CHAPTER 7

Wood and other aquatic habitat

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Summary

~ Riparian vegetation increases stream channel complexity and directly contributes to aquatic habitat through inputs of logs and branches. In turn, the provision of complex habitat has a major influence on aquatic biodiversity.

~ Logs and branches can enhance stream stability, regulate sediment transport and exert significant control on channel complexity in bedrock rivers and channel geomorphology in alluvial rivers.

~ Logs contribute to the formation of physical features in streams, such as scour pools and channel bars, which serve as habitat for in-stream biota.

~ Logs provide physical habitat for biota at all levels of the food chain, ranging from microscopic bacteria, fungi and algae, to macroinvertebrates, fish and turtles.

~ Logs also provide sites where bacteria, fungi and algae can process carbon and other nutrients such as nitrogen and phosphorus, thus contributing to ecosystem processes such as productivity and respiration.

~ In alluvial rivers, logs can modify surface water/ground water exchange and enhance nutrient processing.

~ Logs from Australian riparian zones are relatively immobile. Our streams tend to have a low average stream power, the wood has a high density and many riparian trees have a complex branching structure that ensures they are easily anchored in position.

~ Although vast amounts of wood have been removed from many Australian rivers, what does remain provides important habitat for microbes, invertebrates, fish and other animals.

~ Retention and reinstatement of logs should be a priority for river rehabilitation, instead of removal or even realignment.

7.1 Woody habitat

What is woody habitat?

Several interchangeable terms are often used to describe wood material in rivers and streams, which is made up of the sticks, branches, trunks and whole trees that enter the channel from the riparian zone or floodplain. The scientific literature often refers to this material as either coarse woody debris (CWD) or large woody debris (LWD). This is in keeping with the accepted nomenclature for describing organic matter particle-size fractions; that is, dissolved organic matter (DOM), fine-particulate organic matter (FPOM), coarse-particulate organic matter (CPOM) and LWD.

Another term commonly used in Australia is 'snag', although this typically refers to a complex structure that generally consists of very large, highly branched debris. Recently, the term 'structural woody habitat' (Gerhke & Brooks 2003, Koehn et al. 2004, Howell et al. 2004) has been used, in an attempt to encapsulate the structural as well as the ecological attributes of wood in streams. Throughout this chapter we have used the term wood or woody habitat, in line with recommendations made by Gregory et al. (2003) to refer to logs and branches in streams and rivers that have been derived from riparian and floodplain vegetation. We have deliberately avoided the term 'debris' or 'snag' because of their negative connotations (see Cottingham et al. 2003).

Logs and branches are a significant ecological component of streams and rivers, both in Australia (Lloyd et al. 1991, O'Connor 1991a, Gippel et al. 1996a) and overseas (Marzolf 1978, Bilby & Likens 1980, Benke et al. 1985). This material forms an important structural

Photos on these pages Andrew Brooks.

component, influences many ecological processes (see Chapter 4) and provides essential habitat for aquatic and terrestrial organisms. In alluvial rivers, wood plays a critical role in stream morphology, stability and sediment transport. In some perennial sand bed-rivers it has been shown that the majority of morphological complexity is associated with in-stream wood loading (Brooks et al. 2003). Indeed, it has been demonstrated that in some circumstances, the formation of alluvial channels and entire floodplains is dependent on the presence of in-stream wood (Montgomery et al. 1996, Brooks & Brierley 2002). Conversely, wood removed from streams can increase sediment transport capacity by up to three orders of magnitude, thereby exceeding thresholds, which make it very difficult to maintain channel stability (Simon 1989, Simon & Darby 1997, Brooks & Brierley 2004). In mountain rivers, many of the in-stream alluvial features and associated habitat units are directly associated with log steps and log jams (Keller & Swanson 1979, Keller et al. 1995, Montgomery et al. 2003).

Sources, amounts and longevity

Most wood enters streams from adjacent and upstream riparian land. In forested, laterally stable rivers, inputs from riparian land generally occur at a rate similar to that at which live wood is transferred to fallen dead wood in a forest ecosystem (Harmon et al. 1986). However, in many alluvial rivers, lateral channel migration and expansion can increase wood recruitment to rates well above background tree mortality rates (Cohen & Brierley 2000, Benda et al. 2003). In steep headwaters, land-sliding can inject large volumes of timber to the channel network, often in the form of large log jams (Benda 1990, Benda et al. 2003). A river reach wood budget is also influenced by the input of wood transported from upstream (Harmon et al. 1986, Benda et al. 2003). Rare extreme floods that occur in some rivers can have a long-lasting impact on riparian zones and influence the supply of wood to the channel (Jacobson et al. 1995). However, floods can also remove wood from river channels and deposit it on the floodplain (Piegay 2003). Along Australian rivers, self-pruning of *Eucalyptus* species due to osmotic stress in hot weather is often a major cause of input of larger branches (Lloyd et al. 1991). In the Murray River, most river red gum snags are sourced directly from eroding banks (Nicol et al. 2001, Koehn et al. 2004).

Historical records from the Murray–Darling River system indicate that our larger inland rivers historically contained much greater volumes of wood than they do today. Since the 1850s, wood has been removed from streams and rivers under the guise of so-called river-improvement strategies designed to prevent hazards to navigation, reduce damage to in-stream structures, rejuvenate or scour channels, and increase hydraulic capacity to reduce flooding (Strom 1962, Gregory & Pressey 1982, Shields & Nunnally 1984, Gippel et al. 1996a).

Empirical evidence from a number of undisturbed forested systems up the east coast of Australia indicates that wood loadings can be extremely high due to the slow decay of Australian hardwoods in temperate perennial systems (Marsh et al. 2001, Brooks & Brierley 2002, Webb & Erskine 2003). This highlights the fact that those rivers in cleared landscapes that are now largely devoid of wood, once had large wood accumulations falling in from adjoining riparian land and supporting a diverse range of aquatic life.

These photos show the importance of wood in a range of river types. Wood in rivers is vitally important for in-stream health and biodiversity.

These trees are holding the bank together with their roots and when they eventually fall into the river will provide habitat for a host of aquatic organisms. Photo CSIRO Sustainable Ecosystems.

De-snagging of the Murray and Murrumbidgee Rivers commenced in 1855 with a boat captain, Francis Cadell, clearing by hand a little under 160 kilometres of each river (Mudie 1961). Systematic de-snagging was started by the South Australian Government with the launch of a 'snag boat', the *Grappler*, in 1858 (Mudie 1961). Snag boats were capable of removing 300–400 logs per month, and one boat, the Industry, is reported to have removed 3 million logs from the Murray River between 1911 and the late 1960s (Phillips 1972). By 1973 it was estimated that there were about 1200 logs along 330 kilometres of the Murray River between Lock 6 in South Australia, and Wentworth in New South Wales (Hall & Mudie 1975). This is only three logs per kilometre, a far cry from the days when logs were reported as '… standing up like a regiment of soldiers …' (Mudie 1961). Three logs per kilometre is the same density now present in the Willamette River in Oregon, after extensive de-snagging reduced densities from 550 logs per kilometre (Sedell & Froggatt 1984). De-snagging in the Murray River has continued more recently, with 24,500 logs removed between Lake Hume and Yarrawonga over the period 1976 to 1987 (Murray–Darling Basin Ministerial Council 1987).

There is limited historical evidence of wood loadings from other river systems around Australia, although we know that widespread de-snagging has taken place wherever intensive agriculture and irrigation has been developed. For example, rivers of the Swan coastal plain south of Perth were progressively de-snagged from the late 1930s to increase drainage for agricultural land (Bradby & Mates 1995). De-snagging, as part of general 'river improvement' (which also included bank clearance, bank training and relocation of the low-water channel) has been commonly practised throughout Australia under the authority of state government agencies (Strom 1962, Turnbull 1977, Erskine 1990). In some instances this has resulted in increased erosion and flooding and reduced invertebrate and fish populations in the affected reaches (Zelman 1977, Johnson 1978, Gregory & Pressey 1982, Hortle & Lake 1983).

Available data on current wood loads in Australian and overseas rivers are limited. Furthermore, most of the data relate to rivers that have been de-snagged, or to rivers that flow through cleared riparian land. Australian data and some USA data are summarised in Table 7.1 (see page 122). However, natural wood loadings of Australian streams are generally higher than those of streams in the northern hemisphere. This is consistent with the higher proportion of wood recorded in litter fall in Australian forests compared with northern hemisphere forests (Campbell et al. 1992a). Two additional factors also contribute to higher natural wood loads in Australia. These are the relatively low stream power (the ability of moving water to do work) of Australian streams, and the dense, long-lasting nature of Australian timbers. The trees that grow in the riparian zone of Australian rivers tend to be hardwoods that have a higher density and are stronger than the softwoods often occurring along northern hemisphere rivers. For example, tree species from southeastern Australian are, on average, 65% denser and approximately three times the hardness of tree species from the Pacific northwest of North America (White 1998).

Natural wood loads would be expected to vary depending on the climate and vegetation, especially along the riparian and floodplain corridor. For example, many dryland rivers have low wood loads reflecting their sparse riparian tree cover (Davies et al. 1995). Recent research in Australia has highlighted the relationship between the density of vegetation in the riparian zone and wood loading in streams. Although wood varied

widely both within and between rivers, Marsh et al. (2001) found a linear relationship between riparian tree volume and wood loading in streams across eastern Australia (Figure 7.1). This model assumes that immediate riparian input is the dominant recruitment process, and that the extant riparian vegetation structure and cover is indicative of the long term state. This relationship is described by the following equation:

Wood volume (m^3/m) = 0.2*

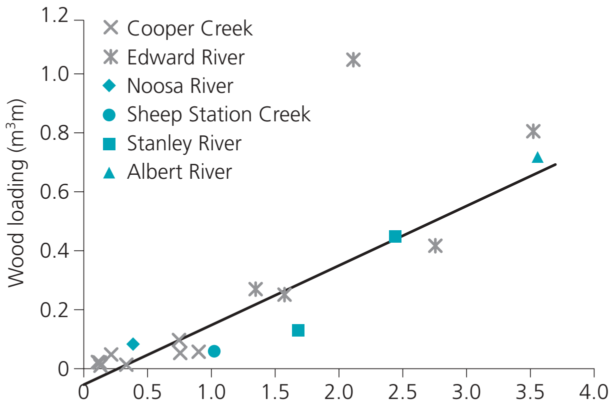
Overhanging tree volume (m^3/m) — 0.05 (R^2 = 0.91)

This not only provides a benchmark for reinstatement of wood in de-snagged rivers, but also reinforces the importance of the riparian zone as the long-term source for this material.

It has generally been considered that as stream size or stream order increases, the volume of wood present relative to channel capacity decreases (Harmon et al. 1986, Robison & Beschta 1990). The data presented in Table 7.1 for some Australian streams tend to confirm this. However, undisturbed low-gradient, high-order streams in the United States have been shown to have comparable wood loadings to headwater streams elsewhere in the United States (except for those streams in the Pacific north west) (Wallace & Benke 1984). Although wood loadings may decrease as stream size increases, some research has indicated that the amount of wood actually located within the wetted channel increases as stream size increases. For example, wood loadings were twice as high in a 4.6 metre wide stream than in a 25.6 metre wide river (Robison & Beschta 1990). However, only 19% of wood fell within the channel of the smaller stream compared with 62% in the larger river. (High-gradient streams generally have a small channel width, so falling wood tends to span the channel, becoming suspended above the stream surface level and not acting directly on the stream.) In effect, the larger river contained twice as much in-channel wood as the smaller stream.

Natural wood accumulation. Photo Tim Cohen.

Figure 7.1. Wood loading and fringing riparian vegetation density along six south-eastern Australian streams (from Marsh et al. 2001).



With the realisation of the importance of wood to stream ecosystems, researchers have started to quantify the amounts of wood in streams. Wood loadings can be measured in a number of ways, but this can make comparisons between different systems difficult. A simple measure is the number of wood pieces per length of river bank. This provides an indication of density, but no indication of the amount of surface area available as habitat or of the mass of wood present. Surface area (m^2) and volume (m^3) can be calculated by measuring the diameter and length of pieces and, if wood density is known, mass (kg) can be also calculated. These various measurements can be expressed on an area basis per square metre of stream bed. The proportion of total habitat area available as log surface compared with other benthic surfaces can also be estimated.

Table 7.1. Wood loadings in Australian and some US rivers.

Stream	Catchment size km^2 (stream order)	Wood loading kg.m^{-2} (m^3/m^2)	Density items/100 m (both banks)	Surface area m^2/m^2 stream bed	Proportion of total habitat area available as log surface	Land use	Riparian vegetation	Reference	Comments
Pranjip Creek (Vic)	787	0–5 (0–0.008)		0–0.2		Agriculture	Degraded	O'Connor (1992)	
as above	>787	3.9–42.4 (0.005–0.055)		0.28–0.91	21–47%	Agriculture	Intact	O'Connor (1992)	
Keppel Creek (Vic)	14.3 (4)	4.3 (0.007)	490	0.31	21%	Forested	Intact	Treadwell et al. (1997), S. Treadwell & I. Campbell (unpub.)	
Wellington River (Vic)	122 (4)	(0.0057)		0.097		Forested	Intact	I. Campbell & M. Shirley (unpub.)	
Carey River (Vic)	244 (5)	(0.0004)		0.015		Forested	Intact	as above	
Dolodrook River (Vic)	145 (5)	(0.0056)		0.048		Forested	Intact	as above	
Murray River billabongs (NSW and Vic)					5–15%	Agriculture	Various	M. Shirely (unpub.)	
Murray River Yarrawonga (NSW)			14			Agriculture and forested	Various	J. Koehn (unpub.)	Mature red gum trees along banks
Murray River Barmah Forest (NSW)			9.5			Forested	Intact	Gippel et al. (1992)	Channel de-snagged in past
Murray River Overland Corner (SA)			2.7			Agricultural	Degraded	Lloyd et al. (1991)	Channel de-snagged in past
Goulburn River (Vic)	16 125		23.6			Agriculture and forested	Intact	Anderson & Morison (1988)	Logs and log jams
Thompson River (Vic)	3540	(0.0172)	12.1	0.1184		Agriculture	Intact	Gippel et al. (1996a)	

Johnstone River and Mulgrave River (north Qld)	(1)		9.2					B. Pusey, A. Arthington & M. Kennard (unpub.)	Wood only within 1 m of bank = > underestimate
as above	(2)		22.4					as above	as above
as above	(3)		14.4					as above	as above
as above	(4)		3.8					as above	as above
as above	(5)		4.8					as above	as above
as above	(6)		0.2					as above	as above
Dandelup River (WA)	(4)				0.4%	Agriculture	Degraded	Beesley (1996)	Channel de-snagged in past
Serpentine River (WA)	(4)				1.8–2.4%	Agriculture	Intact	Beesley (1996)	
as above	(4)				1.6–7.9%	Forest	Intact	as above	
Willamette River (Oregon)	29 138		55: before de-snagging 0.3: after de-snagging				Extensive riparian forest now cleared for agriculture	Sedell & Froggatt (1984)	
Walton Creek (Colorado)	26.1 (2)	(0.001)	20				Degraded	Richmond & Fausch (1995)	
Ogeechee River (Georgia)	7000 (6)	6.5 (0.0148)		0.43				Wallace & Benke (1984)	Limited de-snagging
Black Ck (Georgia)	755 (4)	5.0 (0.0168)		0.57				Wallace & Benke (1984)	Limited de-snagging
Satilla River (Georgia)	3100–7300 (5/6)			0.05–0.07	4–6		Cypress–black gum swamp	Benke et al. (1984, 1985)	Extensive de-snagging
Several headwater streams in Oregon	(1 and 2)	8–25						Cummins et al. (1983)	
McKenzie River (Oregon)	1024 (6)	0.5 (0.001)				Forest	Intact forest floodplain	Keller & Swanson (1979)	
Lookout Creek (Oregon)	60.5 (5)	11.6 (0.023)				Forest	Intact	Keller & Swanson (1979)	

Longevity

The slow decay and high stability of wood contributes to its dominance as the major organic matter size-fraction present in undisturbed temperate streams and rivers. An example of the longevity and stability of wood can be found in the Stanley River, Tasmania, where many in-stream logs of Huon pine, *Lagarostrobos franklinii*, and celery-top pine, *Phyllocladus aspleniifolius*, present as individual logs or as part of accumulations, had fallen into the water up to 5000 years ago (Nanson et al. 1995). Wood buried in the floodplain had been there for 3500 to 9000 years, with one buried log (King William pine — *Athrotaxis selaginoides*) having died 17,100 years ago (Nanson et al. 1995). Logs of similar antiquity (up to 13,000 years old) were also dated from floodplains in East Gippsland (Brooks & Brierley 2002). Based on the age of some logs, some accumulations appear to have been stable for up to 2000 years (Nanson et al. 1995), indicating the ability of wood to reduce stream power and stabilise channel beds and banks over long periods (Brooks et al. 2003).

Pattern and structure

The spatial arrangement and physical characteristics of structural woody habitat was examined in the Murray River between Lake Mulwala and Tocumwal using low-level, high-resolution aerial photography (Koehn et al. 2004). It was found that wood occurred in aggregations that were closely associated with eroding banks on meanders. The physical characteristics of the wood in these aggregations varied (basal diameter range 0.44–2.45 metres, length range 1–44 metres), however small to medium-sized trees (basal diameter range 0.7–1.4 metres, length range 5–20 metres) were most common. Most wood was oriented in the 0–90° downstream arc. The association between eroding banks and woody habitat suggests that bank erosion may be an important determinant in the formation of structural woody habitat aggregations. The pattern of wood within the river landscape was also determined at a range of scales (Hughes 2001, Nicol et al. 2001) with the distribution appearing to reflect the energy of meander bends.

7.2 Direct use of wood as habitat

Logs and branches provide habitat over a range of spatial scales for many aquatic organisms. Wood provides a hard substrate for direct colonisation by biofilm and invertebrates, and a surface on which some invertebrates and fish deposit eggs. In a study of wood habitat surface complexity, it was concluded that the more complex the wood surface, the larger the surface area available for colonisation, the greater the resource availability and the greater the invertebrate species richness (O'Connor 1991b).

These fallen trees are providing valuable habitat for aquatic organisms. Photo Tim Cohen.

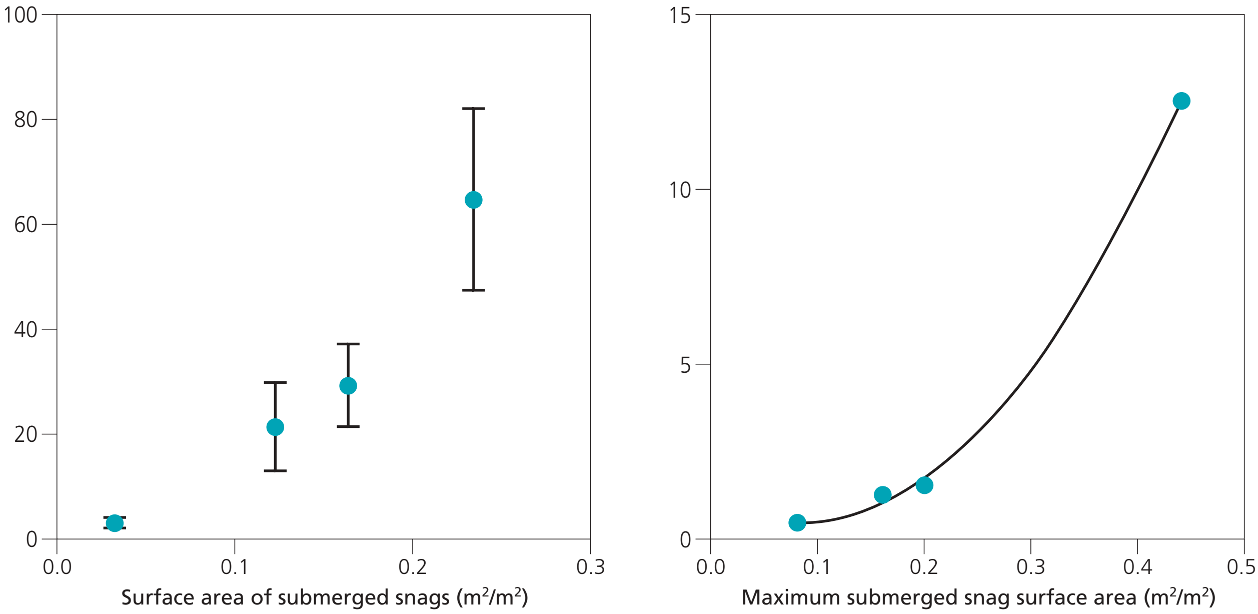


Figure 7.2. Primary production by biofilms growing on wood surfaces as a function of total stream production increases as submerged wood surface area increases. Left: In rivers that have low log surface area, for example rivers that have been desnagged, the amount of primary production by biofilms growing on wood surfaces is low. Right: The greater the log surface area the higher the overall contribution that biofilm primary production makes to total ecosystem production (S. Treadwell, unpublished data for sites in the Ovens and Murray Rivers).

Logs and branches form complex three-dimensional structures in the water column and provide a number of different-sized spaces or habitat zones. The small spaces formed by sticks, twigs and other material trapped against logs provide refuge and feeding areas for small and juvenile fish, as well as invertebrates (Triska & Cromack 1980, Kennard 1995), while the larger spaces around branches and logs provide space for larger species. Hollow logs provide essential habitat for some fish, and branches that extend into the water column and above the water surface provide habitat at different water levels.

Microbes

The complex surface structure of wood provides a suitable substrate for rapid colonisation by a range of microbes, including fungi, bacteria and algae (Willoughby & Archer 1973, Aumen et al. 1983, Sinsabaugh et al. 1991, Scholz & Boon 1993), commonly referred to as 'biofilm'. The activities of these microbes are essential to the generation and processing of organic carbon and nutrients in aquatic environments. Fungal and algal biomass was found to be greater on wood substrates than on an inert substrate (Sinsabaugh et al. 1991). In rivers with unstable sand and silt substrates, wood may provide the only stable substrate for biofilm development.

Wood provides a significant stable substrate for algae (O'Connor 1991), however, its growth can sometimes be affected by fine sediment and changes in river height (as a result of river regulation) that reduce light availability and which favour other organisms. Where algal development is so restricted, fungi and bacteria are likely to constitute the greatest biomass in biofilm on logs and branches, and heterotrophic respiration is likely to be the major process (see Figure 7.2).

Invertebrates

Wood in Australian streams and rivers provides a major substrate for colonisation by invertebrates (Lloyd et al. 1991, O'Connor 1991a, Tsyrlin 1994, McKie & Cranston 1988). Most studies have recorded specific communities existing on wood in preference to other substrates. This highlights the importance of wood in contributing to biodiversity. Most invertebrates that colonise wood graze biofilm and other fine-particulate organic matter on the wood surface (O'Connor 1991b, Tsyrlin 1994) but some, such as freshwater hydras, sponges, and the larvae of blackflies (Simuliidae) and net-spinning caddis (Hydropsychidae), use the hard surfaces as attachment sites to filter feed (Tsyrlin 1994).

In river systems with sandy, unstable substrates, logs and branches provide the only stable substrate for invertebrate colonisation, particularly during high-flow periods (Beesley 1996). In intermittent streams, wood can provide a refuge for invertebrates, enabling them to survive periodic dry periods (Boulton 1989). Certain invertebrate species feed specifically on woody substrate and are instrumental in modifying wood surfaces, thereby

A range of different organisms depend on wood for habitat. Photos (left column) Andrew Brooks, (right column) John Koehn.

contributing to surface complexity and promoting further colonisation (Flint 1996, McKie & Cranston 1988). In-stream wood also traps organic matter (Bilby & Likens 1980) and increases overall biodiversity (Wondzell & Bisson 2003), including macroinvertebrates (Benke et al. 1984, O'Connor 1991).

De-snagging, particularly in rivers where logs and branches are the only significant stable substrate, could significantly reduce invertebrate density and species richness and contribute to a loss of invertebrate biodiversity. De-snagging has been identified as a threat to at least four species of freshwater crayfish found in lowland rivers throughout Australia (Horwitz 1994). Particular threats are faced by the largest freshwater crayfish in the world, the giant Tasmanian freshwater lobster, Astacopsis gouldii (Horwitz 1991), and by the West Australian marron, *Cherax tenuimanus*, a large freshwater crayfish popular with recreational fishers (Morrissy 1978).

Fish

The importance of wood to riverine fish has been illustrated with positive relationships shown between salmon diversity and abundance and instream wood at both larger basin scales (Tchaplinski & Hartman 1983, Reeves et al. 1993, Quinn & Peterson 1996, Cederholm et al. 1997) and micohabitat scales (Flebbe & Dollof 1995, Inoue & Nakano, 1998). There have been similar findings for non-salmonid species with Lehtinen et al. (1997), Angermier and Karr (1984), Todd and Rabeni (1989), Scott and Angermier (1998), Jepsen et al. (1997) and Daugherty and Sutton (2005) all describing fish associations with wood. Wood has been shown to be an important microhabitat component for both adult and age–0 Murray cod (Koehn 2006) supporting previous natural history observations (e.g. Dakin & Kesteven 1938) and for Mary River cod (Simpson & Mapleston 2002) and trout cod (Growns et al. 2004, Nicol et al. 2004, 2006).

Much of the in-stream habitat available for fish originates from riparian zone vegetation (Koehn & O'Connor 1990, Nicol et al 2001). In Australian lowland streams wood is usually the major form of in-stream structural habitat used by many species. Fish need complex structures to hide from predators and to avoid intense sunlight and high current velocities. Woody habitat may also provide cover for predators. For instance, short-finned eels, *Anguilla australis*, in a Victorian stream show preferences for dense log jams. This may be related to their ability to ambush prey, rather than to their own requirements for shelter from predation (Koehn et al. 1994).

Fish also use logs as markers to designate territory and maintain position in the stream. Radio tracking of Murray cod, *Maccullochella peelii peelii*, has indicated they can migrate up to several hundred kilometres during spawning and return to a 'home' log (J. Koehn unpublished data). Providing velocity refuge for fish is a key function of wood in streams (Fausch 1993, Crook & Robertson 1999). Velocity refuges can also be provided by variations in the riverbed substrata caused by wood. Selection of such habitats by Murray cod may reflect this (Koehn 2006), with fish sheltering in substrate 'pockets' created by scour around wood or among the wood itself.

Logs and branches create a diversity of habitats by redirecting flow and forming variations in depth and water velocity. Such a diversity of habitats provides for the needs of a variety of fish species and for fish of various ages. Logs also provide habitat for biofilm and invertebrates that form important links in the food chain for fish. Further, they provide important habitat in deeper, lowland streams, where the benthic substrates are generally composed of finer particles and are more uniform.

Large logs and branches provide spawning sites for species that lay their adhesive eggs on hard surfaces (Cadwallader & Backhouse 1983). River blackfish, *Gadopsis marmoratus*, lay a relatively small number of eggs in the safety of hollow logs (Jackson 1978). Mary River cod, *Maccullochella peelii mariensis*, one of Queensland's most endangered fish species, are thought to require hollow logs for spawning (Simpson & Jackson 1996). Some fish species prefer to live in and around logs, and their numbers can often be directly correlated with the amount of such habitat available. For example, Mary River cod favour slow-flowing pools with in-stream cover in the form of logs, log piles or a combination of logs and bank overhangs, but may also occur in shallower pools where heavy shading and discoloured water provide additional cover (Simpson 1994).

During flooding, logs and branches in floodplain channels provide a substantial increase in available fish habitat (including spawning sites) and may play a major role in factors (such as site selection and post-hatching predation) which influence recruitment (Koehn 2006). Avoidance of predation has been suggested as a reason for fish habitat selection where wood can provide additional shelter.

At least 34 native freshwater fish species from around Australia use wood as a major habitat source or for spawning (see Table 7.2). Given the paucity of knowledge of the biological requirements of many species, it is reasonable to assume that the true figure is much higher. The removal of wood has been widely recognised as a threat to native freshwater fish (Cadwallader 1978, Koehn & O'Connor 1990, Wager & Jackson 1993). In Victoria, the removal of wood from streams and the degradation of native riparian habitat are listed as 'potentially threatening processes' under the Flora and Fauna Guarantee Act 1998 (DCNR 1996a, 1996b). The loss of habitat for any species is likely to lead to a reduction in numbers. This is particularly so for habitat-dependent species and for those species which require a particular habitat for a critical purpose, such as spawning.

Table 7.2. Native freshwater fish species with a documented use of wood as a major habitat or for spawning.

Common name	Species name	Reason for use	Reference
River blackfish	*Gadopsis marmoratus*	Spawning site, preferred habitat	Jackson (1978), Koehn (1986), Koehn et al. (1994)
Two-spined blackfish	*Gadopsis bispinosus*	Likely spawning site, preferred habitat	Robison & Beschta (1990), Koehn (1987, 2005)
Murray cod	*Maccullochella peelii peelii*	Spawning site, preferred habitat	Llewellyn & MacDonald (1980), Cadwallader & Backhouse (1983), J. Koehn (2006)
Trout cod	*Maccullochella macquariensis*	Spawning site, preferred habitat	Cadwallader (1978), Growns et al. (2004), Nicol et al. (2004, 2006)
Eastern freshwater cod	*Maccullochella ikeii*	Spawning site, preferred habitat	Merrick & Schmida (1984)
Mary River cod	*Maccullochella peelii mariensis*	Spawning site, preferred habitat	Simpson & Jackson (1996), Simpson & Maplestone (2002), Merrick & Schmida (1984)
Spotted galaxias	*Galaxias truttaceus*	Preferred habitat includes wood	Williams (1975)

Table 7.2. continued

Common name	Species name	Reason for use	Reference
Tasmanian mudfish	*Galaxias cleaveri*	Preferred habitat includes wood	McDowall (1980)
Mountain galaxias	*Galaxias olidus*	Preferred habitat includes wood	Marshall (1989)
Catfish	*Tandanus tandanus*	Affected by de-snagging	Reynolds (1983)
Australian bass	*Macquaria novemaculeata*	Preferred habitat includes wood	Marshall (1979)
Estuary perch	*Macquaria colonorum*	Preferred habitat includes wood	Sanders (1973), McCarraher (1986)
Barramundi	*Lates calcarifer*	Preferred habitat includes wood	Merrick & Schmida (1984)
Australian smelt	*Retropinna semoni*	Preferred habitat includes wood	Cadwallader (1978)
Tupong	*Pseudaphritis urvilii*	Preferred habitat includes wood	Hortle (1979), Hortle & White (1980)
Southern purple-spotted gudgeon	*Mogurnda adspersa*	Spawning	Allen (1989)
Striped gudgeon	*Gobiomorphus coxii*	Spawning	Cadwallader & Backhouse (1983)
Western carp gudgeon	*Hypseleotris klunzingeri*	Spawning	Lake (1967), Llewellyn (1971)
Golden gudgeon	*Hypseleotris aurea*	Preferred habitat includes wood	Merrick & Schmida (1984)
Empire gudgeon	*Hypseleotris compressa*	Spawning	Allen (1989)
Barnett River gudgeon	*Hypseleotris kimberleyensis*	Preferred habitat includes wood	Allen (1989)
Prince Regent gudgeon	*Hypseleotris regalis*	Preferred habitat includes wood	Allen (1989)
Midgeley's carp gudgeon	*Hypseleotris* sp. A	Preferred habitat includes wood	Allen (1989)
Northern trout gudgeon	*Mogurnda mogurnda*	Spawning	Allen (1989)
False-spotted gudgeon	*Mogurnda* sp.	Preferred habitat includes wood	Allen (1989)
Snakehead gudgeon	*Ophieleotris aporos*	Spawning	Allen (1989)
Sleepy cod	*Oxeleotris lineolatus*	Spawning	Allen (1989), Merrick & Schmida (1984)
Giant gudgeon	*Oxeleotris* sp. A	Preferred habitat includes wood	Allen (1989)
Flat-head gudgeon	*Philypnodon grandiceps*	Spawning	Allen (1989)
Dwarf flat-head gudgeon	*Philypnodon* sp.	Preferred habitat includes wood	Allen (1989)
Swan River goby	*Pseudagobius olorum*	Spawning	Allen (1989)
Lake Eacham rainbowfish	*Melanotaenia eachamensis*	Preferred habitat includes wood	Merrick & Schmida (1984)
Westralian pygmy perch	*Edelia vitata*	Preferred habitat includes wood	Merrick & Schmida (1984)

Wood provides an important component of habitat for many animals, not only those that live in the stream. Photo Ross Digman.

Other animals

Logs and branches provide habitat for other aquatic and terrestrial species. Birds, reptiles, amphibians and mammals use logs and branches for resting and foraging and as lookout sites (Harmon et al. 1986). Birds commonly use the exposed branches of logs as perch sites, while turtles climb out of the water using log surfaces. Partially submerged logs provide habitat for both terrestrial and aquatic organisms and also allow small terrestrial animals to approach the water surface to drink and bathe. Logs spanning channels may provide stream-crossing points for a range of animals. Riparian vegetation along streams and rivers also provides significant habitat for many terrestrial species, as do logs and branches on riparian land and on larger floodplains.

7.3 De-snagging and river 'improvement'

Clearing the riparian zone and de-snagging rivers under the guise of 'river improvement' has undoubtedly contributed to channel degradation in many Australian rivers (Brooks et al. 2003, Brooks 1999a), and the decline of aquatic species that depend on these structures for shelter and food (e.g. Koehn et al. 2000, Crook & Robertson 1999, O'Connor 1992). De-snagging can have a catastrophic effect on channel stability, especially when combined with channelisation. Altered hydraulic roughness associated with wood removal can increase sediment transport capacity by an order of magnitude in sand-bed streams (Brooks et al. 2003). This can then lead to increased bank and bed erosion, especially in sandy-bed rivers (Bird 1980, Brookes 1985, Erskine 1990, Gippel et al. 1992, Shields & Gippel 1995, Brooks et al., 2003), which in turn leads to further increases in stream power and hence channel instability. Brooks et al. (2003) outlined a case in which an autocatalytic response induced by wood removal led to in increase in sediment transport capacity of three orders of magnitude.

Furthermore, the removal of timber from the riparian zone and floodplains means that future sources of wood are now greatly diminished. For example, preliminary estimates provided by MacNally and Parkinson (1999) suggest that the amount of fallen wood remaining on the floodplains of the southern Murray–Darling Basin is approximately 15% of that present prior to European settlement. Wood on the floodplain is likely to play a significant role in maintaining local biodiversity given that fish and aquatic macroinvertebrates are known to utilise this habitat during inundation (e.g. MacNally 2000). The loss of wood on the floodplain and the patchy distribution of that which remains means that we have also lost potential habitat for birds, invertebrates, reptiles and mammals, in addition to aquatic organisms.

'River improvement', which in many cases in the past was a euphemism for desnagging, appears to have been implemented in an uncoordinated manner, with little regard for the impact of the works on upstream and downstream reaches or for cost–benefit analysis (Zelman 1977, Warner 1984). In fact, the consequences of river-improvement practices are often the opposite of those intended. A particular example is the report of an increase in the severity of flooding of the Ovens River around Wangaratta, Victoria, following river-improvement activities that were designed to reduce flooding (Zelman 1977).

Elevated log sill structure has trapped flood debris that will later provide valuable habitat. Photo Andrew Brooks.

Recent recognition of the role wood plays in river structure has resulted in several recommendations to restore woody habitat to Australian streams (Gippel et al. 1996a, 1996b, Cottingham et al. 2003, Brooks et al. 2004, Brooks et al. 2006). It is now widely acknowledged that flooding and erosion are essential components of a healthy riverine ecosystem. Rivers will flood irrespective of the presence of wood, and the minor erosion that occurs around logs is a natural process and contributes to the diversity of habitat available to riverine biota. Thus the focus of river management over the past decade has moved from one of actively removing logs to retaining or reinstating them as part of river rehabilitation efforts. Wood retention in the mid and upper reaches of rivers can indeed be an effective strategy for reducing flooding in downstream reaches, through attenuation of flood hydrographs (Anderson et al. 2004, and Chapter 5 of this document). Desnagging has been recognised as a major threat to many native species and a cause for the decline of populations (Cadwallader 1978, Koehn & O'Connor 1990, Murray-Darling Basin Commission 2004).

7.4 Other riparian influences on aquatic habitat

Undercut banks and tree roots

The roots of riparian trees stabilise stream banks and allow them to become undercut without collapsing (Cummins 1986). (See also Chapter 6.) Undercut banks provide shelter from predators and high flows for a wide range of aquatic invertebrate and vertebrate species. For example, glass shrimps (Atyidae) tend to congregate under banks, large submerged boulders, and amongst aquatic vegetation (Williams 1980). The fibrous root mats of some riparian species exposed in undercut banks also offer a complex habitat for aquatic invertebrates.

The spotted galaxias, *Galaxias truttaceus*, is usually found behind boulders and under logs and undercut banks (Hortle 1979). Freshwater catfish adults, *Tandanus tandanus*, in the Logan River, south-east Queensland, are collected most often from undercut banks and root masses (Kennard 1996). Binding and roughening of banks by abundant riparian vegetation allows the development and maintenance of lateral scour pools and related features. These are thought to benefit salmonid fishes and other drift feeders by putting the main drift of food close to prime concealment cover (White 1991).

Many species of fish actively seek shelter among the roots of overhanging trees (Koehn & O'Connor 1990). For example, sleepy cods/gudgeons, *Oxyeleotris* spp., usually inhabit slow-moving water and tend to live near the cover of roots, rocks or logs (Herbert & Peters 1995). Smaller gudgeons prefer leaf litter or bank-side roots for cover. The Tamar River goby, *Favonigobius tamarensis*, and blue-spot goby, *Pseudogobius olorum*, may construct burrows beneath rocks or tree roots (Koehn & O'Connor 1990).

Platypus, *Ornithorhynchus anatinus*, construct their burrows where the roots of native vegetation consolidate the banks and prevent the burrows from collapsing (Serena et al. in review). The distribution of burrows in streams is clearly associated with the presence of intact riparian vegetation and stable earth banks.

Overhanging and fringing vegetation

Overhanging vegetation can provide resources such as large instream wood, smaller wood and organic material that provides shelter for small fish and invertebrates. It has been shown to be an important habitat component for both adult and age–0 Murray cod (Koehn 2006). Southern pygmy perch, *Nannoperca australia*, juveniles and adults occur in shaded, weedy, slow-flowing waters and are most common among dense bank-side vegetation away from fast currents (Koehn & O'Connor 1990).

Macrophytes provide important habitat for pygmy perch, *Edelia vittata*, in south-western Australia (Pusey et al. 1989). However, shading of streams by riparian vegetation, particularly of the shallow littoral margins, is likely to decrease the extent of aquatic macrophyte cover (see Chapter 3) for some species of fish.

Overhanging and trailing vegetation also provides shade and cover for stream organisms. Species richness of invertebrate fauna in streams is clearly related to riparian cover. In a recent study of 29 New Zealand streams, it was found that the number of mayfly, stonefly and caddisfly taxa was significantly correlated with the proportion of native forest cover in the riparian zone (Collier 1995). The importance of riparian cover for trout and other salmonids is also well documented (Barton et al. 1985, Wesche et al. 1987). Similar observations have been made for many species of native Australian fish. For example, the mountain galaxias, *Galaxias olidus*, and broad-finned galaxias, *Galaxias brevipinnis*, are both found in the headwaters of small, fast-flowing, clear mountain streams which have overhanging vegetation and a good forest canopy (Hortle 1979). Overhanging vegetation also provides important cover from predators for platypus as they enter and leave their burrows.

Emergent macrophytes and other fringing vegetation are sometimes used for spawning and for recruitment by some species of fish. Duboulay's rainbowfish, *Melanotaenia duboulayi*, (a species found in coastal drainages in northern New South Wales and southern Queensland), deposits adhesive eggs amongst aquatic macrophytes and submerged overhanging vegetation within 10 centimetres of the water surface (Kennard 1996). Similarly, the fire-tailed gudgeon, *Hypseleotris galii*, attaches adhesive eggs to the underside of submerged structures such as leaf litter, logs, branches and rocks (Kennard 1996).

In the upland forested streams of the northern jarrah forest (south-western Australia), trailing vegetation is an important habitat for the larvae of filter-feeding insects. The most common of these, *Condocerus aptus* (Trichoptera), attaches its case to emergent or trailing vegetation at the air–water interface. From these perches, individuals filter the water surface, catching and ingesting detritus and prey items. Vegetation which is situated or suspended in regions of intermediate velocity (approx. 20 cm $^{-1}$) supports the greatest larval abundances.

Inundated riparian vegetation

During high flows, fish and other aquatic animals may move into inundated riparian vegetation to avoid downstream displacement or to feed or spawn. For example, the inanga, a primary species in New Zealand's whitebait fishery, spawns in riparian vegetation near the upstream extent of saltwater penetration in river estuaries (Mitchell & Eldon 1991). Some banded kokopu populations spawn in flooded riparian vegetation (Mitchell & Penlington 1982).

In Australia, spawning sites of the common galaxias, *Galaxias maculatus*, are often among grasses and vegetation on river estuary margins which are inundated by high spring tides (Koehn & O'Connor 1990). The pygmy perch, *Edelia vittata*, migrates out onto the floodplain (into riparian vegetation) during winter to spawn (Penn & Potter 1991). Submerged riparian vegetation provides habitat for Murray cod at higher flows (Koehn 2006).

Overhanging vegetation is vital for shelter and providing habitat for fish and other organisms. Photo Andrew Brooks.

7.5 The geomorphic role of wood in rivers

Until recently, many river managers considered that logs were significant contributors to channel instability (e.g. bank erosion) and flooding. We now realise that logs contribute significantly to stream stability and their role in flooding has been overstated. The presence of wood can exert significant control on channel complexity in bedrock rivers and channel geomorphology in alluvial rivers (Figure 7.3), and ultimately the long-term evolution of river channels and floodplains. For example, a comparative study of the Cann and Thurra Rivers in East Gippsland, Victoria, highlighted the importance of wood to stream geomorphology. Europeans settled the floodplain of the Cann River in the 1860s, while the floodplain of the adjacent Thurra River remains relatively undisturbed. Both catchments have been subject to logging and wildfire. The defining difference between the catchments was the widespread clearance of the riparian zone and the removal of wood from the Cann River (Brooks et al. 2003, Brooks & Brierley 2002, Brooks 1999a, b). When compared with the contemporary Thurra River and palaeo-channel condition of the Cann River, the contemporary Cann River has:

~ a wider channel width,
~ deeper mean depth,
~ greater bankfull discharge and velocity,
~ greater stream power,
~ larger median grain size (suggests increased export of fine sediment and greater downstream transport of coarse material),
~ greater likelihood of bank failure,
~ no stable riffle-pool sequences (see photos below), and
~ greater lateral migration.

The significance of wood in rivers and its control on channel geomorphology has also been described overseas, particularly in North America (e.g. Abbe & Montgomery 1996, Montgomery et al. 1996, 2003).

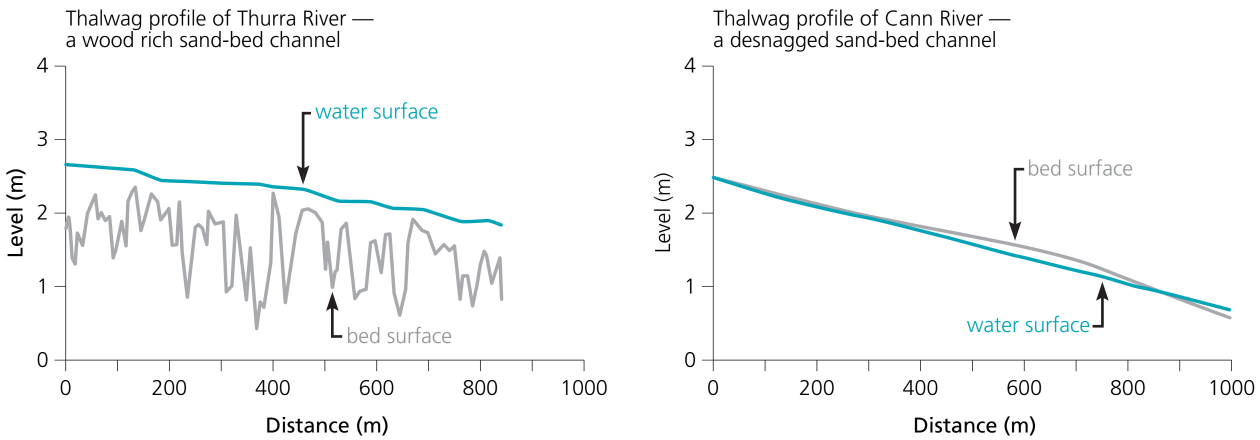


Figure 7.3. The effect of desnagging on channel complexity in forested sand-bed channels. Note. A palaeo-reconstruction of the Cann channel suggests it was previously very similar to the Thurra. The photos below show the difference in channel geomorphology when wood is taken out of a river. Left: A wood rich stream (Thurra) and right, a desnagged stream (Cann). Photos: Andrew Brooks.

Orientation to flow	Habitat formed	
	Upstream	*Downstream*
Parallel	Scour pool	Bar or island
Angled	Combination pool and bar	Combination pool and bar
Perpendicular: on bed	Depositional zone	Scour pool
Perpendicular: above bed	Scour pool	Scour pool

Table 7.3. Habitat development as determined by log orientation.

The control on channel geomorphology imparted by in-stream wood can have profound implications for stream ecology and river rehabilitation. For example, the presence of wood can provide macro- and microhabitat (Figure 7.2), and effect attributes such as stream power, channel dimensions and wood transport potential. Bed substrate microhabitat has been shown to be finer and spatially more complex in streams with high wood loads compared to those without (Buffington & Montgomery 1999).

As well as providing direct habitat, accumulations of logs and branches affect channel morphology and can modify habitat formation by initiating and accelerating the formation of major in-stream habitat types such as scour pools, bars, islands and side-channels (Keller & Swanson 1979, Montgomery et al. 1995, Abbe & Montgomery 1996, Richmond & Fausch 1995, Wallace et al. 1995).

The type of channel structure formed by logs and branches depends on the orientation of key pieces (see Table 7.3). Scour pools formed by logs and branches contribute to an increase in residual pool volume — the volume of water that would remain in pools if stream surface flow stopped (Skaugset et al. 1994). This contribution is greatest in smaller streams (Skaugset et al. 1994, Andrus et al. 1988). Residual pool volume is important in streams that have low summer flows with the associated potential for low surface flow. If these streams stop flowing, the pools associated with logs and branches provide the only available habitat for all aquatic species. These residual pools also provide a source of recruitment for new colonisation. It has been reported that the lower the stream gradient and the greater the amount of wood in the stream the bigger the pools (Carlson et al. 1990).

Log induced pool, Allyn River NSW. Photo Tim Abbe.

As is discussed in Chapter 5, at European settlement streams in the humid to semi-arid regions of Australia were full of fallen timber. Deflection around this material certainly caused local bank erosion, but this effect was moderated by the densely vegetated banks. There are numerous reports of dense layers of wood incorporated in the sandy beds of lowland streams (Brooks & Brierley 2002). De-snagging crews often removed several layers of large logs from sandy beds, which led to dramatic deepening (Strom 1962). It is now recognised that that timber was playing a critical role in stabilising the bed of channels, acting as a reinforcing matrix in the sediment. It is difficult to isolate the influence of de-snagging from the numerous other human impacts on streams. Certainly, though, the loss of this reinforcing has led to much of the dramatic river instability that we see today.

Wood and channel erosion

In natural systems that possess good riparian vegetation cover as well as a high in-stream wood load, the overwhelming effect of wood is to reduce net erosion and increase channel stability. Even in highly altered riparian landscapes, the net effect of in-stream wood at the reach scale is to increase channel stability. However, at the scale of individual logs, there may be either a net increase or decrease in erosion, associated with one or more of the following mechanisms:

~ by providing flow resistance in the channel, which reduces average flow velocity, *decreasing* sediment transport capacity and thereby erosion,

- by deflecting flow onto the stream banks, thereby directly *increasing* bank scour,
- by deflecting flow away from the banks, thereby directly *decreasing* bank scour,
- by directly protecting the banks and *decreasing* erosion,
- by increasing local bed depth and consequently *increasing* local bank erosion (because scour pools develop around logs and branches even though the overall effect of the wood is probably to reduce bed scour).

Whether a given piece of wood will increase or decrease erosion depends on:

- the orientation and size of the obstruction,
- the velocity and depth of flow,
- the character of the bed and bank material,
- the height of the bank as a function of its sediment composition (i.e. whether the bank is constrained by mass failure or fluvial particle entrainment),
- whether the bank is subject to other coexistent disturbance factors — e.g. stock trampling.

Most of these variables are in some way controlled by the size of the stream. There has been some research into the effects of wood on bed scour (Cherry & Beschta 1989, Marsh et al. 2001) but almost none into its effects on bank erosion. This is because it is difficult to isolate the effects on erosion of a single piece of timber in a stream from the numerous other processes that are operating. Monitoring and modelling programs have now begun in Australia and the points discussed in this section are preliminary. At present, the best way to consider the effect of wood on erosion is by analogy with engineering structures in rivers (such as groynes, weirs and deflectors).

Wood in river rehabilitation

Wood reintroduction projects and experiments are now underway in numerous locations around the world (see Reich et al. 2003, Abbe et al. 2003, Brooks et al. 2006, Borg et al. 2004). An assessment of these projects is beyond the scope of this chapter, and a full overview of these works can be found in the *Design guideline for the reintroduction of wood into Australian streams* published by Land & Water Australia in 2006 (see www.rivers.gov.au). Experiments currently underway in Australia have demonstrated that wood can be safely and effectively reintroduced into rivers, however, the initial results suggest that large volumes will be required over extensive lengths of rivers to have a measurable response at the system scale. Brooks et al. (2006) have demonstrated that channel degradation can be reversed through the reintroduction of logs, with results from the first 5 years of monitoring showing that sediment storage can be increased on average by 40 m^3/1000 m^2 of bed area. This equates to around 3.5 m^3 of additional sediment storage (i.e. reduced erosion) per m^3 of wood added.

Instream wood is seen as an important habitat component for fish and its reinstatment of has been suggested as an important rehabilitation measure for fish populations (Murray-Darling Basin Commission 2004, Lintermans et al. 2005, National Murray Cod Recovery Team 2006). Techniques and technical guidelines for such works are now available (Nicol et al. 2002) and indeed, the reintroduction of wood into river channels in two major studies (Koehn et al. 2000, Brooks et al. 2003, Nicol et al. 2004) has found increases in fish populations, including Murray cod and the endangered Trout cod (Nicol et al. 2004).

Left: Constructing a log jam. Right: Stream with hydraulic changes as a result of wood reintroduction. Both photos Dan Keating.

River rehabilitation using an engineered log jam. Photo Tim Howell.

Some general principles

When considering the influence of wood on channel morphology, the following general rules should be kept in mind.

- Not all erosion is bad. Scour of the bed and undercutting of the banks are essential for producing the 'hydraulic diversity' required for habitat in a healthy stream. Natural streams are lined with undercut banks.
- By the time erosion around a fallen tree is noticeable, there is a good chance the bank erosion from the wood is almost complete. It is probably reasonable to assume that the erosion around wood follows a negative exponential curve. This means that if the same-sized flood occurred on a given stream twice in a row the second flood would cause much less erosion around the same piece of wood than did the first flood. Put another way, the flow velocity or duration of the second flood would probably need to be much greater to generate the same amount of erosion as occurred in the first flood.
- There is an infinite variety of log sizes and orientations. The variables include the relative size of the log to the stream, the length and diameter, and its vertical and horizontal orientation.
- As a rough guide, erosion around an obstruction will usually remove an amount of material equivalent to no more than one or two times the projected area of the obstruction (that is, the area of the obstruction as seen from the front) from the cross-section. For example, if a log has a projected area of 5 m^2, then the erosion around the log is much more likely to remove a total of 5–10 m^2 of the cross-section than, say, 50 m^2.
- It is likely that at low flows a log will deflect flows in the opposite direction to that at high flows.
- Flows passing over a log will be deflected across the top of the log, roughly at right angles to it.
- The common perception that a log oriented with its tip pointing upstream will cause more scour on the adjacent bank may seldom be true. In fact, at high flows it is likely that a log oriented upstream will deflect flow away from the adjacent bank. Scour of the adjacent bank is usually caused by mechanisms which are not strictly influenced by flow deflection.
- The amount of flow deflection produced by wood in a channel is often over-estimated because of what appear to be 'deflection lines' flowing away from the end of a log. These lines of flow often extend right across the channel. In fact, these surface flows do not reflect the true deflection around the obstruction, which is much less than the flow lines would suggest. This has been confirmed in recent flume experiments on groynes (Dyer et al. 1995).
- The effect of logs on a bend will differ from that of the same log in a straight reach because of the effect of secondary circulation in the bend.
- As a general rule, in most Australian streams the effect of wood on erosion decreases with the size of the channel. This can be demonstrated by considering the general planform of the channel. Although wood is often randomly distributed in larger stream channels, and often at high natural densities, larger channels retain their general meandering characteristics. That is, the planform is not controlled by the wood, which is, at most, a secondary impact on erosion processes. The same is not true of wood in smaller streams. There is much literature (admittedly from North America) that demonstrates how wood accumulations control the morphology of small headwater streams by producing large jams and accumulations of wood.

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