742/$FILE/94-52a040.pdf).

2.3 CMA Policy

The National Willows Taskforce is currently conducting a survey to quantify the levels of willow invasion across Australia. The project titled ‘Developing willow management priorities from local to the national level’ will address high priority actions in the Willows National Priority Action Framework by determining the current distribution of naturalised willow taxa. The project will produce risk assessments and interactive maps of the current and potential distribution of all willow taxa present in Australia for State and national planning. It will develop a national prioritisation matrix based on risk and feasibility for coordinated control and establish a process for monitoring change across Australia (S. Holland-Clift 2006, National Willows Taskforce coordinator, pers. comm.).

Upon completion, the data from this project will provide a much needed framework for the development of site specific willow management strategies. Site specific, because as this current report describes, willow removal will have very different ecological outcomes depending on a variety of factors including;

- whether it is a regulated/non regulated river section or a wetland or stream,
- the ecological character of the waterbody (i.e. invertebrate and fish assemblages, primary productivity etc.) and
- the physical conditions of the water body (i.e. presence of other vegetation, bank stability, water temperature, flows, depth and size etc.).

Most Catchment Management Authorities (CMAs) have policies on general weed control, however developing specific policies on willow management is a very complicated task given all the parameters that need to be considered. The North East CMA (NECMA) is one example of a CMA which does have a current willow management policy in place (the policy is currently being reviewed). The policy document for the NECMA has been produced to provide policy guidelines and management directions for the management of willows in North East Victoria (NECMA 2003). The policy uses a combined knowledge of publications and studies, current best practise and local knowledge to deal with the control and prevention of willow spread in waterways with a focus on risk management (NECMA 2003).

Further examples of CMAs that currently have such policies in place or are currently in the process of developing policies include the North Central CMA (J. Leevers 2006, NCCMA, pers. comm.), the Hawkesbury-Nepean CMA (J. Reynolds 2006, HNCMA, pers. comm.), the Goulburn Broken CMA (C. Wilson 2006, GBCMA, pers. comm.) and the Glenelg Hopkins CMA (GHCMA), to name a few. The West Gippsland CMA deals with willow management issues under the state and regional River Health Strategy (M. Gibson 2006, WGCMA, pers. comm.). The Department of Primary Industries in Victoria is in the process of producing a management guide for willows containing up to date information on the biology and management of willows across Australia (J. Davies 2006, DPI Victoria, pers. comm.). The majority of CMAs that do not have such policies in place contact departments such as the Department of Natural Resources or Land & Water Australia for willow management advice or use and respond to national and state policies such as the National Willows Network

(NWN). The NWN has set up an emailing network to provide a forum for sharing information and advice about willows and their management. Currently 253 people from across Australia are on the Network, with a variety of interests, experience and expertise in willow management (S. Holland-Clift 2006, National Willows Taskforce coordinator, pers. comm.).

The high infestation rate of willows coupled with a steady shift within river management authorities from a 'resource-engineering management paradigm' toward a 'watershed ecosystem (integrated catchment) paradigm' (Healey 1998) has led to much focused debate over best willow management within academic, management and broader communities (Wilson 2001). Attempts to remove willows from the riverbanks has been met with strong community opposition, but there is similar opposition to leaving them unchecked (Kennedy *et al*. 2003). Smith and Star (1999) stated that from a southern NSW perspective the willow debate was "possibly the most contentious issue in river management" whilst in Tasmania, community groups have "made it clear" that willow management and control is the most important river management issue (Bobbi 1999). In Victoria, it has been reported that nearly all Victorian river management authorities were engaged in willow management works (lopping, poisoning, or removal) and fewer than 200 willows per year were being planted (Ladson *et al.* 1997) (see section 2.3). Despite this controversy, few studies actually detail the environmental effects of willows and fewer studies describe the effects of removing them.

The decision to remove or retain willows along rivers and streams is often left to water resource managers. They are placed in a difficult position, especially as currently there is inadequate information to thoroughly evaluate benefits and costs of willow removal at multiple scales (Wilson 2001).

3. AN OUTLINE OF THIS LITERATURE REVIEW

Given the possible deleterious effects of willows on Australian aquatic processes, it is no wonder that wide scale willow removal projects are currently underway in Australia. However, the debate between various groups as to whether willows should be left in place, removed or otherwise managed and to the potential effects of removing willows on aquatic systems has called for further information to be gathered on the effects of willows and willow removal on Australian aquatic systems. This literature review will summarise previous literature on the effects of willows on aquatic systems and will attempt to predict the potential short and long term effects of willow removal on the physical and biological components of aquatic ecosystems. The aquatic components that will be addressed include channel morphology, erosion, water usage, water quality, sediment, organic inputs, decomposition, and riparian vegetation. Each of these sections will be divided into a summary of previous literature on willow effects, followed by a discussion on the potential impacts of willow removal based on these effects. The potential effects of willows and willow removal on two groups of aquatic fauna, invertebrates and fish, will also be addressed. As a change in most of the above listed aquatic components will have an affect on invertebrate and fish communities, some of these components will be addressed in the invertebrate and fish sections also.

4. POTENTIAL EFFECTS OF WILLOW REMOVAL ON GEOMORPHOLOGY

4.1 Channel Morphology and Erosion

The geomorphic structure of an aquatic system is highly influenced by riparian vegetation. Riparian trees provide enormous bank stability by increasing resistance to erosion (Smith 1976; Schumm and Meyer 1979; Beeson and Doyle 1995). Tree root systems and large woody debris can also alter bank morphology (Bunn *et al.* 1993), changing channel depth and width, flow and sediment conditions. The ability of willows to grow in continually wet soil conditions coupled with their dense root mats can exert a strong influence on stream behaviour. The many fine, lateral roots and dense thickets of stems can trap large amounts of silt which can decrease channel capacity, exacerbate flooding, change flood patterns and prevent the formation of undercut banks which provide a daytime resting habitat for a large array of fish (Merrick and Schmida 1984; Koehn and O'Connor 1990), tortoises and platypus (Ladson *et al.* 1997).

Willow roots can also grow into the stream channel, trapping silt and layering new roots over old roots, building up the streambed and creating a broad shallow stream. Willows encroaching into the centre of streams can interrupt water flow resulting in stream flows being directed into watercourse banks and causing erosion. In extreme cases, willows can create complete blockages, causing the stream to change course. This problem is most apparent during floods when debris is trapped in willow foliage, effectively creating solid obstacles that water flows around (Ladson *et al.* 1997; Albury/Wodonga Willow Management Working Group 2001).

The ability of willows to consolidate river and stream banks can have long-term effects on channel geomorphology (Bunn *et al.* 1993). In the Snowy Mountains, the channel shape of the Snowy River has changed considerably since regulation. Where sediment has been scoured away and deposited downstream, willows have moved in and colonised these new deposits. Once established in these new deposits the sediment has become stabilised, causing channel contraction through the encroachment of in-stream vegetation (Erskine *et al*. 1999).

4.1.1 Potential Effects of Willow Removal on Channel Morphology and Erosion

The short and long term effects of removing willows from stream banks and beds on channel morphology and erosion are very difficult to predict and will vary between areas depending on stream flow, size, depth, sediment, climate, geology, and topography (Gregory *et al.* 1991). Where there is no risk of erosion occurring, removal of whole willows from the centre of watercourses may have the most immediate positive impacts, preventing further disturbance in stream geomorphology and restoring the natural watercourse. However the removal of in-stream willows growing at a point in the river where there is a change in gradient may need special management consideration. These willows act as a gradient control, and are characterised by a pool of water upstream and faster water immediately downstream (Department of Primary Industries and Water 2006). Total removal of these willows may initiate erosion of the streambed, and therefore, it may be more advisable to leave their root mats in place (Department of Primary Industries and Water 2006).

Removal of whole willows along banks may prevent further changes in stream morphology, however, erosion and associated channel and ecological changes would need to be considered. Large scale willow removal can impact on the ecology of the river with a high possibility of silt release and soil destabilisation occurring following removal (Department of Primary Industries and Water 2006). This has the potential to choke the river, increase turbidity and blanket aquatic habitat with silt (Department of Primary Industries and Water 2006). Perhaps the removal of small sections of willows along streams and rivers at any one time may be a more environmentally ‘safe’ option as the greater the amount of willows removed from a given river section the greater the chance for such problems, and the harder it may be to manage any consequent problems (Department of Primary Industries and Water 2006).

Where willow root mats were left in place following canopy removal no immediate effects were observed on the structure of bank edges and riffle (Figure 1) (Gawne *et al.* 2005). Long term effects may differ as the willow root masses decompose, especially if bank stabilising vegetation does not replace willows. In Ginninderra Creek, Canberra, willow stumps had undergone considerable deterioration from erosion processes six years following willow removal. Due to drought conditions, native vegetation could not be planted to secure the bank (R. McConville 2006, Ginninderra Catchment Group, pers. comm.), leading to potential erosion problems. The possibilities of such problems arising and subsequent solutions should be incorporated into a long term management plan for willow removal.

Figure 1. De-willowed reach (root mats left in tact) in autumn 2005 in the Ovens River at Selzers Lane near Ovens, Victoria. Photo H. Gigney.

5. SEDIMENT

5.1 Sediment

Stream and river banks provide a vital habitat and protective shelter for many aquatic animals. The type of sediment found within these banks is very important in determining invertebrate communities. Fine sediment has been linked with invertebrate feeding interference (Ryder 1989) and decreases in invertebrate density (Minshall 1984). This is generally a result of the fine sediment blocking the interstitial spaces between stones (Lester *et al.* 1994a), and preventing aquatic insects from accessing the hyporheos (Pugsley and Hynes 1983). Studies have shown a positive correlation between dense riparian vegetation and fine sediment (Li and Shen 1973; Hawkins *et al.* 1982) and Lester *et al*. (1996) found an accumulation of fine sediments in dense riparian willow sites in New Zealand.

Dense willow root mats can reduce water velocity leading to stabilization of the stream bed, increased sedimentation and a smaller average substratum size (Young 1980; Lester *et al*. 1996). Lester *et al.* (1994a) found that willow roots in densely lined willow sections can wrap around rocks and occupy interstitial spaces, locking in sediment so that the entire width of a stream becomes highly silted.

5.1.1 Potential Effects of Willow Removal on Sediment

The removal of whole willows in these areas may lead to an increase in substratum size in the long term with most significant results probably arising in areas where all willows and root masses have been cleared. The effects of root removal disturbance on the aquatic ecosystem is currently unknown, however, short term effects on food webs and bank stability would need to be considered. Removing willow canopies, poisoning the tree stump and allowing the root masses to decompose slowly is a frequently used alternative option, but again the effects of the poison, the rotting material, especially in densely lined rivers and streams, small streams, wetlands or lotic systems have not been investigated.

6. WATER USAGE

Water uptake by riparian trees is highly variable and depends on the tree species, tree dimension, local moisture conditions and climate (Lambs and Muller 2002). Studies conducted on the San Pedro River in southeastern Arizona, US, found that willows (*Salix gooddingii*) only used groundwater for transpiration and did not utilise water from rainfall events from the upper soil layers (Snyder and Williams 2000). River red gums on the other hand have been shown to utilise a selection of different water sources including rainfall-derived shallow soil water, stream water and groundwater (Thorburn and Walker 1994; Jolly and Walker 1996; Dawson and Pate 1996).

In Australia, direct comparisons on water usage between willows and river red gums along rivers and streams have, until now, not been undertaken. However, many arguments have been based on removing riparian willows due to their potential 'high water usage' compared to river red gums. A study conducted between August 2005 and March 2006 in central NSW demonstrated that willows located in waterways used 3-4 $MLyear^{-1}ha^{-1}$ more water than river red gums located on stream banks (Figure 2) (Benyon and Doody 2006). The study also showed that water quantities used by willows and river red gums did not differ when comparing willows and river red gums on stream banks (Figure 2) (Benyon and Doody 2006). The potential for willows to utilise more water is only likely to manifest when willows invade water-courses.

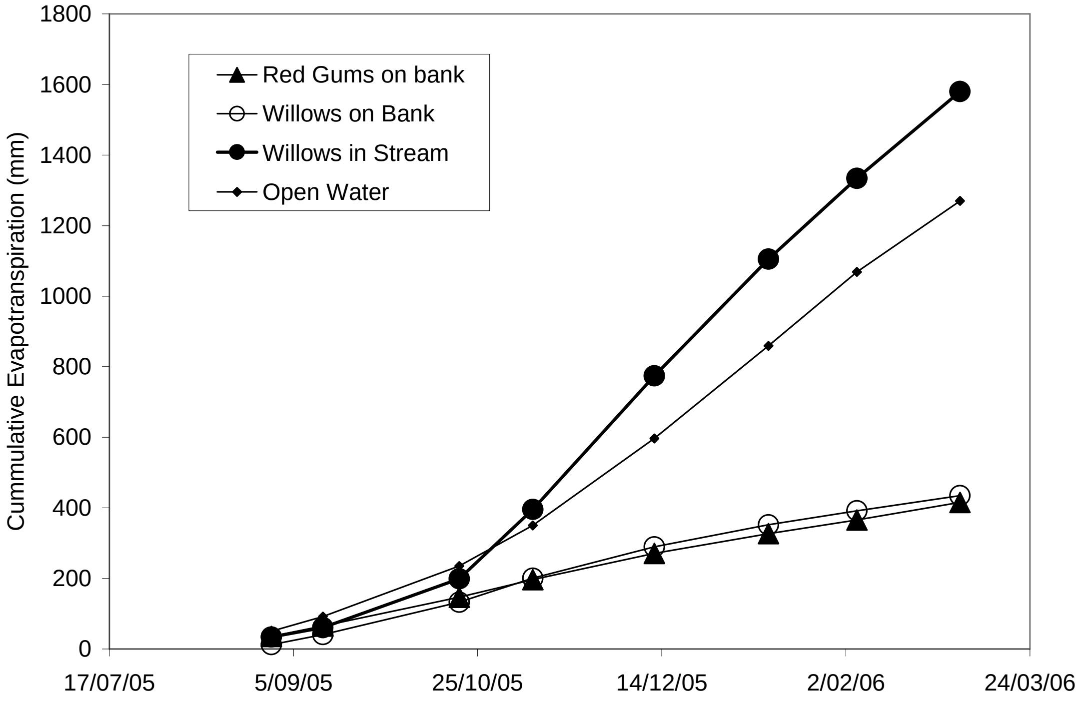

Figure 2. Cumulative total willow water use, 3 Aug. 2005 to 5 March 2006. (Source: Benyon and Doody 2006)

7. POTENTIAL EFFECTS OF WILLOW REMOVAL ON WATER QUALITY

7.1 Light

Light is a vital factor controlling stream ecosystems (Vannote *et al.* 1980; Rutherford *et al.* 1997). Riparian vegetation plays an important role in regulating light intensity (Hill 1996; Bunn *et al.* 1999) and spectral qualities (Van Kraayenoord *et al.* 1995). Riparian vegetation intercepts light in the visual end of the spectrum (i.e. ultraviolet (UV) radiation) and the removal of riparian canopy can increase the exposure of aquatic organisms to UVB light (280-320 nm) which has been shown to be harmful to the eggs, embryos and larvae of some fish (Gutierrez-Rodriguez and Williamson 1999), attached algae and invertebrates (Bothwell *et al*., 1993).

Mature willows produce dense canopies, that significantly reduce the availability of incident illumination to banks and watercourses (Lester *et al.* 1994a; Gehrig and Ganf 2003). Lester *et al.* (1994a) found a reduction in incident photosynthetically active radiation (PAR) of 80% in summer and of at least 50% in winter in New Zealand willow-lined streams. This reduction is significant in the Australian context because river red gums have a year-round light reduction of approximately 50% (S. Gehrig 2006, Adelaide University, pers. comm.).

7.1.1 Potential Effects of Willow Removal on Light

Increased light resulting from de-willowing operations could have long term impacts on various biological aspects within the river system. In the Ovens River, NSW, photosynthetic irradiance was found to be more than 5 times greater in recently de-willowed sites than in the reference reach (Gawne *et al*. 2005). Possible changes in a system could include increases in germination, establishment, growth and survival of native vegetation, increases in water temperature, increases in periphyton biomass (primary production) and changes in periphyton composition (Van Kraayenoord *et al.* 1995).

Periphyton is a complex matrix of algae and heterotrophic microbes attached to submerged substrata in almost all aquatic ecosystems and serves as an important food source for invertebrates. The ability of riparian vegetation to significantly reduce primary production in streams through shading was first documented by Allen (1951) and this has been confirmed elsewhere (Keithan and Lowe 1985; Hill and Harvey 1990; Quinn *et al.* 1997). Thus the removal of shade following a de-willowing operation could directly increase primary production and indirectly increase secondary productivity and invertebrate densities and affect shifts in the number of taxa from particular functional feeding groups (Plafkin *et al.* 1989). This in turn could indirectly lead to further changes in the trophic structure such as in fish and bird communities with the magnitude of effect likely to be greatest in small streams where riparian vegetation has the greatest impact (Lamberti and Steinman 1997, Rutherfurd *et al.* 1997)

7.2 Temperature

Water temperature plays a large role in stream ecosystem structure and function. It can affect development and growth of aquatic insects (Butler 1984), growth, reproduction and disease resistance in adult fish and hatching and development of fish larvae (Pusey and Arthington, 2003). Elevated water temperatures also increase the metabolic rate of stream dwellers, thereby decreasing dissolved oxygen concentrations (Quinn and McFarlane 1989) and impacting adversely on stream assemblages (Rutherford *et al.* 1997). Several invertebrate species have low thermal tolerances and their reported absence from unshaded pasture streams in New Zealand may be the result of high water temperatures (Quinn and Hickey 1990; Quinn *et al.* 1994).

7.2.1 Potential Effects of Willow Removal on Temperature

As with all riparian vegetation, willow canopies play a significant role in controlling the transfer of thermal energy to aquatic systems and in determining temperatures in non-flowing systems (Van Kraayenoord *et al.* 1995). A reduction in riparian cover can result in greater mean summer water temperatures (Lynch *et al.* 1984; Quinn *et al.* 1992; Pearson and Penridge 1992), lower winter water temperatures (Lynch *et al.*

1984; Amour *et al*. 1994) and an increase in the degree and rate of change of daily fluctuations of water temperature (Lynch *et al.* 1984; Quinn *et al.* 1992). In-stream temperature changes may also extend to downstream of the willow removal site into reaches with intact riparian zones and therefore affect downstream habitat quality (Van Kraayenoord *et al.* 1995). One study found that temperatures in a stream disrupted by riparian removal only returned to normal after passing through 300 m of intact forest (Storey and Cowley 1997).

These effects would be most evident in lotic systems and in small and shallow streams (Hopkins 1971; Graynoth 1979; Quinn *et al.* 1994; Rutherford *et al.* 1997; Quinn *et al.* 1997; Rutherford *et al.* 2004). Shallow streams are particularly sensitive to modifications in shade because, for a given surface heat flux, the rate of temperature variation is inversely proportional to depth (Rutherford *et al.* 2004). A shallow stream would therefore have significantly higher daily maximum and lower daily minimum water temperatures than a deep stream with the same mean velocity (Comer and Grenney 1977) and these temperatures would be reached faster (i.e. heat quicker in the morning and cool faster in the evening) (Rutherford *et al.* 2004).

In larger or fast flowing systems, short term impacts of willow removal on water temperature may be expected to be minor. Gawne *et al*. (2005) found no immediate difference in water temperatures between de-willowed sites and reference sites in non summer months, despite a significant loss of shade in the de-willowed reaches. In the long-term, increases to light penetration following willow removal may increase water temperature over summer months. In Portugal, 2nd to 5th order streams lined with deciduous trees recorded consistently lower stream temperatures in summer than eucalypts due to their dense canopy covers (Barlocher and Graca 2002). Rutherford *et al*. (1997) found that for 2nd and 3rd order streams in New Zealand, 50% shade may maintain daily water temperatures below 25^{o}C whereas 70% shade may maintain temperatures below 20^{o}C. Rutherford *et al*. (2004) found maximum daily temperature changes of ± 4°C immediately downstream (600 to 960m) of areas with 40 to 70% changes in riparian shading, in small slow flowing second order streams in Western Australia and south-eastern Queensland. Temperature changes of this magnitude can have a significant effect on aquatic ecosystems.

Increased temperatures can lead to decreased dissolved oxygen levels, affecting different life stages of invertebrate (Nebeker 1996) and fish species (Llewellyn 1973; Pearson and Penridge 1992). The interaction of higher stream temperatures and increased illumination may increase the growth rates of in-stream primary producers which may in turn lead to an increase in the productivity of primary producers (e.g. water snails and insect larvae) that are reliant on autotrophic organisms as a food source (Bunn *et al.* 1999). It should also be noted that some invertebrates and fish have low upper thermal tolerances so the immediate impact of large scale willow removal or the complete removal of willows in one area on thermal regimens should be recognised. Especially if removal is done over the summer months when it has been shown that thermal regimes of large water bodies or streams under higher flows may be influenced by willows.

7.3 Nutrients

Total nitrogen (TN) and total phosphorus (TP) levels present in an aquatic system can indicate how nutrient polluted (eutrophied) or vulnerable the system is to nuisance plant growth (ANZECC and ARMCANZ 2000). Levels of TN that range between 100–1000 μgL^{-1} and TP between 10–100 μgL^{-1} are within the range recommended for Australian watercourses (e.g. modified SE-Australian rivers and streams) to retain healthy aquatic systems (ANZECC and ARMCANZ 2000).

Nutrient inputs from willow leaf litter are very different than that from river red gums due to differences in the timing and amount of leaf litter fall and leaf litter composition. The whole willow canopy senesces in late Autumn, providing a large amount of litter fall to the river system as compared to river red gums which have a peak litter fall in late summer but continue to retain a large proportion of their canopy (Gawne *et al*. 2005). The large influx of organic matter into aquatic systems from willows can have significant influences upon nutrient fluxes in riverine/stream environments (Cowen and Lee 1973; Royer *et al*. 1999).

Upon entering the stream, willow leaves rapidly leach simple organic compounds such as reducing sugars, amino acids and phenolic compounds (Iversen 1974; Gessner and Schwoerbel 1989). As much as 25% of the nitrogen, 50% of the phosphorus and

85% of the potassium in the leaf is rapidly released to the water column (Taylor and Barlocher 1996). In the Murray and Murrumbidgee rivers, NSW, both fresh and weathered willow leaves (*babylonica hybred)* had higher N and P contents than fresh and weathered river red gum leaves (Esslemont *et al*. in prep) (Table 2). N concentrations were also higher in streams lined with introduced deciduous trees such as oaks (*Quercus* sp), alder (*Alnus* sp.) and chestnuts (*Castanea* sp.) (8.06 $gNm^{-2}yr^{-1}$) than in eucalypt lined streams (2.63 $gNm^{-2}yr^{-1}$) (Pozo *et al*. 1997). Willow leaves (*S. viminalis*) were reported to have relatively higher N concentrations (e.g. up to 1.8% litter dry mass [DM]) (Haapala *et al.* 2001) when compared with grey alder (*Alnus* sp.) leaves that have N-fixing symbionts (2-3% DM) (Haapala *et al.* 2001), and had higher initial N and P concentrations than *Populus* and *Platanus* species (Casas and Gessner 1999). Lester *et al*. (1994b) found that willow leaves submerged in a stream for 56 days possessed approximately three times as much N and carbohydrate, twice as much protein, and similar amounts of chlorophyll *a* as periphyton. This suggests that while willow leaf litter is decomposing, it can contribute to elevated nutrient levels in streams.

Willow leaves have a rapid decomposition rate mainly due to physical abrasion (Schulze and Walker 1997). This can increase nutrient leaching rates within a system with studies showing that as much as three times the amount of soluble nutrients (630 μgg^{-1}) can be leached from physically abraded leaves compared to intact leaves (Cowen and Lee 1973) and this volume can be further increased during flooding events (Glazebrook and Robertson 1999).

Increased nutrient input into streams and rivers can also result from the removal of riparian vegetation zones (Schoonover *et al.* 2005). These zones act as buffers to diffuse and decrease the velocity of surface water runoff and promote infiltration, sediment deposition, and nutrient retention as well as reduce nutrients in groundwater (Lowrance *et al.* 1997, Dosskey 2001). In Cypress Creek, a 2nd order tributary of the Cache River in southern Illinois, riparian buffer zones significantly reduced incoming nutrient masses (nitrate, ammonium, and phosphate) from surface water runoff (Schoonover *et al*. 2005).

High nutrient and light conditions favour the development of filamentous algae which invertebrate consumers do not readily consume (Prosser *et al.* 1999; Bunn *et al.* 1999). The increase of nutrients, namely N and P and filamentous algae can lead to eutrophication, which has been shown to impact negatively on invertebrate shredder taxa (Metcalfe-Smith 1994; Merritt and Cummins 1996) and fish diversity (Sleehausen *et al.* 1997). Eutrophication can also lead to the development of toxic algal blooms which reduce water quality and decrease dissolved oxygen levels (Codd 1995) leading to anoxic conditions that can lead to stress and potential death in aquatic biota (Oliver and Ganf 2000).

Table 2. Nitrogen and phosphorus concentrations in willow and river red gum leaf litter from the Murray and Murrumbidgee rivers. Data are means ± standard deviation.
(Source: Esslemont *et al.* in prep)

Tree	**Leaf Condition**	**N (M.Kg^{-1})**	**P**
Willow	Fresh	0.95±0.16	0.061±0.018
Willow	Weathered	0.82±0.12	0.052±0.011
River Red Gum	Fresh	0.8±0.	0.03±0.01
River Red Gum	Weathered	0.56±0.07	0.028±0.009

7.3.1 Potential Effects of Willow Removal on Nutrients

The removal of willow leaf litter input into streams may reduce high nutrient pulses and overall nutrient levels in streams in the long term, especially in small streams, lotic systems, wetlands or in weir pool environments. This may decrease the potential for eutrophication and toxic algal blooms to occur and has the potential to lead to increased water quality. However, the removal of such a large input of nutrients from aquatic systems could also affect the food source of invertebrate and fish populations. Until alternative vegetation is established, the removal of willows will also remove the riparian buffer, leading to an increase in the amount of nutrients, chemicals and sediment entering the stream, and possibly to a reduction in water quality (Schoonover *et al.* 2005). In large rivers and fast flowing environments it is very hard to predict the effects of willow removal on nutrient levels as leaves would be carried downstream and distributed throughout the system.

8. POTENTIAL EFFECTS OF WILLOW REMOVAL ON ECOLOGICAL PROCESSES

8.1 Organic Inputs

Organic inputs into streams from riparian vegetation provide a strong influence on aquatic community structure and ecosystem processes (Vannote *et al.* 1980; Wallace *et al.* 1997; Casas and Gessner 1999). They provide critical energy sources for aquatic food webs (Boulton and Boon 1991; Gregory *et al.* 1991; Allan 1996) and so underpin the energetics of the stream ecosystem (Webster *et al.* 1997; Wallace *et al.* 1997; Benfield 1997). For example, Fisher & Likens (1973) reported that nearly 99% of the energy in Bear Brook, New Hampshire, was derived from riparian vegetation. Generally the greatest proportion of leaf litter entering freshwater systems comes through the direct vertical input of leaves (i.e. leaf drop through leaf abscission or senescence) and to some extent through lateral inputs (leaf drop through wind, run-off etc.) (Pozo *et al.* 1997; Sabater *et al.* 2001). The quantity and composition of organic inputs is influenced by the age, species and health of the riparian vegetation (Bunn *et al.* 1993).

The dense leaf mass of riparian willows supply large amounts of allochthonous organic matter into streams (Gregory *et al.* 1991). The deciduous nature of willows means that peak litter inputs occur in late autumn (Murphy and Giller 2000; Gawne *et al.* 2002), and smaller pulses of litter inputs may occur in summer during times of low flow as a result of leaf abscission induced by water stress (Sabater *et al.* 2001). Calculations undertaken by Latta (1974) ascertained that 25.5 kg (dry weight) of leaves would be shed in autumn by a willow tree with a diameter of 0.5 m. Therefore, in a given river section with willows spaced at 10 m intervals on both banks, over 5000 $kgkm^{-1}$ would be deposited into the river and onto the banks (Latta 1974). An examination of litter inputs on the Murray River at Albury revealed that willows, comprising 20% of riparian veg, contributed $18g.m^{-2}.y^{-1}$ compared to river red gums (80% of riparian veg) that dropped 50 $g.m^{-2}.y^{-1}$, with willows dropping their litter in autumn (Gawne *et al*. 2002). It was estimated that willows drop 3.5 times the litter of a river red gum.

8.1.1 Potential Effects of Willow Removal on Organic Inputs

The removal of willows from a stream, river or wetland would also be removing the large annual input of organic materials into these systems. In the long term, the removal of this organic input may alter processing rates by resident stream microbes and invertebrates (Petersen *et al*. 1989; Wallace *et al*. 1995; Angradi 1996; Allan 1996), affect stream energetics and be reflected in the composition of the stream biota (Campbell 1993; Schulze and Walker 1997). In reaches where willows are cleared and there is bare bank, gross organic matter accession and in-stream community metabolism and consequently macroinvertebrate communities would be expected to be very different than in reaches with riparian vegetation (Wilson 2001).

8.2 Decomposition

Decomposition of plant litter is a fundamental ecosystem process in a wide range of aquatic systems, including rivers, streams, and littoral zones of lakes (Hieber and Gessner 2002). Leaf litter decomposition rates are regulated by temperature (Suberkropp *et al.* 1975; Peter *et al*. 1987; Legssyer *et al.* 2003), nutrient availability, oxygen availability, current velocity, hyphomycete diversity, the number of invertebrates present and litter chemistry (Chergui and Pattee 1991; Baldy *et al.* 1995). The process of leaf litter breakdown includes both physical aspects including abrasion and leaching and biological aspects including mineralization and modification. These processes lead to the formation of CO_2 and other inorganic compounds, dissolved and fine-particulate organic matter (DOM and FPOM, respectively) and decomposer biomass (Webster and Benfield 1986; Suberkropp 1998; Gessner *et al*. 1999). The biological process of leaf litter decomposition in an aquatic environment is governed by three main type of organisms; detritivorous macroinvertebrates or shredders (Chergui and Pattee 1993; Wallace and Webster 1996), bacteria and fungi (Barlocher 1992; Baldy *et al.* 1995; Suberkropp 1998).

Fungi are the initial colonizers in the leaf litter decomposition process with bacteria following to possibly complement rather than replace the fungi when the leaf material has become partially broken down (Suberkropp and Klug 1976; Baldy *et al.* 1995). Baldy *et al*. (1995) found that fungi assimilated 16% of the initial willow leaf mass (as carbon) into either CO_2 or fungal biomass (mycelial or conidial carbon) after four weeks of leaf submersion in the Garonne River, south-western France.

Leaf litter decomposition rates are strongly influenced by litter chemistry with the initial lignin content of leaves having strong predictive power for decomposition rates in both small streams and large rivers (Gessner and Chauvet 1994; Baldy *et al.* 1995). This was illustrated by Baldy *et al*. (1995) with willow leaves having the lowest initial lignum concentrations (20% of dry mass) as compared to *Populus* and *Platanus* spp. (23% and 30%, respectively), and the fastest decomposition rates. Pidgeon and Cairns (1981) found that *S. babylonica* leaves had practically disappeared 4 weeks after entering the stream and they supported lower numbers of invertebrates than native *Eucalyptus blakelyi* leaves after the 4 week period. Schulze and Walker (1997) found that willow leaves (half life 14-26 days) had a faster decomposition rate than river red gum leaves (half life 27-50 days). Whilst at Sunnyside Swamp in Murray Bridge, SA, Janssen and Walker (1990) found willow leaf litter had lost 65% of its initial weight after 10 weeks, with the most rapid decomposition occurring in the initial four weeks of leaf litter submergence. In comparison eucalypts had lost only 50% after 10 weeks (Janssen and Walker 1999). They suggested that willow leaf litter decomposition occurred predominantly through leaching and abrasion, which accounting for 45% of loss, whilst 25% of the loss was due to invertebrate feeding and other unidentified factors (Janssen and Walker 1999).

The faster processing rates of willow leaves vs. river red gum leaves in the River Murray (Schulze and Walker 1997) may result in willow leaves supplying a pulsed input to the aquatic ecosystem with a low stabilising impact, whilst river red gum leaves, which provide an on-going, low-level nutrient input to the stream that may assist the resistance of the ecosystem to disturbance (Schulze and Walker 1997). River red gum leaves are able to provide habitat for extensive biofilm growth, they are able to support higher diatom abundances than willow leaves, which may enhance invertebrate feeding preference; and they are able to support a higher density of micro-organisms for longer as willow leaves are skeletonised after approximately 8 weeks of submersion (Schulze and Walker 1997).

9. POTENTIAL EFFECTS OF WILLOW REMOVAL ON RIPARIAN VEGETATION

9.1 Riparian Vegetation

Riparian willows that grow at the boundary between terrestrial and aquatic ecosystems play a large role in regulating the transmission of solar energy into streams and rivers. The prolific spread of willows inhibits the regeneration of indigenous plants. Willows can compete for water, nutrients and light with native plants (McLeod *et al*. 2001). They are renowned for their dense canopy which can decrease light access to streams by 80%. The shading and crowding effect caused by mature riparian willows can suppress the regeneration of local plants by natural seeding, reduce growth of existing indigenous understorey plants and prevent the growth and proliferation of aquatic macrophytes (Canfield and Hoyer 1988; Gregory *et al.* 1991). Previous studies have suggested that willow shade prevents recruitment of all but a few shade tolerant species (Frankenberg 1995; Askey-Doran *et al*. 1999) and Patridge (1993) reported that willow species have the capacity to out shade pre-existing native vegetation by ‘overtopping’. Studies have shown that in plots where complete willow removal has been undertaken, herbaceous biomass has almost tripled (750 gm^{-2}) in contrast to control plots (260 gm^{-2}), probably in response to increases in light (Dulohery *et al*. 2000).

The willow’s ability to displace indigenous plants has earned it the status as an ‘environmental weed’. Environmental weeds can invade areas of native vegetation due to their highly competitive qualities and have a tendency to out-compete native plants and replace them over time (Albury/Wodonga Willow Management Working Group 2001). A recent synopsis on the State’s biodiversity listed willows as a serious threat to riparian ecosystems in over half of the State’s bioregions (Gouldthorpe and Gilfedder 2002). For example, in Tasmania over 25 plant species were directly threatened by willow infestations in 2002 (Table 2).

9.1.1 Potential Effects of Willow Removal on Riparian Vegetation

The removal of willows could have both short and long term benefits for the establishment and conservation of native terrestrial and aquatic vegetation if the cleared area is managed in an appropriate manner, including weed and stock control. The removal of the dense canopy shading and crowding effect would provide opportunities for native vegetation to proliferate.

However, the removal of willows could also have immediate negative impacts on vegetation communities. The removal of existing willows can increase herbivore access to seedlings, expose understorey plants and macrophytes to higher light and temperature levels and lower humidity levels (McLeod *et al.* 2001). These changes could lead to a decrease in evapotranspiration and to greater evaporation loss from the surface soil and ground vegetation (McLeod *et al.* 2001). An overall decrease in evapotranspiration would result in the water table rising closer to the surface (Dulohery *et al.* 2000).

The removal of willow canopies also has the potential to facilitate the spread of terrestrial and aquatic introduced weeds (Sattler 1993; Tait 1994; Pusey and Arthington 2003). The proliferation of such weeds can lead to a range of changes in habitat structure (Arthington *et al*. 1983), water quality and food-web composition (Van Kraayenoord *et al.* 1995; Bunn *et al*. 1997; 1998). An increase in in-stream exotic vegetation can alter aquatic habitat by trapping sediment and channalising flows, ultimately leading to channel contraction (Bunn *et al.* 1998). In northern Australia, introduced grasses such as the para grass (*Urochloa mutica*) pose a significant threat to the maintenance of aquatic biodiversity through a range of direct and indirect effects on aquatic environments and their biota (Clarkson 1995).

Following willow removal, control of competition between native and exotic vegetation is usually attempted through a variety of techniques depending on the type of vegetation. Site preparation methods generally endeavour to create a good bed for planting seed or seedlings and suppressing the potential competing vegetation (Clewell and Lea 1989). Hardwood species usually require frequent control of the vegetation during the first few years (Matthews 1989). In particular, seedlings planted in areas recently cleared of willows will have competition from abundant herbaceous vegetation, which is usually controlled by herbicides or mowing (McLeod *et al.* 2001). Establishment of riparian tree plantations without weed control usually is not successful, especially if the site is also fertilized (Hansen *et al*. 1993).

The recoverability of a particular site is related to the condition of the native vegetation present at the site and upstream of it, which provides a source of propagules for natural regeneration. The geomorphic condition of the river reach is also a key to recovery. Once willows and stock have been excluded, riparian native vegetation will often regenerate naturally (Tasmanian Conservation Trust). The Tasmanian Conservation Trust suggests that natural regeneration could be a preferred approach over revegetation because it is more economical, has a higher success rate and achieves greater environmental outcomes, at least in the short to medium term. Of course, the decision to revegetate or to allow natural revegetation to occur would need to be managed on a case by case basis.

Removal of willows can assist in the establishment of native riparian and aquatic vegetation but at the same time can also increase the immediate risk of weed proliferation and of competition between native and introduced species. In the long term, with proper management, the re-establishment of native riparian vegetation should advance the rehabilitation of river environments and provide key functions to aquatic biota (Read 1999). Selective removal of exotic vegetation while restoration is taking place may also ensure a higher success of native vegetation establishment in the long term.

Table 3. Vegetation species directly threatened by willow infestation in Tasmania, 2002.

Threatened species	
Apsley heath *(Epacris apsleyensis)* e	Clasping leaf-heath *(Epacris acuminate)* r
Clubmoss bush-pea (*Pultenaea selaginoides)* v	Common hemp bush (*Gynatrix pulchella)* r
Cranbrook paperbark (*Melaleuca pustulata)* r	Curly sedge *(Carex tasmanica)*
Davies' wax flower *(Phebalium daviesii)* e	Drooping sedge *(Carex longebrachiata)* r
Fennel pondweed *(Potamogeton pectinatus* r	Hairy anchor plant *(Discaria pubescens)* e
Hovea tasmanica	Midlands Wattle *(Acacia axillaris)* v
Mountain sedge *(Carex gunniana)* r	Narrow leaf Pomaderris *(Pomaderris phylicifolia)* r
Native wintercress *(Barbarea australis)* e	Plain quillwort *(Isoetes drummondii)* v
River buttercup *(Ranunculus amphitricus)* r	Rosemary Bertya *(Bertya rosmarinifolia)* r
Sallow wattle *(Acacia mucronata* var. *dependens)* r	Sea clubrush (*Bolboschoenus caldwellii)* r
Small mudmat *(Glossostigma elatinoides)* r	Small-leaf Spyridium *(Spyridium lawrencei)* v
South Esk heath *(Epacris exserta)* e	South Esk pine *(Callitris oblonga)* v
Water woodruff *(Asperula subsimplex)* r	

Status refers to threatened species (as listed on the Tasmanian *Threatened Species Protection Act 1995* or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*) where e=endangered; v=vulnerable, r=rare and * denotes the species is yet to be classified. Source: DPIWE Tas Weed Management Strategy – Gorse, Tas Weed Management Strategy, willows, Tas Weed Management Strategy, blackberry, Tas Weed Management Strategy, Bridal creeper, Tas Weed Management Strategy, serrated tussock, Tas Weed Management Strategy, Boneseed – All in press

10. POTENTIAL EFFECTS OF WILLOW REMOVAL ON AQUATIC FAUNA

Healthy riparian vegetation is an essential component of stream ecosystem processes (Gregory *et al.* 1991; Elmore 1992; Edwards and Huryn 1996; Friberg 1997). The loss or change in riparian vegetation can have a large impact on aquatic fauna and their associated trophic structures (Thompson and Townsend 2003; Danger and Robson 2004). The interaction between the physical effects of willow removal, the possible associated ecological effects and the complexity of food webs and aquatic community structure is diverse and complex. Given this, the removal of willow canopy and root mats could have direct and indirect short-term affects (STA) and long-term affects (LTA) on aquatic fauna.

Four physical factors that may be altered as a direct result of willow canopy removal and which may influence aquatic fauna communities include:

1. Increase in photosynthetically available radiation (PAR) resulting from a decrease in shade (PAR = light) (LTA).
2. Increase in water temperature resulting from a decrease in shade and an increase in PAR (LTA).
3. Removal of above ground foliage and habitat (STA and LTA).
4. Decrease in the amount of organic input entering the water body as a result of removing the annual leaf litter fall (LTA).

Two physical factors that may be altered as a direct result of willow root mat removal and which may influence aquatic fauna communities include:

1. Removal of habitat for bacteria, algae, invertebrates, fish, and birds (STA and LTA).
2. Decrease in the amount of organic input in the water from the decomposition of willow root masses (LTA).

These factors and the effects they can have in a basic aquatic food chain are illustrated in figures 3 and 4. The next two sections of this literature review will discuss the possible effects of willows and willow removal on two types of aquatic fauna, invertebrates and fish.

Removal of Willow Canopy and Trunk

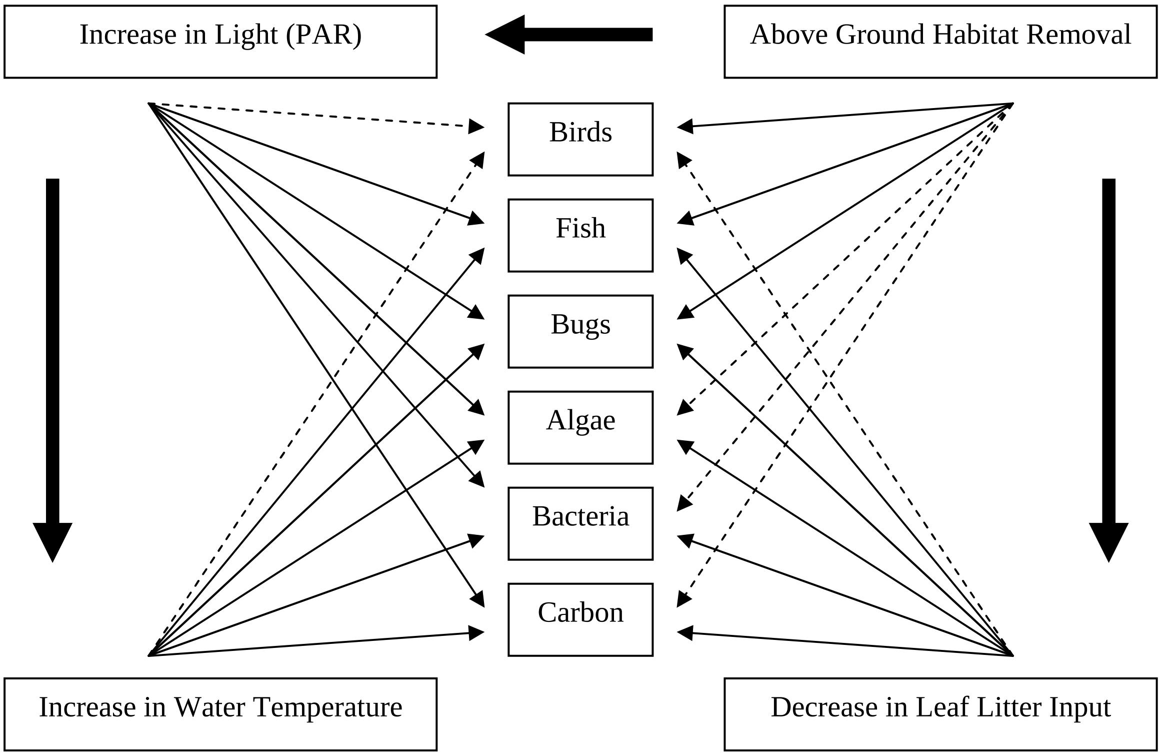

Figure 3. Possible long-term direct (–) and indirect (- -) effects on a basic freshwater trophic chain through an increase in light and temperature, foliage / habitat removal and a decrease in organic input following the removal of willow canopy and trunk.

Removal of Willow Root Mass

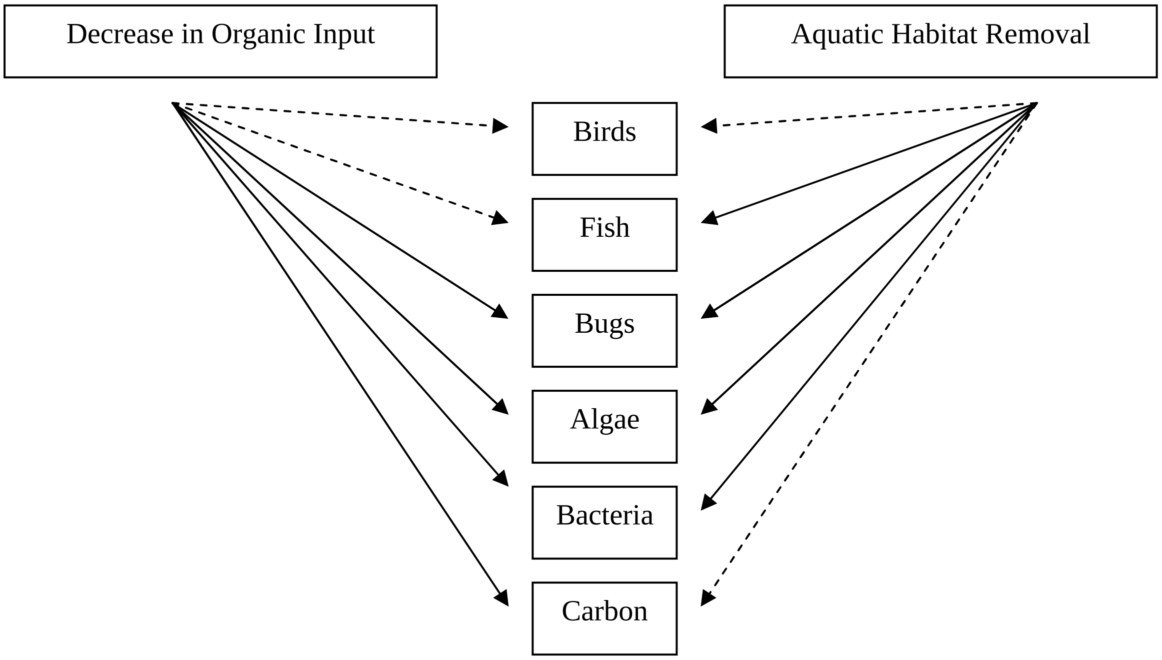

Figure 4. Possible long term direct (–) and indirect (- -) effects on a basic freshwater trophic chain through habitat removal and a decrease in organic input following removal of willow root mats.

11. POTENTIAL EFFECTS OF WILLOW REMOVAL ON INVERTEBRATES

10.1 Background Studies

In streams and rivers, leaf litter from riparian vegetation is a vital source of organic matter, providing energy and nutrients for aquatic organisms. In Australian freshwater systems, the majority of the food supply for aquatic invertebrates is derived from the surrounding riparian vegetation with invertebrates playing a large role in the energy transfer from terrestrial environments to aquatic ecosystems.

In streams and rivers, leaf litter from riparian vegetation is a vital source of organic matter, providing energy and nutrients for aquatic organisms (Wotton 1994; Allen 1995; Yeates and Barmuta 1999). In small streams, the majority of the food supply for aquatic invertebrates is derived from the surrounding riparian vegetation (Cummins *et al.* 1989; O'Connell *et al.* 2000; Sabater *et al.* 2001). In all systems, the movement of invertebrates plays a large role in the energy exchange between terrestrial environments and aquatic ecosystems (Hanlon 1982; Hildrew *et al.* 1984; Chergui and Pattee 1988; Baxter *et al*., 2005).

The extensive invasion of willows into Australian rivers and streams has altered the quantity and composition of this important food supply as well as habitat conditions for invertebrate communities along willow lined regions. While this has raised widespread concern that this change may be detrimental to invertebrate communities, to date there has been no concrete evidence to support this theory. Some international studies have shown that willows can have positive effects whilst others have revealed negative effects on invertebrate assemblages. Australian studies that have directly compared the biota within willow and native tree lined stream reaches have been inconclusive (Pidgeon 1978; Besley 1992; Hardwick *et al.* 1995; Schulze and Walker 1997; Read and Barmuta 1999), with only Pidgeon (1978) showing a notable difference. The study found lower macroinvertebrate biomass and production at willow lined reaches compared to native woodland lined reaches on a Victorian stream.

In the littoral zones of large rivers in the Murray-Darling Basin, numerous studies have shown that invertebrate abundance and assemblage composition is not significantly different at sites lined by willow or native trees (Besley 1992; Hardwick *et al.* 1995; Schulze and Walker 1997). In the River Murray, South Australia, Schulze & Walker (1997) found no significant differences in invertebrate diversity or species assemblages between sites lined with willows (*Salix babylonica*) and river red gums. Whilst in New Zealand streams, Glova and Sagar (1994) found benthic invertebrate species richness and diversity to be greater in willowed verses non willowed stream sections. In their native environments, willows have been shown to support high numbers of arthropods when compared to alien species. Five native willow species in Great Britain hosted 450 insect and mite species compared to 22 species supported by introduced plant species. (Kennedy and Southwood 1984). Whilst in Northern California, the abundance and diversity of aerial and ground-foraging invertebrates in introduced vegetation was half of that compared to native willows (Herrera and Dudley 2003). Furthermore, studies have shown that willows in their native environment support rich assemblages of specialist arthropod consumers (Stein *et al.* 1992; Preszler and Price 1993; Declerck-Floate and Price 1994; Hjalten and Price 1996).

In contrast, Pidgeon (1978), in Pidgeon and Cairns (1981) proposed that, in Australian streams, willows may support a lower diversity of aquatic invertebrates than native vegetation due to their possible role in reducing water velocity, increasing sedimentation (Minshall 1984), decreasing primary productivity (Boston and Hill 1991), reducing summer food supplies (Lester *et al.* 1994a) discouraging species attracted to light (Behmer and Hawkins 1986) and leaching inhibitory chemicals from the leaves, bark or rootlets (Pidgeon 1978; Pidgeon and Cairns 1981).

Lester *et al*. (1994a) also suggested that willows may affect aquatic invertebrates by modifying food supplies (decreasing sunlight and discharging autumnal input of leaves) or habitat (reducing substrate particle size and reducing flow). His studies on two New Zealand streams found that willow (*S. fragilis*) dominated streams supported relatively few invertebrates and that invertebrate biomass and density was significantly lower in willow-lined sections of the streams than in nearby open sections in summer, autumn, and winter. Lester *et al*. (1994a) concluded that the presence of riparian willows was clearly associated with a reduced total macroinvertebrate abundance and biomass.

Lester *et al*. (1996) supported this earlier research with results showing a reduction in macroinvertebrate densities in densely lined willow sections in Heeney Creek, New Zealand. Similar effects showing a decrease in invertebrate abundance associated with willows has also been reported in other New Zealand stream studies (Allen 1951; Glova and Sagar 1994) and overseas studies (Hughes 1966; Behmer and Hawkins 1986).

The vast differences in current literature make determining the possible effects of willow removal on invertebrate communities in Australia difficult. It is clear, however, that willows have a significant effect on habitat, light penetration and hence water temperature and organic matter inputs to streams all of which would be expected to have an impact on the invertebrate community. The following sections will examine each of these changes in detail.

10.2 Habitat

In the Ovens River, NSW, no immediate differences in macroinvertebrate assemblages were found in de-willowed sites where root mats were left intact (Gawne *et al*. 2005). However, the sudden removal of root mats may disrupt the invertebrate communities which utilise the roots as habitat. Willow roots within a New Zealand stream were found to provide a stable habitat to large numbers of the snail *Potamopyrgus antipodarum* (Winterbourn 1970), whilst Linklater and Winterbourn (1993) found abundant *Pycnocentria forcipata* trichopteran shredders amongst root mats in a similar stream. Therefore leaving the root mats in place after removing the willow canopy and poisoning the willow stump may provide less of a system shock and a subtler difference in habitat change over time as the root mass slowly decomposes.

The removal of root systems can also have long term impacts on aquatic invertebrate communities due not only to loss of habitat but also to potential increases in substratum size. Root masses from densely lined willow stream and river stretches can reduce water velocity leading to increased sedimentation and a smaller average substratum size (Young 1980). Lester *et al.* (1994a) found that willow roots tend to wrap around rocks and occupy interstitial spaces, locking in sediment so that the entire width of a stream becomes highly silted. Decreased substratum size is generally observed to be associated with a decrease in invertebrate density (Minshall 1984) as would be expected as the action would deny animals access to the interstitial spaces between stones (Lester *et al.* 1994a). Lester *et al.* (1994a) stated that this action may well be the most important process in determining invertebrate abundance. Therefore although removal of a whole willow tree including root mats may cause an initial disturbance to invertebrate communities, perhaps the long term benefits of a possible increase in substratum size (this would need to be investigated) following root removal may provide justification for such drastic action.

The management of root masses during willow removal will affect the magnitude of the disturbance and may affect the pathway to a more natural condition. Root masses (if poisoned upon willow canopy removal) may decompose within 5-10 years (R. McConville 2006, Ginninderra Catchment Group, pers. comm.) which would allow a gradual change of physical habitat for invertebrates as well as a possible gradual increase in substratum size.

10.3 Light and Water Temperature

Water temperatures influence the growth and development of aquatic insects (Butler 1984). The possible increase in water temperature following the removal of willow canopy may increase in-stream primary productivity, therefore affecting the primary production of the system (Boston and Hill 1991). Also the heavy shade cast by willow canopy does not offer the light required for the provision of high quality food such as algae for invertebrates (Bunn *et al.* 1999). There is potential therefore, for the increased light resulting from willow canopy removal to cause changes in periphyton composition and an increase in biomass thereby altering the long term macroinvertebrate community composition, productivity or abundance (Behmer and Hawkins 1986; Feminella *et al.* 1989; Plafkin *et al.* 1989; Van Kraayenoord *et al.* 1995).

One New Zealand study found that shade was associated with a reduction in invertebrate taxonomic richness (Quinn *et al.* 1997). This study, conducted in the Mangaotama Stream in New Zealand, found total invertebrate and chironomid densities declined with increasing shade from 60 to 90%. The study also undertook shade cloth experiments, in which a marked decline in invertebrate taxa richness was found under 90% and 98% shade as compared to no shade or 60% shade. Dense willow canopy can actually reduce stream light by up to 80% (Lester *et al.* 1994a), which related to the above findings may influence invertebrate communities in densely lined willow river sections. This would need to be taken into consideration when removing willow canopy as the change in light concentrations and possible long term temperature alterations could impact on the existing invertebrate community.

10.4 Organic Input

Willow litter falls occur in late autumn when the whole canopy sheds (Murphy and Giller 2000) as compared to river red gum trees which have peak litter falls in late summer but still retain a large proportion of their canopy (Boulton 1991; Barlocher and Graca 2002). The removal of willows may have long term effects on the amount of litter falling into the stream. This would need to be considered for insects that feed on willow leaf litter, or that have adapted to using willow litter for habitat such as the Caddisfly Oecetis (Gawne *et al.* 2005) and also on the change in amount of nutrients and other chemicals reaching the system (e.g. Rowell-Rahier 1984; Tahvanainen *et al.* 1985; Julkunen-Tiitto 1985; Haapala *et al.* 2001)

Many studies have demonstrated that willow leaves are palatable to biota in Australian and New Zealand streams (Pidgeon and Cairns 1981; Lester *et al.* 1994a; 1994b; Schulze and Walker 1997). For example, Pidgeon and Cairns (1981) found that willow litter was just as palatable to invertebrates as native litter. Parkyn and Winterbourn (1997) found high densities of shredders and non-shredders colonising willow leaves in a small South Island stream in New Zealand suggesting that willow leaves were an adequate food and habitat source for invertebrates. Lester *et al.* (1994b) found that willow leaves were broadly used both directly and indirectly as a food source by organisms of all functional feeding groups in all seasons in willow lined reaches of two Central Otago streams in New Zealand. Whilst in Central

Finland streams, Haapala *et al.* (2001) found no significant differences between willow leaves and Alder and Birch leaves as a food source for shredders.

In fact, some Australian and New Zealand studies have concluded that willow litter is not only palatable, but can be a preferred food source for aquatic macroinvertebrate communities (Lester *et al.* 1994a; 1994b; Schulze and Walker 1997). For example, Lester *et al*. (1994b) concluded that leaves of introduced willows can provide a preferred food source for macroinvertebrates in New Zealand streams. The detritivore larvae examined in the study, *Olinga*, showed a clear preference for 56-day-incubated willow leaves over willow leaves incubated for a shorter duration or periphyton made up of diatoms and some filamentous algae (Lester *et al.* 1994b). Yeates and Barmuta (1999) found each of the three macroinvertebrate species examined, *Notalina* sp., *P. gibbosa* and *Koorrnonga* sp., had a strong preference for green willow leaves and two of the species *Notalina* sp. and *P. gibbosa* grew at a faster rate on a green willow leaf diet than that of a native white gum (S. *fragilis* L.) or manna gum (*Eucalyptus viminalis* Labill.) diet.

Upon entering the stream, willow leaves rapidly leach important nutrients such as nitrogen (N) and phosphorus (P), reducing sugars, amino acids and phenolic compounds (Iversen 1974; Gessner and Schwoerbel 1989). Lester *et al*. (1994b) found that 56-day incubated willow leaves possessed approximately three times as much Nitrogen (N) and carbohydrate as periphyton, twice as much protein, and similar amounts of chlorophyll *a.* The consumption rate of leaves and the growth rate of invertebrates has been shown to be positively correlated with either the N content of leaves (Iversen 1974; Irons *et al.* 1988), or the leaf protein content (McMahon *et al*. 1974). Willow leaves are thus likely to contribute large amounts of nutrients to streams (Lester *et al.* 1994b) which provide important nutrition to the benthic microbial community which can rapidly absorb them (Lock and Hynes 1976).

Although willow leaves can provide an attractive food source for invertebrates, they also contribute large amounts of chemicals including tannins, catechins, phenolics and phenolic glucosides (Julkunen-Tiitto 1985) which may inhibit feeding behaviour in invertebrates (Rowell-Rahier 1984; Tahvanainen *et al.* 1985; Tahvanainen *et al.* 1985; Julkunen-Tiitto 1985; Ostrofsky and Zettler 1986; Irons *et al.* 1988; Lester *et al.* 1996;

Haapala *et al.* 2001) or may impede microbial conditioning processes (Chergui and Pattee 1993; Yeates and Barmuta 1999). For example, Julkunen-Tiitto (1985) found high concentrations of phenolic compounds in leaves of the European willow species *Salix viminalis, Salix phylicifolia, Salix myrsinifolia,* and *Salix aquatica* whilst Haapala *et al.* (2001) found willow leaves had significantly higher tannin concentrations than both Alder and Birch leaves in a Central Finland stream.

Following submersion, willow leaves release these compounds at an initially rapid rate. Lester *et al.* (1994b) found that the phenolic compounds in willow leaves were leached quickly during the first week, after which they decreased at a slower rate until day 56 when the majority of phenolics had dissipated. This high initial release of phenolic concentrations into aquatic environments may cause willow leaves as a food source to be rejected initially. This proposal is further supported by invertebrate food preference studies which have found that willow detritus becomes more appealing to invertebrates after it has been submerged for some time (Collier and Winterbourn 1986; Chergui and Pattee 1993; Lester *et al.* 1994b) as it allows the removal of harmful secondary compounds such as phenolics.

Yeates and Barmuta (1999) stated that although willow leaves could provide a favoured food source for invertebrates, this source would be available for a shorter time than native eucalypt detritus. This may be a result of the possible initial rejection of willow leaf litter, coupled with the rapid decomposition rate of willow leaf litter following submergence (see section 8.2).

Lester *et al*. (1996) proposed that the effects of such chemicals from decomposing willow detritus were more important in determining macroinvertebrate densities than either substrate type or shade concentrations. However, studies have also revealed that river red gum leaves contain high levels of tannins (Campbell and Fuchshuber, 1995) that are toxic to some animals, including certain fish (Gehrke *et al*. 1993) and molluscs (Cheuiryot *et al.* 1981; Hammond *et al.* 1994). Therefore careful management recommendations need to be made if the possible effects of leached phenolics to aquatic ecosystems are to be used as an argument for willow removal.

The removal of willows, therefore, may represent a reduction in food availability for some macroinvertebrates until the riparian canopy is replaced. The extent to which the change in food availability would affect the invertebrate community is difficult to determine for several reasons including;

- The timing and duration of the pulse means that it may not be a significant food source on an annual basis.
- The change in algal productivity that is likely to occur with willow removal may offset the reduction in leaf material for generalist feeders.

10.5 Conclusion

Having outlined the possible effects of willow removal on invertebrate communities, it must be stated that these are effects have the potential to, but may not actually occur following willow removal. There is strong debate in the current literature as to the effects of willows on invertebrate communities and a general lack of literature stating both the short and long term effects of willow removal on invertebrates. Therefore the exact response of an aquatic ecosystem to the removal of willows, be it just the canopy or the whole tree, is largely unknown and difficult to accurately predict. It is clear, however, that willows affect habitat, light penetration and hence water temperature and organic matter inputs to streams all of which affect the invertebrate community. These effects may be negligible, positive or negative depending on circumstances and management objectives. Because invertebrates play a crucial role in the food web, changes in the composition and abundance of invertebrate assemblages may have impacts on other elements of the system. These effects have not, however, been examined in Australian systems. Therefore if a de-willowing operation is to occur, consideration of the effects on habitat, light, temperature and organic inputs should all be considered. Ideally this would include consideration of the treatment of the root mass and the type of vegetation that will be established in place of the willow tree.

12. POTENTIAL EFFECTS OF WILLOW REMOVAL ON FISH

11.1 Background

The riparian zone has a profound influence on riverine fish communities through a variety of direct and indirect linkages (Pusey and Arthington 2003). Direct effects include organic input (food and habitat availability) and light and water temperature regulation (thermal regimen) (Pusey and Arthington 2003). Indirect secondary effects may potentially be realized at many different levels, and can range from 'individual reproductive success' which includes effects on mate recognition, egg and larval survivorship and predator avoidance, through to 'assemblage level effects' due to influences of riparian vegetation on habitat structure and trophic dynamics (Pusey and Arthington 2003). In addition, there is also the potential for an assortment of tertiary impacts to occur which are controlled by both the direct and indirect impacts of fish on other organisms (Pusey and Arthington 2003) (i.e. trophic cascades; (Nakano *et al*. 1999).

Changes in riparian cover have the potential to have a strong effect on fish community composition and characteristics. This includes alterations in species biomass, abundance and richness (Pusey *et al*. 1993; Amour *et al.* 1994; Pusey *et al*. 1995; 2000; Marsh-Matthews and Matthews 2000) and fish assemblages will only recover when riparian integrity is re-established (Penczak 1997). In Australian streams and rivers, the invasion of willows may have altered the composition of many fish assemblages. The removal of willows may represent an important step in restoration but could, in the short term, disrupt current processes in willow lined stream and river stretches. This could result in both short and long term effects on fish population characteristics through an alteration of fish habitat, changes to light penetration, water temperature and food availability.

11.2 Habitat

The immediate effects of willow removal on fish communities may be more noticeable in highly regulated sites (e.g. weir pools). In weir pools, the altered hydrology means that the natural variation in water levels no longer occurs, and willows are well adapted to such stable water conditions. As such willows are generally found to be abundant and healthy in weir pool sites, whereas native trees may find the permanently inundated conditions associated with the stable water levels stressful. In the absence of natural habitat willows may provide a stable habitat to fish. In the Mildura Weir Pool on the River Murray, zooplankton diversity and fish abundance was greatest in the willow-dominated habitats with most small fish found under overhanging willow canopy within the weir pool main channel (Scholz and Davey 2004). Further studies conducted in the Mildura Weir Pool using split beam hydro acoustics to detect fish numbers showed that larger numbers of small fish were found in the bank vegetation during the day as opposed to at dusk when most fish were found in the open waters (V. Matveev 2006, CSIRO Land and Water, pers. comm.). These findings may suggest that the abundance of zooplankton associated with willows in weir pool environments may provide a potential food supply to fish and that the protective dense canopy may provide an excellent diurnal resting habitat for fish communities which may feed nocturnally.

Fish communities in open sites, downstream from willow lined stream or river reaches, could also benefit from willows. Koehn (1987) found native fish numbers increased by a factor of six in the Ovens River, Victoria as a result of willow debris accumulation at a previously open site. In Little Topashaw Creek, Mississippi, the average number of fish species per 150-m reach increased in all three zones (upstream, within the treated reach, and downstream) following debris addition (Shields *et al.* 2003). The study also found relatively large changes in fish numbers, biomass, and species richness observed in the downstream reach which may have been due to the export of benthic drift and organic matter from the treated reach (Shields *et al.* 2003). Thus the impact of willow removal on fish populations should be considered not only in the immediate area of the willows, but also downstream of the willow removal site, especially if there are open areas.

Large woody debris (LWD) within rivers and streams provides ideal habitat and hiding places for invertebrate and fish species. LWD also plays a vital role in retaining particulate organic matter (Bilby and Likens 1980), supplying substrate for the production of biomass by benthic macroinvertebrates (Benke *et al.* 1985), and encouraging higher levels of invertebrate species abundance and diversity (Cooper and Testa 1999) which provides increased food sources for fish communities. LWD provides higher levels of physical diversity from the creation of flow acceleration and deceleration zones (Shields and Smith 1992), which are important to fish communities (Cooper and Testa 1999; Warren *et al*. 2002).

Willows do not provide a good supply of LWD as they have brittle branches which break off and either float downstream or due to their low lignum content decompose rapidly. While live willows may provide good habitat, once dead the material does not persist. As a consequence, removing willows may reduce habitat but the supply of LWD to rivers will take a considerable time to recover due to the slow growth rate of large trees such as river red gums.

During a de-willowing operation, it must also be carefully considered whether to remove the whole tree, or just to remove the canopy and leave the willow roots in tact. The thick root mats formed by riparian willows can play an important role in the formation and maintenance of habitat for fish (Van Kraayenoord *et al.* 1995). Adult stream fish may use the roots as a habitat source (Pusey *et al.* 1998), whilst exposed roots could be used as a spawning substrate and larval habitat (Pusey *et al.* 2001a;. 2001b). The removal of such habitat could cause short term effects on local fish assemblages if they have specific breeding requirements and a lack of vegetation to meet those requirements in the given area.

11.3 Light

Shade can play a large role in habitat structure and diversity of habitats in aquatic environments. Fish utilise shade both as a refuge from predation and as an area to hide in and launch predatory attacks from (Helfman 1981). The removal of a willow canopy and the resulting light increase can have detrimental impacts on fish assemblages. Predator/prey dynamics could be shifted in favor of predator species (Van Kraayenoord *et al.* 1995), and due to increased ultraviolet (UV) B irradiation, increased egg, embryo and larval mortality may occur (Gutierrez-Rodriguez and Williamson 1999).

Increased light concentrations from canopy removal can also shift primary production away from unicellular microalgae to filamentous green algae, therefore reducing food sources for invertebrate secondary producers (Bunn *et al.* 1999) and so potentially lowering food availability for fish communities. This may be balanced out by possible increased stream productivity as a result of increased light availability. Broad *et al*. (2001) found longfin eels further upstream in willow sites were smaller than in pasture or native vegetation in New Zealand streams. One suggestion was that perhaps shading by willows has a strong negative effect on stream productivity in smaller streams (Broad *et al.* 2002).

Increased light conditions can also lead to lead to the growth of submerged macrophytes. Macrophytes play a vital role in fish communities, providing important habitats for fish and larvae (Pusey *et al.* 1993; Kennard 1995; Pusey *et al.* 1995; 1998; 2000; 2001b), valuable spawning substrates for many tropical fish species (Pusey *et al.* 2001a) and acting as refuges from both predation and high water velocity (Mittelbach 1986; Losee and Wetzel 1993).

The quality and quantity of macrophytes which colonise an area following canopy removal will influence fish communities. Increased light conditions can lead to changes in the plant community that may have either beneficial or negative effects on fish. An example of a negative effect is the proliferation of exotic macrophytes such as invasive grasses (Pusey and Arthington 2003) that can reduce habitat diversity, alter the food-web structure and facilitate invasion by exotic fish species (Mackay *et al.* 2001; Pusey and Arthington 2003). Therefore, the impact of willow removal on fish communities will depend, in part, on the vegetation community that establishes at the site.

11.4 Water Temperature

The decrease in stream shade following willow canopy removal can lead to increased summer water temperatures, the extent depending on stream size, depth and flow. Although there is no literature showing the direct link between willow canopy removal and fish assemblages, there is the potential for both short and long term effects to occur if stream temperatures increase. Water temperature can play a critical role in fish assemblages as it directly controls basal metabolic rates (e.g. minimum energy required to survive) which influence growth rates and the allocation of resources for reproduction. Both these factors can have consequences for survival rates and so in the long term can affect population size (Jobling 1995; Pusey and Arthington 2003).

Water temperatures also have the ability to affect disease resistance in adult fish (Pusey and Arthington 2003), tolerance to environmental stressors, such as decreased dissolved oxygen (Llewellyn 1973; Pearson and Penridge 1992) and the embryonic development, hatching time and development of fish larvae (Llewellyn 1973). In shallow or low flow areas where the possible increase in temperature following canopy removal may occur at a faster rate, especially during summer months, these effects are likely to be experienced very shortly after disruption to the riparian zone and may initially be quiet harsh (Van Kraayenoord *et al.* 1995). Long term effects associated with changes in growth, fitness and habitat selection are more likely to occur over a gradual time period and to persist in importance for a longer time as fish communities adjusts to reflect changed habitat conditions (Van Kraayenoord *et al.* 1995).

Such effects have the potential to alter patterns of fish microhabitat use (McCauley and Huggins 1979; Matthews 1998) as well as the distribution of fish at both small and large spatial scales (Van Kraayenoord *et al.* 1995). These effects may also be heightened in small streams with little flow or in wetlands. The effectiveness of dense shade in reducing water temperatures in small streams was evident in a study conducted by Rutherford *et al*. (2004) in Western Australia and south-east Queensland. The study found that temperatures increased by 4-5^{o}C from patches of dense riparian shade to unshaded stream sections in 2nd order headwater streams. The effect of canopy removal on temperature changes should thereby be given special consideration in small streams and wetlands.

11.5 Conclusion

The direct impacts of willow removal on fish assemblages in Australian streams and rivers are unknown. However, given the literature on the role that willows can play in fish communities through habitat, shade, temperature and feeding effects, it can be stated with some confidence that the removal of these trees can have both long and short term impacts under certain environmental conditions. These include reducing potential fish habitat, creating new habitat, affecting fish mate finding and predator evasion, and impacting on egg, embryo and larval growth and survivorship rates. These detrimental effects are likely to be more significant in small streams or situations where willows represent the only source of shade or habitat. These factors would all need serious consideration if large scale willow removal was to be undertaken, especially in regulated weir pool sites, shallow, slow flowing streams and wetlands.

13. WILLOW REMOVAL – A SUMMARY OF POTENTIAL AFFECTS

It is very difficult to predict the potential long term effects of willow removal, be it just the canopy or the whole tree, on aquatic processes. The relationship between riparian vegetation and the aquatic system is very complex and many factors can influence aquatic processes. In a simple system, the removal of willows on aquatic processes could be summarised as shown in table 3.

Table 4. Potential long term effects of willow removal on aquatic processes.

Part of willow removed	**Process**	**Potential effect**
Root mat	Channel morphology	? Change
Root mat	Bank erosion	? Increase
Root mat	Sediment size	? Increase
Canopy	Light levels	Increase
Canopy	Temperature	Increase
Canopy	Nutrient input	Decrease
Canopy	Organic input	Decrease
Canopy	Understorey vegetation	Increase

For invertebrates and fish, this is a far more complex process. The above factors all affect invertebrate and fish communities so not only do direct influences of willow removal need to be considered but also secondary and tertiary influences. The removal of just the canopy or the canopy and roots also makes a significant difference to these effects. Figures 5 to 8 attempt to summarise the potential effects of removing willow canopies and root systems on invertebrate and fish communities.

INVERTEBRATE COMMUNITY

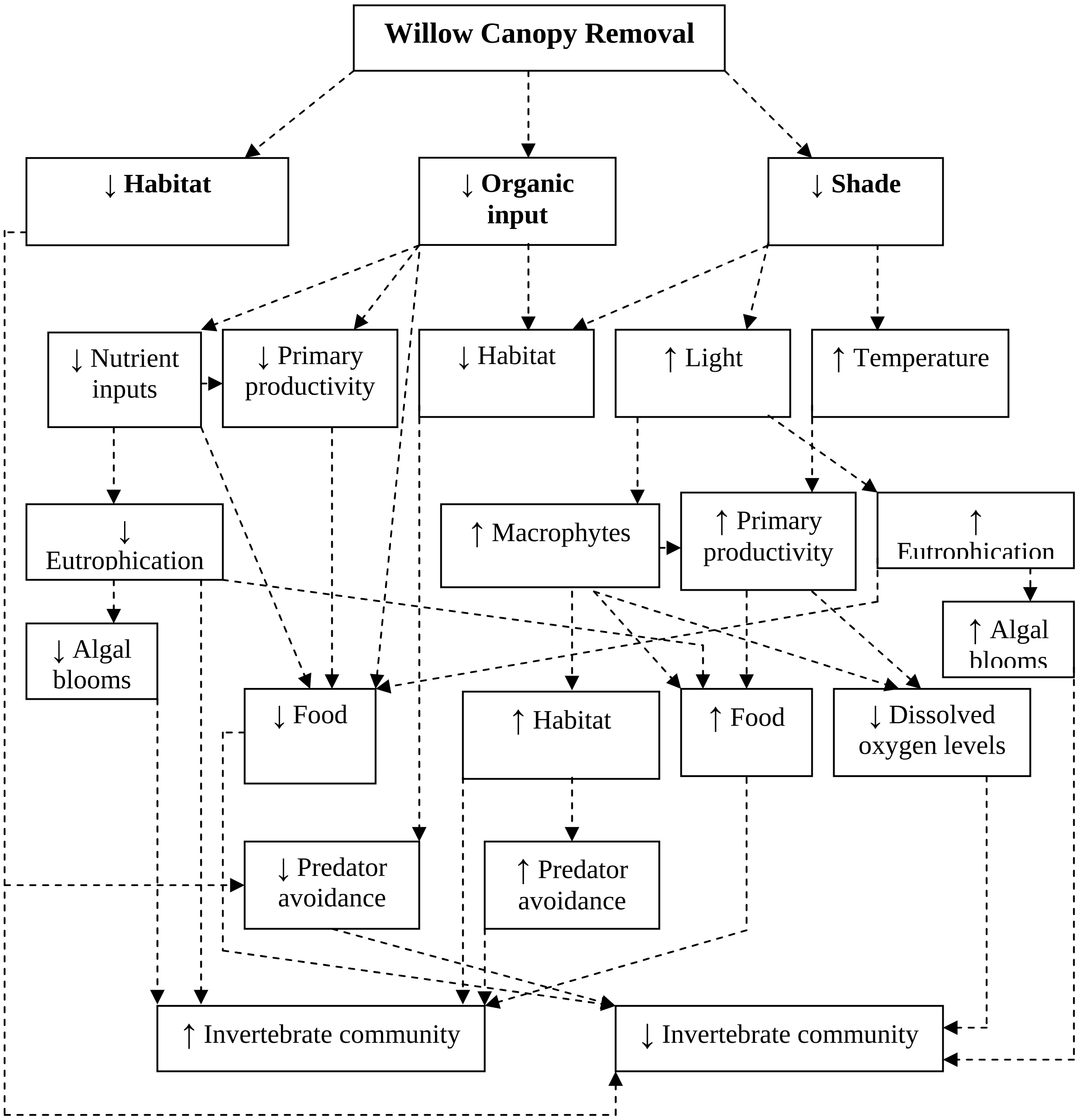

Figure 5. Potential effects of willow canopy removal on an aquatic invertebrate community.

INVERTEBRATE COMMUNITY

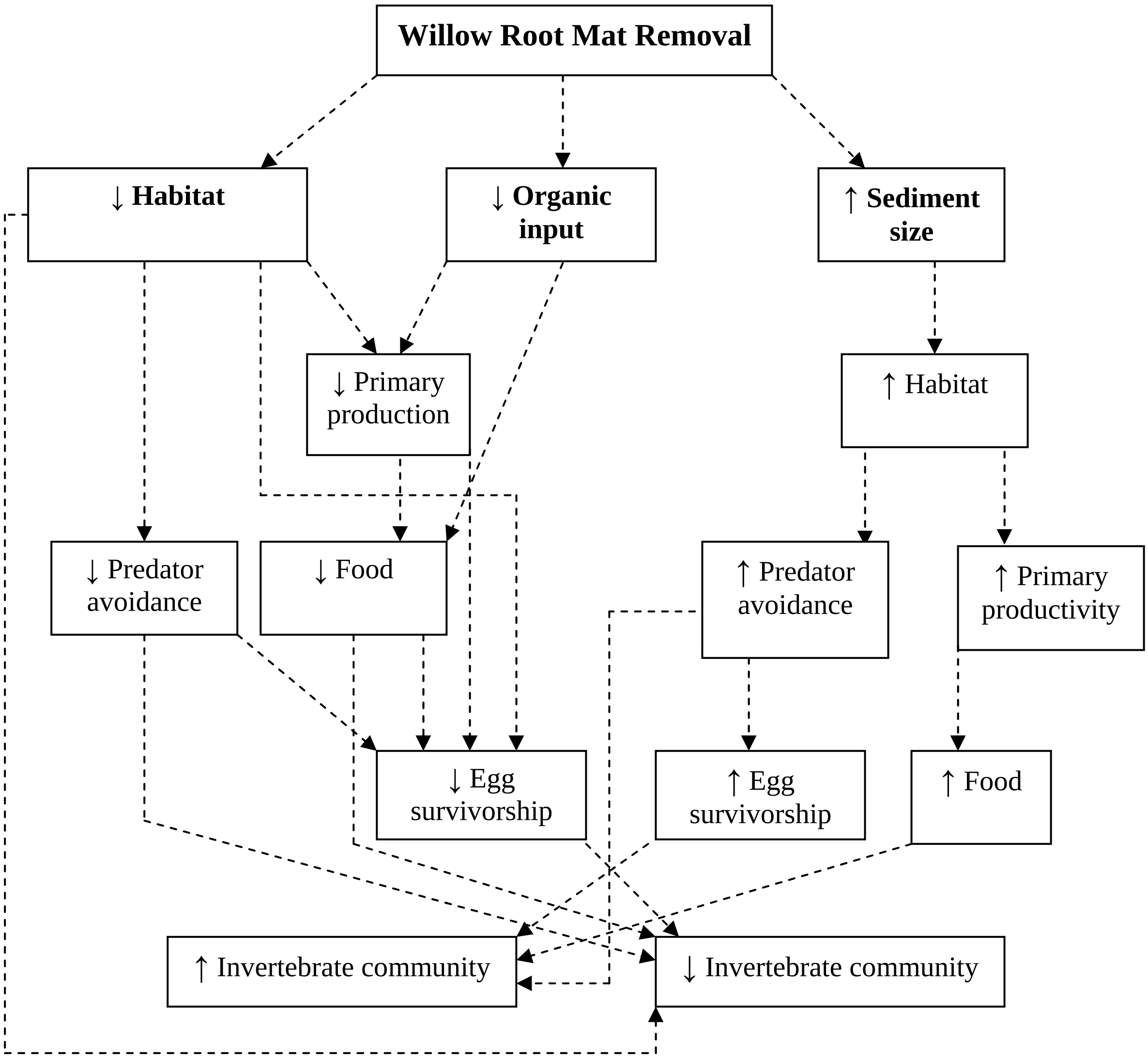

Figure 6. Potential effects of willow root mat removal on an aquatic invertebrate community.

FISH COMMUNITY

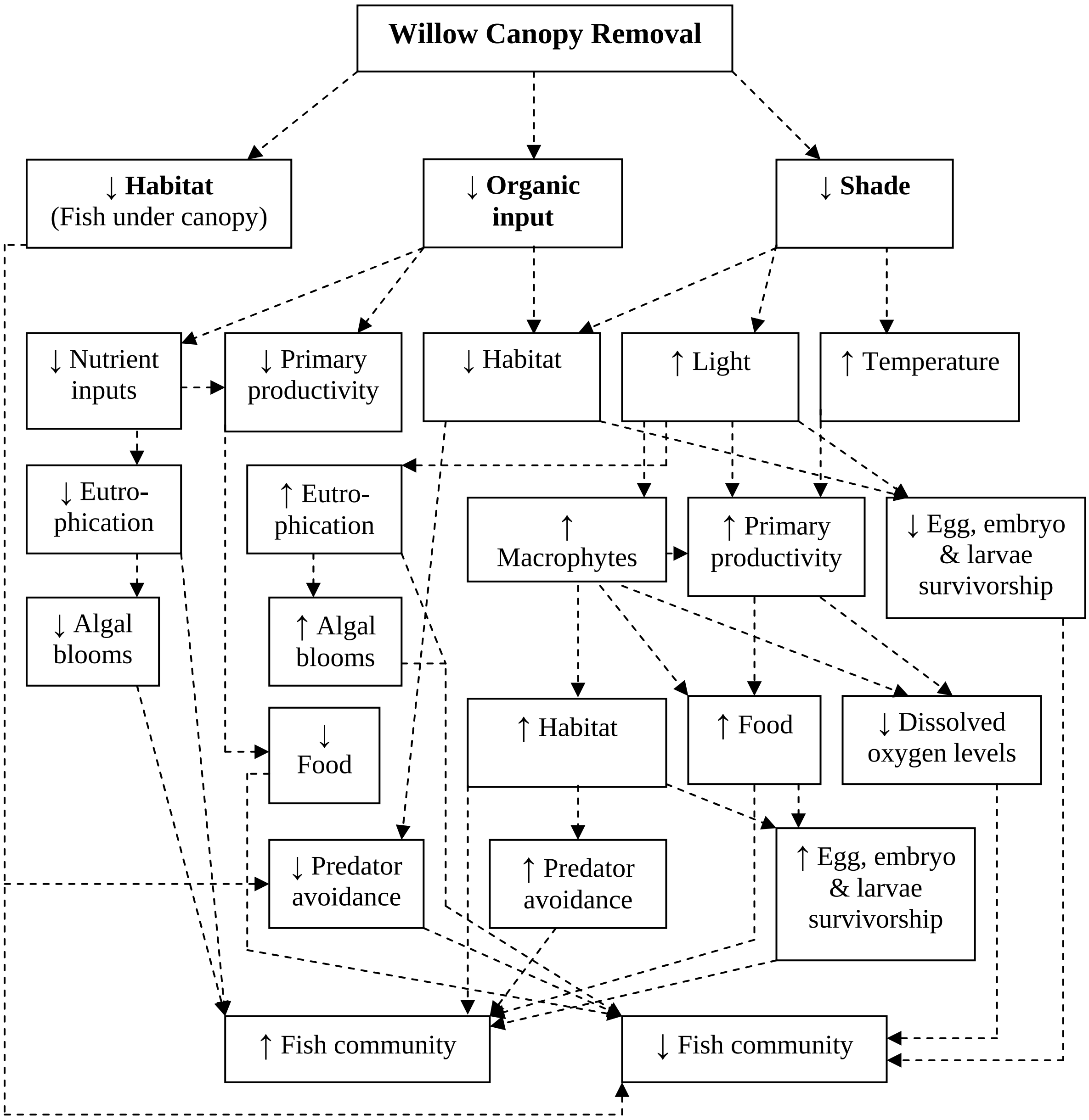

Figure 7. Potential effects of willow canopy removal on a fish community.

FISH COMMUNITY

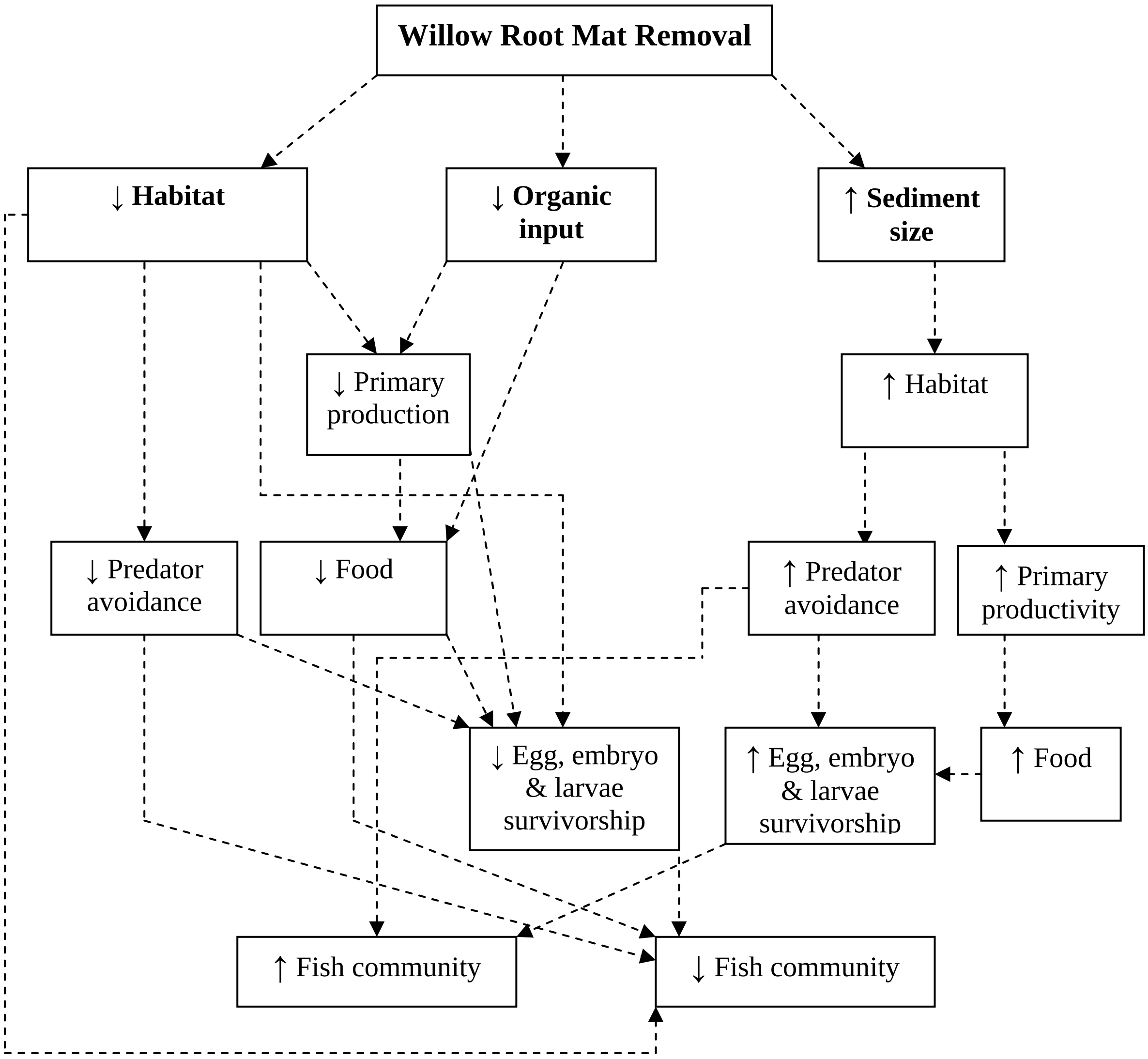

Figure 8. Potential effects of willow root mat removal on a fish community.

14. WILLOW MANAGEMENT

The decision to remove, leave or otherwise manage willows in Australian streams, rivers and wetlands is a much debated topic between natural resource managers, academics and the broader community. The debate is complicated due to the large knowledge gaps and inconclusive and conflicting findings on the effects of willows on aquatic biota and a lack of literature on the effects of removing willows from aquatic ecosystems.

The ongoing extent of willow invasion and the large scale movement of asexual propagules downstream from existing stands means catchment and regional planning strategies are particularly relevant. Priority setting requires quantitative knowledge of impacts, costs and benefits from willow invasion and willow removal at both reach and catchment scales (Wilson 2001). In addition, catchment managers require access to knowledge that will enable willow removal to be undertaken in a manner that minimises detrimental short term impacts and accelerates recovery of the system.

Determining levels of acceptable and unacceptable change to a range of variables influenced by riparian willows would need to be addressed. These should include litter quality and quantity, in-stream community metabolism, channel aggradation, LWD dynamics, riparian DOM sources, thermal regulation and macrophyte, invertebrate and fish communities each of which can be strongly influenced by riparian vegetation. Changes to any of these variables could be beneficial or detrimental depending on the context. The Draft Australian Water Quality Guidelines for Fresh and Marine Water (ANZECC 1998) provides a potentially useful framework that could be applied to willow research and management. The adoption of rigorous experimental designs such as MBACI (or ‘beyond-BACI’), (Underwood 1997; ANZECC 1998) that target key parameters most likely to be influenced by willow removal (Wilson 2001) would be beneficial to address knowledge gaps.

An additional multi-disciplinary challenge is thus to determine when a change in a parameter is beneficial and when detrimental. Quantifying the impacts of willows and willow removal at multiple levels of ecosystem organisation and evaluating under which circumstances such changes are beneficial or harmful is a complex combination but one which is necessary to provide management direction (Wilson 2001).

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