CHAPTER 7

Aquatic Fauna of the Karri Forest

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Abstract

This paper reviews current knowledge of the aquatic fauna of the karri forest, lists existing research projects and outlines the most important additional research projects that are required. Streams in the karri forest tend to have lower gradients and slower flow rates than most streams elsewhere. The majority of the energy driving karri stream ecosystems appears to come from the breakdown of vegetation growing outside the stream. Nine species of fish and several hundred species of aquatic invertebrate occur in karri streams. The invertebrate fauna is poorly known. Studies elsewhere have shown that land disturbance can affect the biology of streams and recent research has shown that, unless appropriate prescriptions are used, timber harvesting can affect the community composition of streams in the karri forest. Research topics that should receive high priority in the karri forest are an inventory of aquatic invertebrates, more detailed examination of the impact of timber harvesting and regeneration, identification of the sources of energy that drive stream processes, measurement of bed structure and sediment loads in streams, and documentation of the life cycles of fish.

INTRODUCTION

There is little information available about the aquatic fauna of the karri forest (see Christensen 1986). As a result, this review makes extensive use of relevant studies elsewhere in Australia and overseas in an attempt to determine any important biological features of the karri forest stream system that may be influenced by forest management. The major topics that we cover are:

(1) the types of streams that occur in the karri forest and their physical attributes;

(2) sources of energy input into the streams;

(3) the distribution and ecology of the animals inhabiting the streams, including their conservation status;

(4) the effects of forest management on the streams and their fauna.

PAST RESEARCH AND CURRENT KNOWLEDGE

Stream Types

Stream headwaters usually consist of a seepage area where groundwater is coming to the surface. As water begins to follow a distinct drainage line it constitutes a first-order stream. First-order streams have no tributaries, second-order streams are formed by the confluence of two first-order streams, third-order streams by the confluence of two second-order ones and so on. Rivers are usually at least fifth-order (Hynes 1970).

A recent survey of the karri forest by the authors showed that the headwaters of streams therein are mostly low-gradient swampy areas with soils that are rich in organic matter and covered with leaf litter. The main forest trees, *Eucalyptus diversicolor* and *E. calophylla*, rarely occur in headwaters; instead there is a closed canopy of smaller tree and shrub species, including *Melaleuca* spp, and sedges and rushes occur in the understorey. Free water is found on the surface only in winter and spring although the water table is close to the surface throughout the year.

First-order streams dry out over summer unless they are particularly long and in a high rainfall zone; however, groundwater occurs close under the stream bed. Most first-order streams are low-gradient and swampy. They usually have a clay base in their upper reaches, near the stream headwaters, but the substratum becomes sandy a few hundred metres downstream. Flow rates are usually moderate to slow. In some cases *E. diversicolor* and other eucalypts grow to the edge of the stream; elsewhere the headwater vegetation extends along the stream. It is common for rushes and sedges to grow in the stream bed. Sometimes submerged macrophytes occur, although the extent of their occurrence is probably determined largely by the openness of the canopy and the degree of organic staining in the water.

Second-order streams are similar to first-order ones except that some of them are permanent, albeit extremely slow-flowing in summer (most dry out). During winter and spring they flow faster and frequently reach 0.5 m in depth. As a result they often have a more pronounced stream channel than first-order streams.

Third-order and fourth-order streams are permanent, reach depths of up to 1 m but otherwise are similar to second-order streams.

Rivers are essentially similar to streams except that they are larger. They have sandy substrata and often have steep, eroded banks covered in sedges, rushes and shrubs. Water flow is usually moderate and they can be several metres deep. *Agonis flexuosa* and *A. junerperina* trees usually grow along the edge of the river on a flat 'terrace' that occurs either side before the land rises to the surrounding forest.

The above description covers the 'typical' karri forest stream types. They are not typical of forest streams elsewhere in Australia, or the rest of the world, where gradients are often much greater, which leads to higher water velocities that cause erosion of the stream bed with fine sediment and sand being scoured away to expose pebbles and boulders (Hynes 1970; Bayly and Williams 1973). Sections of eroded 'riffle-zone' streams do occur in the karri (e.g. in Carey Brook,); they are generally second and third-order streams, although waterfalls (e.g. Beedelup National Park) provide extreme examples of eroded areas on higher-order streams.

In the southern and south-western part of its distribution karri grows in an even flatter landscape. The streams in these areas often flow through extensive areas of heath that occur on low sandy 'flats', while karri grows on the gentle hills. These streams usually have very darkly stained water and there is a shrubbier and taxonomically-different riparian vegetation.

The unusual nature of karri forest streams means that it is often inappropriate to extrapolate results from eastern Australian, and overseas, studies to Western Australia.

Energy Sources

The energy that drives ecological processes in streams is derived from two major sources: direct sunlight that stimulates the growth of photosynthetic aquatic plants (algae and macrophytes) in the stream; or allochthonous organic material that has been produced outside the stream and is dropped or washed into it. Allochthonous material consists of terrestrial plant matter in various stages of breakdown. Streams deriving most of their energy from photosynthesis within the stream (i.e. photosynthesis, P, is greater than respiration, R) are called autotrophic while those in which most of the energy comes from allochthonous material ($R > P$) are called heterotrophic.

Sources of energy in karri forest streams have not been studied. Instream primary production has been found to be unimportant in northern hemisphere forested streams. This has also been found to be the case in eastern Australia (Blackburn and Petr 1979). It is likely that allochthonous production is the major energy source in the low-order streams that occur in the karri forest; the larger streams and rivers draining them may rely on photosynthetic production to a greater extent because there is a general trend for the relative importance of instream production to increase as the stream channel becomes more open to sunlight (Vannote *et al.* 1980).

In most studies of the input of allochthonous material into streams three size classes of material are recognized (Bunn 1986a):

(1) coarse particulate organic matter (CPOM ≥ 1 mm);

(2) fine particulate organic matter ($0.5\ \mu m < FPOM < 1$ mm);

(3) dissolved organic matter ($DOM < 0.5\ \mu m$).

CPOM comprises mostly leaf litter, fruits, twigs, bark and branches. In Australia most CPOM enters streams in summer and is of comparatively poor quality (Bunn 1986a). *Eucalyptus marginata* is the only species that has been studied in Western Australia in terms of CPOM input into streams and its leaves have extremely long processing times and low nutritional content (Bunn 1986a). *Eucalyptus diversicolor* leaves are probably less refractile than those of *E. marginata* but still of poor quality by world standards (D.H.D. Edward[1] personal communication).

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There has been little study of sources of DOM and FPOM input into streams in Australia but it has been shown that they can comprise a substantial component of the total allochthonous input in northern hemisphere streams; Fisher and Likens (1973) found that 25 per cent of allochthonous input into a forested stream entered as DOM in the groundwater and 31 per cent entered as FPOM and DOM from the stream headwaters. Input of FPOM increases during times, and in situations, of high runoff. In agricultural areas, especially after heavy summer rain, this can lead to eutrophication and anoxia in rivers (Bunn 1986a). The same phenomenon has been reported in farm dams in Western Australia (Morrissy 1974).

There are no data available about the relative importance of FPOM and DOM input in Western Australian streams although D.H.D. Edward (personal communication) suggests that because of the refractile nature of eucalypt leaves, the small size of most invertebrate species and the lack of shredders in the jarrah forest, the input of FPOM and DOM from stream headwaters is the most important source of energy in jarrah forest streams. This organic matter is derived principally from the breakdown of sedges and other litter in the seasonally-wet headwaters.

Work by I.O. Growns[2] (unpublished data) has shown that the amphipod *Perthia* cf *acutitelson*, which grows up to 10 mm long, occurs in some karri forest streams at densities up to 600 m^{-2}. Large numbers of trichopterans and tipulids also occur. All these animals feed on CPOM and their presence suggests that CPOM is a more important energy source in the karri than jarrah forest and may be at least as significant as FPOM and DOM.

Aquatic Fauna

Faunal composition and conservation status

Although in general terms the same groups of animals occur in streams throughout the world, relative proportions of the groups and the actual species vary across continents and within regions. The limited work that has been done suggests the faunas of jarrah and karri forest streams are similar (Tables 1 and 2; I.O. Growns and D.H.D. Edward personal communication) although karri streams appear to contain more species. Edward believes more sampling will show that the karri forest acts as a refugium for aquatic macroinvertebrates and, hence, contains the jarrah stream fauna plus additional species restricted to karri streams, including many Gondwanaland relicts. Limited collecting by I.O. Growns, S.E. Bunn[3] and B. Knott[4] (personal communication) supports this view: all have found additional species, usually undescribed, that appear to be restricted to karri forest streams. *Kosrheithrus boorarus* and *Plectrotarsus minor* and an undescribed ephemeropteran from Carey Brook are examples.

Approximately 260 species of aquatic invertebrate have been collected in jarrah forest streams (D.H.D. Edward personal communication). An idea of the community composition may be gleaned from the Appendix in Bunn *et al.* (1986) which listed 145 species (Table 3). The fauna was dominated by insects, especially chironomids and trichopterans. Coleopterans, ephemeropterans and simuliids were the next most common groups. However, faunal composition varies markedly between the stream headwaters of a river and its larger channels (see Vannote *et al.* 1980), and Table 3 reflects only faunal composition of low-order streams.

Table 3 also gives a preliminary idea of the composition of the invertebrate fauna of karri forest streams, although one of the karri communities sampled contained a strong pond element. Like the jarrah forest streams, those in the karri are dominated by insects with chironomids and trichopterans being the most common groups. Coleoptera and tipulids appear to be the next most common groups. Even taking into account that some ostracods collected in the karri forest came from ponds, karri forest streams appear to contain more crustacea than those in the jarrah forest (although this may reflect that more sampling was done in stream headwaters in the karri).

Because the samples on which Table 3 is based were collected mainly from lower-order streams it omits decapod crustaceans which constitute the most important animal group, in terms of biomass, in most rivers and larger streams. Five species occur in the karri forest area: the marron (*Cherax tenuimanus*) in rivers; gilgies (*Cherax quinquecarinatus* and *Cherax crassimanus*) mostly in streams, which may be temporary; and koonacs (*Cherax plejebus* and *Cherax glaber*) mostly in swamps on the flats to the south of the karri forest although they can also occur on the banks of streams. [The taxonomy of *Cherax* species is controversial. Riek's (1967) classification was recently revised by Austin (1979, 1986) in unpublished Honours and PhD theses.]

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3 Dr S.E. Bunn, Division of Australian Environmental Studies, Griffith University, Queensland.

4 Dr B. Knott, Department of Zoology, The University of Western Australia.

Table 1

Macroinvertebrates recorded from karri forest streams and pools connected to those streams on the southern acidic flats (Pusey and Edward 1990a). Taxa that have been recorded in jarrah forest streams are marked *, taxa not recorded in jarrah streams but widespread in the south west are marked +. N.B. Some of the species (e.g. probably all the Hydracarina, all the Cladocera, most Collembola and some Ostracoda) are still-water species and, hence, unlikely to occur in karri or jarrah forest streams.

Taxonomic group	Common name	Species
Mollusca	Snails and mussels	*Glacidorbis occidentalis**
		*Ferrissia pettardi**
		Physastra sp*
Annelida	Worms and leeches	Oligochaeta sp
Hydracarina	Water mites	Oribatida sp 1
		Oribatida sp 2
		Oribatida sp 3
		Bdellidae sp
		Mesostigmata sp
		undescribed genus
		Limnesia sp
		Oxus sp
		Arrenurus sp
		Coaustraliobates sp
		Koenikea sp
Ostracoda	-	*Ilyodromus* sp 1*
		Ilyodromus sp 2*
		Ilyodromus sp 3
		Ilyodromus sp 4
		Gomphodella sp
		Cypretta sp
		Newnhamia sp*
		Limnocythere mowbrayensis+
		Limnocythere sp
		undescribed genus
Copepoda	-	Harpacticoidea sp 1
		Calamoecia attenuata+
		*C. tasmanica subattenuata**
		*Macrocyclops albidus**
		*Metacyclops cf arnaudi**
Cladocera	Water fleas	*Biapertura affinis*+
		Echinisca cf *capensis*
		Neothrix armata+

Table 1 (*continued*)

Taxonomic group	Common name	Species
		Simocephalus acutirostratus⁺
		Chydorus sp
Isopoda	-	*Amphisopus ?lintoni*
		Amphisopus ?annectans
Amphipoda	-	*Perthia acutitelson**
		Perthia sp 1
		Perthia sp 2
		undescribed genus
Decapoda	Crayfish	*Cherax ?plebejus**
Collembola	Springtails	*Sminthurides ? stagnalis*
		Xenylla sp
		Brachystomella sp
		Isotoma sp
Zygoptera	Damselflies	Lestidae sp*
Ephemeroptera	Mayflies	*Bibulena kadjina**
		*Nyungara bunni**
Plecoptera	Stoneflies	*Newmanoperla exigua**
		*Leptoperla australica**
		Gripopterygidae sp
Trichoptera	Caddisflies	*Lectrides parilis**
		Triplectides sp B*
		Oecetis sp*
		Notalina sp*
		Notalina sp A*
		Symphitoneuria sp 1
		Symphitoneuria sp 2
		Leptoceridae sp 1
		*Acroptila ?globosa**
		Oxyethira sp*
		Hellyethira/Acritoptila sp*
		Hellyethira sp B
		Maydenoptila sp A*
		Maydenoptila sp*
		*Ecnomina ?trulla**
		*Ecnomus pansus**

Table 1 (*continued*)

Taxonomic group	Common name	Species
		Ecnomidae sp*
		Kosrheithrus sp
Hemiptera	Bugs	*Diaprepocoris* sp
		Notonecta sp
Coleoptera	Beetles	*Sternopriscus browni**
		*S. marginatus**
		Sternopriscus sp 1
		*Homeodytes scutellaris**
		*Rhantus suturalis**
		*Uvarus pictus**
		Antiporus sp*
		Helodidae sp*
		Hydrophilidae sp 1*
		Hydrophilidae sp 2
		Curculionidae sp 1
		Curculionidae sp 2
Simuliidae	Blackflies	*Austrosimulium furiosum**
		Austrosimulium sp A*
		?*Cnephia* sp 1*
		?*Cnephia* sp 2*
Ceratopogonidae	-	Ceratopogonidae sp A*
		Ceratopogonidae sp F*
		Ceratopogonidae sp G*
Tipulidae	-	*Limnophila* sp
Muscidae	Flies	*Limnophora* sp*
Culicidae	Mosquitoes	*Anopheles* sp*
		Aedes sp
Chironomidae	Midges	*Aphroteniella filicornis**
		Aphroteniella sp*
		Chironomus aff *alternans**
		*Cladopelma curtivalva**
		Cladopelma sp
		*Cryptochironomus griseidorsum**
		Dicrotendipes conjunctus
		Dicrotendipes sp*

Table 1 (*continued*)

Taxonomic group	Common name	Species
		Harnischia sp*
		*Kiefferulus martini**
		?*Paratendipes* sp V12*
		Polypedilum sp V3*
		Polypedilum sp V33*
		Rheotanytarsus sp 1
		Rheotanytarsus sp 2
		Riethia sp V4*
		Riethia sp V5*
		Stempellina sp*
		Limnophyes sp*
		?*Limnophyes* sp 1
		?*Limnophyes* sp 2*
		Orthocladinae sp SW23
		Orthocladinae sp SW28
		Orthocladinae sp SW29
		Orthocladinae sp SW30
		Orthocladinae sp VCD2
		*Cricotopus annuliventris**
		*Stictocladius uniserialis**
		Stictocladius sp SW32
		?*Parakiefferiella* sp *
		Thienemanniella sp *
		Ablabesmyia sp*
		Macropelopia dalyupensis
		*Paramerina levidensis**
		Paramerina sp*
		Procladius sp*

Table 2

Macroinvertebrates recorded in Carey Brook in the karri forest by I.O. Growns but not found by Pusey and Edward (1990a).

Taxonomic group	Common name	Species
Mollusca	Snails and mussels	*Westralunio carteri*
Hydracarina	Watermites	*Piona* sp
Ostracoda	-	*Candonocypris novaezelandiae* *Bennelongia ?barangaroo*
Isopoda	-	*Hyperdesipus ?plumosis*
Zygoptera	Damselflies	*Argiolestes pusillus* *A. minimus*
Anisoptera	Dragonflies	*Acanthaeschna anacantha* *Austrogomphus lateralis* *Synthemis cyantincta* *Hemigomphus armiger* *Lathrocordulia metallica*
Megaloptera	Alderflies	*Archichauliodes* sp
Ephemeroptera	Mayflies	*Tasmanocoenis* sp *Baetis soror* *Neboissophlebia* sp undescribed genus Q undescribed genus R
Trichoptera	Caddisflies	*Taschorema pallescens* *Apilsochorema urdalum* *Ecnomina sentosa* s.1. *E. scindens* s.1. *Diplectrona* sp *Smicrophylax australis* *Adectophylax ?volutus* *Hydrobiosella* sp (MMBW sp 16) *Kosrheithrus boorarus*
Tanyderidae	-	*Radinoderus ?occidentalis* *Eutanyderus* sp
Pelecorhynchidae		*Pelecorhynchus* sp

Table 2 (*continued*)

Taxonomic group	Common name	Species
Psychodidae	Mothflies	two species
Tipulidae	Craneflies	eleven species
Empididae	-	two species
Athericidae	-	one species
Ceratopogonidae	Biting midges	four species
Thaumaleidae	-	three species
Tabanidae	March flies	two species

Table 3

Numbers of species in different taxonomic groups in streams of northern jarrah forest (Bunn *et al.* 1986) compared with preliminary data from karri forest streams (Tables 1 and 2).

Taxonomic group	Common name	No of species	
		Jarrah	Karri
Cnidaria	Hydras	1	-
Platyhelminthes	Flatworms	2	-
Nematoda	Roundworms	1	-
Nematomorpha	Gordian worms	1	-
Mollusca	Snails	3	4
Annelida	Worms and leeches	1	1
Hydracarina	Water mites	1	12
Ostracoda	-	1	12
Copepoda	-	2	5
Syncarida	-	1	-
Isopoda	-	1	3
Amphipoda	-	2	4
Decapoda	Crayfish	3	1
Ephemeroptera	Mayflies	6	7
Zygoptera	Damselflies	2	3
Anisoptera	Dragonflies	9	5
Plecoptera	Stoneflies	3	3
Hemiptera	Bugs	2	3
Megaloptera	Alderflies	1	1
Tipulidae	Craneflies	5	12
Psychodidae	Mothflies	2	2
Culicidae	Mosquitoes	1	2
Chironomidae	Midges	33	36
Ceratopogonidae	Biting midges	5	7
Simuliidae	Blackflies	8	4
Thaumaleidae	-	2	3
Tabanidae	Marchflies	1	2
Athericidae	-	1	1
Dolichopodidae	-	1	-
Empididae	-	3	3
Trichoptera	Caddisflies	26	27
Coleoptera	Beetles	14	12

Cherax tenuimanus is particularly important because marron fishing constitutes a major recreational pursuit in south-western Australia and the larger rivers in the karri forest are intensively fished when the season is open (Morrissy 1978; Morrissy *et al.* 1984). In the 1970s the biomass of *Cherax tenuimanus* in the lower reaches of the Warren River exceeded 600 kg ha^{-1} (N.M. Morrissy[5] personal communication), making it the dominant animal species in the system. However, there has been a dramatic decline in numbers of *Cherax tenuimanus* throughout the species' range in recent years. This led to the closure of the marron fishery for the 1987/88 season (Fisheries Department 1988). The cause of the decline appears to be over-fishing and the increasing eutrophication of rivers (Morrissy *et al.* 1984), combined with a series of dry years.

Nine species of native fish are thought to occur in karri forest streams, eight of which are endemic to south-western Australia (Table 4; Christensen 1982). *Lepidogalaxias salamandroides* is of considerable scientific interest; Rosen (1974) claims it is the sole southern hemisphere representative of the esocoid group, which includes northern hemisphere pike.

In addition to the other nine species, *Favinogobius suppositus* has been recorded in Big Brook (L.J. Pen[6] personal communication) although that is far removed from its recognized habitat (Allen 1982). Both *Favinogobius suppositus* and *Pseudogobius olorum* occur in the estuaries of rivers passing through the karri forest and extend into the lower reaches of the rivers, as well as occurring in coastal lakes. The estuarine *Leptatherina wallacei* has moved upstream into the Avon River from the Swan Estuary and, because it occurs in south-coast estuaries, may do the same in rivers passing through the karri forest as they become increasingly saline (L.J. Pen personal communication).

Four species of introduced fish have been recorded in karri forest streams, namely *Salmo trutta, Onchorhynchus mikiss, Perca fluviatilis* and *Gambusia affinis* (I.C. Potter[7] and L.J. Pen personal communication) although *Gambusia affinis* is rarely found. It is possible that *Carassius auratus* and *Carassius carassius* also occur but they have not been recorded.

Feeding ecology

The aquatic invertebrates inhabiting streams and rivers can be divided into four more-or-less distinct groups on the basis of their feeding ecology (Cummins and Klug 1979). Analysis of stream faunas according to the number of species in each feeding group has frequently been used to indicate the relative importance of different kinds of energy input into the stream or as an indicator of stream health (e.g. Gurtz and Wallace 1984; Bunn 1986b). This work is under-pinned by an extensive body of theory, best summarized in the River Continuum Concept (Vannote *et al.* 1980; Minshall *et al.* 1985). The feeding groups are (Cummins and Klug 1979):

Shredders - (e.g. amphipods) feed on CPOM. The shredder/CPOM system is a complex one and is best

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Table 4

Species of native fish in karri forest streams, their conservation status and habitat preferences in south-western Australia.

Scientific name	Common name	Preferred habitat type[a]	Main distribution in woodchip area[b]	Range[c]	Status[b]
Bostockia porosa	Nightfish	stream	all habitats	south-west	common
Edelia vittata	Western pigmy perch	stream	forest, especially karri	south-west	common
Galaxiella nigrostriata	Black-stripe minnow	pond	?flats	?inland from Albany	rare
Galaxias occidentalis	Western minnow	stream	?forest, especially jarrah	Perth to Albany	mod. common
Galaxiella munda	Mud minnow	pond	jarrah and flats	Perth to Albany	common
Lepidogalaxias salamandroides	Salamander fish	pond	jarrah and flats	Augusta to Albany	common
Nannatherina balstoni	Balston's pigmy perch	stream	?all habitats	Augusta to Albany	rare
Geotria australis	Pouched lamprey	stream	?all habitats	Perth to Albany	common[d]
Tandanus bostocki	Freshwater cobbler	river[d]	-	coastal south-west	?common[d]

[a]G.R. Allen personal communication
[b] Christensen (1982)
[c] Allen (1982)
[d] I.C. Potter and L.J. Pen personal communication

explained with reference to leaf material. The same principles apply to other types of CPOM but processing times are much longer. When leaves fall into the water (or, in the cases of temporary streams, are first inundated) there is a fairly rapid initial loss of weight as the leaves are leached, i.e. DOM is produced. This is followed by a period when leaf weight remains fairly constant and the leaves are colonized by bacteria and hyphomycete fungi. These microbes transform CPOM to FPOM and DOM through their own metabolism and significantly improve the digestibility of the leaves for shredders. The major production of FPOM occurs, however, as CPOM is broken down by shredders eating it and passing the digested fragments out as FPOM in their faeces. Physical abrasion on the stream bed also results in CPOM being broken down into FPOM.

Collectors - feed on FPOM. Collector-gatherers, such as many chironomid and ephemeropteran larvae, feed on sediment-related FPOM whereas collector-filterers, of which simuliid and net-spinning trichopteran larvae are examples, feed on FPOM carried in the water column. Collectors feed on FPOM from a variety of sources: direct input from the stream headwater, CPOM broken down by shredders or abrasion, DOM that has flocculated or which decomposing microbes have metabolized and the faeces of other invertebrates.

Scrapers - (e.g. limpets and some ephemeropteran larvae) graze periphyton and other food adhering to solid surfaces. Scrapers are more common in autotrophic systems, often in areas of faster flowing water.

Predators - (e.g. zygopteran larvae) capture live prey.

Some species are polytrophic and occupy several of the above feeding categories. The *Cherax* species occurring in the karri forest are probably primarily shredders but also feed on live plants (particularly plant roots) and other animals, including their young (N.M. Morrissy personal communication).

Although they are not usually fitted into the above feeding scheme, fish are either predators or scrapers that also feed on macrophytes (Hynes 1970). All the native fish, except *Geotria australis*, occurring in karri forest streams are predators, feeding mainly on aquatic insects and insect larvae although *Galaxias occidentalis* feeds extensively on terrestrial insects (Pen and Potter 1991b) and *Edelia vittata* and *Nannatherina balstoni* occasionally eat juvenile fish. The composition of the diet of *Lepidogalaxias salamandroides* and, presumably, other species shows changes during the year (G.R. Allen[8] personal communication). Larval *Geotria australis* feed on algae and on bacteria associated with decaying organic matter; adults do not feed while in freshwater (Potter *et al.* 1986).

In an analysis of the functional organization of the invertebrate communities in jarrah forest streams in south-western Australia, Bunn (1986b) found that low-order streams were dominated by detritivores, especially collectors, which confirmed that the streams are heterotrophic. Shredders occurred but were less common than predicted by the River Continuum Concept (Vannote *et al.* 1980), probably because of the refractile nature of eucalypt leaves. [In recent years the general applicability of the River Continuum Concept, especially to Australian streams, has been questioned (e.g. Lake and Barmuta 1986).] As expected, collector-filterers were more common in winter, when FPOM is in suspension, than in summer when flow rates are low. Less predictably scrapers, which feed on algae, were more common in winter than summer. The reason for this was unclear but it suggested that primary productivity is never high in these small, closed-canopy streams. Lebel (1987) confirmed Bunn's results.

There have been no studies of organic matter processing in karri forest streams or the major energy inputs so it is impossible to do more than speculate about the functional organization of karri forest streams. However, it appears reasonably certain that the major source of carbon in low-order streams is allochthonous and preliminary indications from the work of I.O. Growns are that shredders are an important component of the fauna of these streams (see **Energy Sources**).

Microhabitats

Adults of most insect groups occurring in streams are terrestrial. They usually live in the riparian zone beside the stream and are dependent on riparian vegetation for their habitat (e.g. Riek 1970a,b).

Aquatic insect larvae and other aquatic invertebrates are directly dependent on stream habitat, utilizing four main substrata within the stream:

(1) rocks/boulders/pebbles;

(2) gravel/sand/silt;

(3) organic material (wood, leaves etc);

(4) aquatic plants.

Selection of particular substrata by individual species is influenced by feeding requirements, water velocity, biological interactions and other factors (Hynes 1970; Mackay and Wiggins 1979; Pinder 1986).

8 Dr G.R. Allen, Department of Ichthyology, Western Australian Museum.

Preliminary work by I.O. Growns (personal communication) has shown that in first and second-order tributaries of Carey Brook in the karri forest, sand/silt substrata are populated by large numbers of trichopterans and amphipods. Plecopterans and ephemeropterans occur but in smaller numbers. The number of animals in the mid-sections of Carey Brook, among the boulder/pebble riffles, is extremely variable. In some areas trichopterans, simuliids and ephemeropterans are common. Plectoperan abundance seems to be related to season, being high in spring and low in summer. Chironomids comprise approximately 50 per cent of the invertebrate population at any location. In areas of accumulated leaf debris ostracods and calanoid and harpacticoid copepods occur as well as amphipods.

Cherax tenuimanus adults live on the bottom in deeper sections of rivers, which usually have sand substrata. Juveniles live among the litter in shallow water, to escape predation by adults, in shaded sections of rivers where poor visibility prevents predation by birds (N.M. Morrissy personal communication).

Although a few species of fish are confined to particular types of substratum, most fish occur independently of substratum except when spawning. Depth of water and velocity of current are more important in determining fish distribution (Hynes 1970). Shelter is also important to most species of fish, largely because it provides refuge from the current, and they tend to congregate where log-jams, macrophytes or changes in stream contour provide this (Hynes 1970). The fish species in karri forest streams probably require shelter, especially *Edelia vittata* (Hutchinson 1991) and *Nannatherina balstoni*, but species that occur mostly in ponds such as *Lepidogalaxias salamandroides* and *Galaxiella nigrostriata* are frequently found in areas with a clear bottom (G.R. Allen personal communication).

Life histories

There has been comparatively little work published on life histories of aquatic invertebrates in Australia and almost nothing on species occurring in streams of the south-west other than Edward (1986) and Bunn (1988b). The work published on plecopterans, ephemeropterans and trichopterans in eastern Australia showed that a tremendous array of life cycles can occur, with some species having larval/nymphal stages of three or four years duration while others can have three generations a year. Nevertheless the most common pattern is a univoltine one (i.e. one generation per year) (Hynes and Hynes 1975; Marchant *et al.* 1984; Yule 1985; Campbell 1986; Dean and Cartwright 1987). Rates of development are strongly influenced by temperature and, it seems, to a lesser extent by food (Campbell 1986). Different temperatures can alter the degree of synchrony in emergence and, in some cases, can affect the number of generations per year. The very small amount of work done in jarrah or karri forest streams suggests that a number of the animals occurring there, and particularly the Gondwanaland relicts, are probably univoltine (Bunn 1988b; D.H.D. Edward personal communication).

The temporary nature of many first-order streams in the karri forest means that the species inhabiting them must have special adaptations in terms of life histories or habitat preferences that enable populations to be maintained long-term (Towns 1985; Boulton and Suter 1986). Possible adaptations in life histories are:

(1) having a drought-resistant stage to survive the period when the stream is dry;

(2) recolonizing the stream from nearby pools (on the same watercourse) or adjacent permanent streams after above-ground flow recommences. This requires fairly strong powers of dispersal (e.g. a flying adult stage) to recolonize from adjacent streams, or tolerance of low oxygen levels and other adaptations to still water if recolonization is to occur from pools in the creek system;

(3) rapid larval growth during periods of stream flow.

Alternatively, animals can survive dry periods by moving down into the stream bed to where water is still present. Koonacs and, to a lesser extent, gilgies do this by burrowing (N.M. Morrissy personal communication) and D.H.D. Edward (personal communication) suggests this is a common phenomenon amongst macroinvertebrates in jarrah (and probably karri) forest streams although it has not been properly documented. The best data documenting this type of movement come from the northern hemisphere (e.g. Williams and Hynes 1976, 1977).

Most species of fish live several years. Often they are sedentary in the non-breeding season although some species exhibit seasonal movements related to water depth or other environmental factors. Many species migrate to breed. In some cases fish that spend their adult life at sea or in estuaries move into rivers to lay eggs, the larvae from which spend the early development period in rivers before moving out to the sea. Many lake-dwelling species also spawn in rivers. Frequently river-dwelling fish move upstream into low-order creeks or onto flood-plains to breed. Timing of the breeding season is determined by photoperiod, water temperature or flow rate (Hynes 1970).

Although there has been little work on fish in the karri forest, there has been a recent spate of studies in other habitats on the biology of fish that occur in karri forest streams. *Lepidogalaxias salamandroides* and *Geotria australis* are the most intensively studied species. Allen and Berra (1989) have shown that *L. salamandroides* lives three or four years, has high annual mortality and breeds any time of the year that there is sufficient water. McDowall and Pusey (1983) reported that adults dig a tubular burrow and aestivate in damp mud when water dries out in the pools they are occupying. They also stated that eggs are laid in spring and are probably drought-resistant; Allen and Berra (1989) reported hatching in spring and implied that young fish aestivate as pools dry out. Males become sexually mature at the end of their first year of life, in females maturity is delayed until the second year.

Geotria australis has a more complicated life history (Potter *et al.* 1986). Spawning in south-western Australia (e.g. Donnelly River) occurs in October or November, the young then spend four or five years as larvae. Metamorphosis begins in January or February (just over four years after spawning) and is completed by the time downstream migration occurs in July or August. The downstream migration into the ocean coincides with increased discharge rates in rivers.

After spending a considerable time in the ocean, where they feed on fish, adults return to freshwater to spawn. They enter the Donnelly and Warren Rivers in June or July and spawn in October or November of the following year.

Galaxias occidentalis, *Bostockia porosa* and *Edelia vittata* have been studied in the Collie River, which is in the jarrah forest (Pen and Potter 1990, 1991a,b). All three species spend summer and autumn in the main branch of the Collie River. They breed in late winter/early spring after undertaking an upstream migration during winter. Sexually maturing *Galaxias occidentalis* occur predominantly in stream headwaters and low-order creeks but *Bostockia porosa* and *Edelia vittata* occur in significant numbers at this time in floodwaters adjacent to the river.

Galaxias occidentalis and *Edelia vittata* populations consist predominantly of fish in their first year of life although they can survive up to three years. Sexual maturity is reached at the end of the first year. *Bostockia porosa* is longer-lived, with a small proportion of the population living beyond three years (maximum life span is at least six years), and females do not mature until the end of their second year although some males mature in the first year.

Pusey and Edward (1990b) provide some information about the life cycles of *Galaxiella munda*, *Galaxiella nigrostriata* and *Nannatherina balstoni*. However, there are substantial gaps in knowledge of the latter two species; L.J. Pen and I.C. Potter (unpublished data) have fairly comprehensive data on *Galaxiella munda*. M.J. Hutchinson[9] (personal communication) has recently observed the spawning behaviour of *Tandanus bostocki* but there is little known about the life history of this species.

Forest Management

Timber harvesting

There are numerous overseas studies showing that land disturbance in general, including clearing for agriculture, timber harvesting, road construction and wildfire, can cause substantial changes in the composition of fish and stream invertebrate communities (e.g. Graynoth 1979; Newbold *et al.* 1980; Gurtz and Wallace 1984; Wallace and Gurtz 1986; see Blackie *et al.* 1980; Doeg and Koehn 1990b for bibliographies). Whether timber harvesting and associated road construction cause changes in the biota of Australian streams is less clear. By analogy with overseas situations, changes have been predicted (Michaelis 1984; Campbell and Doeg 1989; Doeg and Koehn 1990a,b) but results are available from only three studies.

Robinson (1977) and Richardson (1985) both suggested that timber harvesting resulted in changes in streams communities in eastern Australia. Doeg and Koehn (1990a) have pointed out methodological problems in both Robinson's and Richardson's work but concluded that the differences observed by Richardson above and below a logged section of stream and a road crossing nine months after logging ceased were probably real. This is in contrast to what was implied by the work of Cornish (1980) in the same area, who found that logging had little effect on the quality of drinking water. The studies of Richardson and Cornish suggest that methods traditionally used to monitor the effect of logging on water quality *per se* are inadequate to predict what effect there will be on stream fauna.

A recently completed study in the karri forest of Western Australia showed that timber harvesting without stream buffers resulted in changes to community structure (but not species richness or abundance) that lasted at least eight years after harvesting ceased (Growns and Davis 1991). The community structure of a stream with a buffer 100 m

9 M.J. Hutchinson, Department of Geography, The University of Western Australia.

wide was similar to unlogged control streams; Growns and Davis (1991) concluded that a 100 m wide buffer prevented community changes.

There are nine ways by which timber harvesting and associated road construction might cause changes to the aquatic communities of karri forests streams. In all cases changes can be prevented by retaining adequate buffer strips of undisturbed vegetation and by careful design and construction of road crossings over streams.

(1) Most sediment originates from roads and snig tracks, especially where they cross streams, and landings constructed as part of the timber harvesting operation (Melbourne and Metropolitan Board of Works 1980; Campbell and Doeg 1989). Leaving buffer strips of intact vegetation on both sides of streams and constructing stream crossings carefully substantially reduces the amount of sediment entering streams as a result of timber harvesting (Clinnick 1985).

Most sediment transport occurs during very short periods after rain (Gilmour 1971; Weston *et al.* 1983). Campbell and Doeg (1989) showed that many studies of water quality in Australian streams have under-estimated sediment transport because peak flows were not sampled. This, together with the fact that sediment levels are largely influenced by topography and soil type as well as intensity of rainfall events (Olive and Walker 1982), makes it difficult to compare the severity of impacts in different studies.

There are two types of sediment that can affect aquatic fauna - *suspended* and *deposited.* Whiteley (1978) observed increased suspended sediment levels during wet weather in most karri forest streams he sampled after harvesting with buffers. The levels of flow-weighted suspended sediment levels increased six-fold in a March Road stream in the karri forest after clear-felling without buffers (Borg *et al.* 1987a). They reached a maximum concentration of about 550 mg L^{-1} during heavy rain (H. Borg[10] personal communication), which is similar to the maximum level of 860 mg L^{-1} recorded by Graynoth (1979) in New Zealand, where increased sediment had pronounced effects on the fauna.

Increased levels of suspended sediment can clog the gills of some animals and kill them directly; it also increases rate of invertebrate drift. Doeg and Milledge (1991) provided preliminary data suggesting the threshold at which suspended sediment affects some aquatic invertebrates in eastern Australia is <250 mg L^{-1}. The ability of different species to tolerate sediment varies greatly, however, and an indication of this variability and/or the extent of natural disasters is provided by the fact that the concentration of suspended sediment can exceed 100 000 mg L^{-1} in streams flowing through areas prone to erosion after wildfire and heavy rain (see **Fire**).

Deposited sediment can carpet the stream bed (reducing the availability of organic matter and making conditions anoxic) or can fill the interstitial spaces in which many invertebrates live (Cordone and Kelly 1961; Chutter 1969; Doeg *et al.* 1987; Bunn 1988b). Bunn *et al.* (1986) compared the faunas of 'undisturbed' streams and those in which sediment had been deposited over the stream bed as a result of bauxite mining operations in the Western Australian jarrah forest. They found little difference apart from the occurrence of a silt-tolerant species of ephemeropteran in sedimented streams. However, subsequently Bunn (1988b) found the breakdown of CPOM by invertebrates was virtually eliminated in the sedimented streams. There were substantial differences between the leaf litter communities of sedimented and undisturbed streams: sedimented streams contained more animals but they were mostly predators and very few shredders were present.

Richardson (1985) attributed the changes she had observed in the invertebrate fauna downstream from timber harvesting and a logging road across a stream in New South Wales to the effect of increased sedimentation. Elevated sediment levels were one of the factors that appeared important in changing community composition in the study by Growns and Davis (1991) in the karri forest.

(2) Increased concentration of salts in streams has been shown to affect community composition in North American and New Zealand streams (Bormann *et al.* 1974; Graynoth 1979; Lemly 1982). The extent and duration of increases in salinity in Western Australian forest streams after timber harvesting depends on several factors of which rainfall and buffer width are most important (Borg *et al.* 1987b). In the most extreme cases without buffers in the karri forest, salinities will take about ten years after timber harvesting ceases to return to pre-logging values. Buffers largely prevent increases in salinity (Borg *et al.* 1987b).

10 H. Borg, Water Authority of Western Australia.

Harvesting without a buffer, however, caused salinities during periods of low flow-rate in a March Road creek in the karri forest to increase more than two-fold (from 700-1500 mg L^{-1} for a month, Steering Committee for Research on Land Use and Water Supply 1987). Growns and Davis (1991) observed changes in the community composition of March Road, and another stream where harvesting occurred without a buffer, and concluded that salinity was one of the factors responsible for the changes.

Hart *et al.* (1990, 1991) suggested that adverse biological effects occur in Australian streams if salinities increase beyond 1000 mg L^{-1}. Robson (1990) noted changes in the invertebrate fauna of streams in wandoo forest of Western Australia as a result of salinities increasing to 3000-5000 mg L^{-1}.

(3) Elevated water temperature owing to lack of shading after harvesting affects the life cycles of many animals and, thus, community composition (Brown and Krygier 1970; Lee and Samuel 1976; Rishel *et al.* 1982). Because of the comparatively high temperatures in south-western Australia, it is likely that harvesting without buffers would elevate water temperature enough to disrupt life cycles of some species until the same level of shading is achieved by regrowth (see Hynes and Hynes 1975; Campbell 1986; Bunn 1988b). The increase in temperature that occurs when harvesting without buffers has not been measured in Western Australia.

Increased temperatures can be prevented by leaving buffer strips of undisturbed vegetation.

(4) Increased input of FPOM (or fine sediment) can lead to eutrophication in streams, with concomitant effects on the fauna (Graynoth 1979; Bunn 1986a). However, adequate buffers prevent elevated input of FPOM into streams.

Borg *et al.* (1988) observed increases in FPOM in the karri forest streams in the Sutton and Poole blocks after harvesting without a buffer. In the subsequent two years algal blooms developed in the Sutton block stream. This was probably the result of increased insolation of the stream and, perhaps, nutrient enrichment as a result of the extra input of organic matter. It is possible that eutrophication *per se* would affect karri stream communities (see Lemly 1982), in addition to the direct effects of increased insolation on temperature and, hence, productivity.

Elevated FPOM eight years after harvesting was one of the differences between logged and unlogged streams in the Sutton and Poole blocks studied by Growns and Davis (1991) where differences in community compositions occurred. The lower nitrogen levels in logged streams, however, suggested that the differences between streams were not the result of nutrient enrichment.

(5) Deposition of logging debris in streams can result in substantial changes to stream profiles, thus affecting fish and some aquatic invertebrates (Graynoth 1979; Winterbourn 1986; Campbell and Doeg 1989). However, retention of buffer strips ensures that logging debris does not enter streams.

Borg *et al.* (1988) observed significant changes in the profile of the stream channel when logging was conducted on the banks of the Sutton block stream in the karri forest. Graynoth (1979) showed that this affected the biota of streams in New Zealand.

(6) Short-term alteration in the pattern of input of allochthonous material and increased primary production (as a result of opening the canopy) may lead to changes in community composition (Lyford and Gregory 1975) although this is not the case in studies undertaken in New Zealand (Winterbourn 1986). Most studies have found increased use of periphyton by invertebrates after timber harvesting. In spite of theoretical expectations, there are no data indicating that changed patterns of allochthonous input have affected invertebrates (Campbell and Doeg 1989). The likelihood of these effects in the karri forest is unknown but adequate buffer strips circumvent the problem by preventing increased primary production and changes in patterns of allochthonous input.

(7) Long-term reduction in litter input from riparian vegetation after timber harvesting and regeneration may affect aquatic communities although adequate stream buffers should prevent a reduction of litter input.

There are two components of litter used by aquatic animals - *leaf litter* and *branches or logs*. For many years after regeneration forests in North America release less leaf litter into streams and the litter released has a different species composition from that released by mature forest (Webster and Waide 1982; Webster *et al.* 1987). This leaf litter provides an energy source for invertebrates inhabiting streams but leaves of some plant species that are abundant in regenerating Australian forests, such as *Acacia,* are not palatable to stream invertebrates

(Campbell and Doeg 1989). Overseas studies suggest that the reduction of leaf litter input may result in a depauperate stream community (Haefner and Wallace 1981).

Although a lot of branches and logs may enter streams during harvesting, with the consequences discussed in (5) above, in the longer term the quantity of branches and logs entering streams is reduced after timber harvesting. Golladay *et al.* (1987) suggested the number of debris dams may be depressed for 100-400 years after harvesting and regeneration in North America. There is evidence to suggest the reduction of debris reduces fish and invertebrate populations (Elliott 1986; Hutchinson 1991) through loss of habitat and cover.

(8) Even if CPOM is the major energy source in karri forest streams the input of FPOM and DOM from the swampy stream headwaters will still be important (see **Energy Sources**). Harvesting areas adjacent to headwaters without buffers may result in community changes in downstream areas because of different organic matter inputs (as well as increased sediment loads), even though the downstream reaches are protected by buffer strips.

(9) Poor road design where roads cross streams can result in barriers to the movement of fish. However, roads are only one of a number of barriers to fish movement in south-western Australia; others include farm dams on streams, gauging stations, debris pushed into streams during land clearing and natural obstructions. Cumulatively, the man-made barriers may lead to reductions in populations of native fish through limiting access to potential breeding habitat, preventing dispersal between habitats and trapping fish in receding pools during dry periods (L.J. Pen and M.J. Hutchinson personal communication).

Like many roads serving other purposes in the karri forest, the stream crossings of some logging roads cannot be easily negotiated by native fish. Appropriate design specifications are now available for road crossings and gauging stations (Aquatic Research Laboratory 1991; L.J. Pen personal communication); farm dams and careless land clearing remain problems.

As already indicated, adverse effects of timber harvesting and associated road construction can be prevented by leaving buffers of undisturbed riparian vegetation along streams. Clinnick (1985) reviewed published data and concluded that for Australian timber harvesting operations a buffer of 30 m either side of the stream should be left to ensure acceptable water quality and minimal disturbance of the stream ecosystem. Clinnick (1985) regarded a buffer of at least 20 m width along temporary streams and stream headwaters as essential to achieve this protection.

So far, the adequacy of the buffer widths advocated by Clinnick has not been investigated experimentally with respect to invertebrates and fish (see Campbell and Doeg 1989). However, Growns and Davis (1991) found that wider buffers (100 m) along karri forest streams provided adequate protection for the aquatic community and commented that any buffer width that maintained water quality would probably be adequate. Borg *et al.* (1988) found that 50 m wide buffers were sufficient to maintain water quality in karri forest streams, although Whiteley's (1978) study suggested wider buffers (or tighter controls over harvesting operations including, perhaps, better road design) may be required. Correct implementation of harvesting prescriptions to prevent breaches of buffer strips is probably a more critical issue in stream protection than the exact width of buffer used. At present buffer strips of 50-200 m either side of the watercourse are used along all rivers and many streams in the karri forest and it is likely that this system will be extended (R.J. Underwood[11] personal communication).

Fire

There is little information available about the effect of fire on stream invertebrates (see Campbell and Doeg 1989) but the principles that apply to timber harvesting should also apply to fire when similar levels of disturbance result.

Low-intensity fires, such as prescribed fuel-reduction burns, have little effect on soil-water infiltration rates or other parameters likely to affect water quality in streams (Gilmour and Cheney 1968) but wildfires can increase sediment levels, salinity, nutrient levels and the amount of organic material in streams (Shea *et al.* 1981; Olive and Walker 1982; Campbell and Doeg 1989). The extent of increases in the above parameters depends on fire intensity, nature of the catchment, period between fire and the first significant rainfall event, and the intensity of the rainfall event (Chessman 1986; Campbell and Doeg 1989).

Increased accession of sediment to streams is probably the effect of fire that has most impact on stream invertebrate and fish communities although there is often a pronounced increase in stream discharge as well. Seven months after wildfire in the

11 R.J. Underwood, Department of Conservation and Land Management.

Snowy Mountains, New South Wales, sediment concentrations of 112 000 mg L^{-1} and 143 000 mg L^{-1} were measured in creeks that had highest recorded pre-fire maxima of 334 mg L^{-1} and 7052 mg L^{-1}, respectively (Brown 1972). Chessman (1986) found sediment concentrations of 2300 mg L^{-1} in the Cann River after the Ash Wednesday fires in Victoria. Lower concentrations (47-283 mg L^{-1}) have been recorded elsewhere (Midgley 1973; Burget *et al.* 1980, 1981; Chessman 1986).

Depending largely on the rate of revegetation, water quality often improves rapidly after wildfire although sediment will remain in the streambed. Chessman (1986) noted that water quality had begun improving four months after the Ash Wednesday fires. In contrast, Burgess *et al.* (1980, 1981) reported that wildfire near Eden, New South Wales, caused larger changes of greater duration in sediment load than did clear-felling. The greatest increases in sediment loads were caused by timber harvesting followed by high-intensity fire (Burgess *et al.* 1981).

CURRENT RESEARCH

Research currently underway in karri forest streams can best be summarized under the headings of **Fauna** and **Impacts of timber harvesting.** We have also summarized relevant studies in the jarrah forest and other parts of south-western Australia. Doeg and Koehn (1990a) have recently summarized current forest stream research in Australia on a State-by-State basis.

Fauna

Fish

Three institutions are involved in fish research in the karri forest.

At the University of Western Australia, B.J. Pusey recently completed a PhD in the Zoology Department on the biology and life history of *Lepidogalaxias salamandroides* and other native fish in the flats on the southern edge of the karri forest (Pusey and Edward 1990a,b). M.J. Hutchinson has just finished a PhD in the Geography Department, studying the factors affecting fish distribution in the Murray River, including the effect of the introduced trout (*Salmo trutta*) and *Perca fluviatilis* and the effect of man-made barriers, such as gauging weirs and roads (Hutchinson 1991). The Aquatic Research Laboratory in the Zoology Department, led by D.H.D. Edward, is carrying out some research into the biology of fish in the jarrah forest as part of their extensive monitoring program for the Western Australian Water Authority (Aquatic Research Laboratory 1988, 1991; Pusey *et al.* 1989).

At Murdoch University there is a strong research group studying fish in the School of Biological and Environmental Sciences, although the only work being done in the karri forest is a study by L.J. Pen on the effect of dams and weirs on fish migration being conducted at Big Brook for the Water Authority (Pen *et al.* 1988) and research being conducted on lampreys (*Geotria australis*) by I.C. Potter and colleagues (Potter *et al.* 1986). However, the results of work by Pen and Potter (1990, 1991a,b) on the biology of fish in the Collie River are relevant to management of stream fauna throughout the south-west.

G. Allen and T. Berra of the Western Australian Museum are carrying out inventories and taxonomic research throughout south-western Australia, including the karri forest, and have recently completed a detailed study of the life history of *Lepidogalaxias salamandroides* (Allen and Berra 1989).

Aquatic invertebrates

A PhD study in the karri forest by I.O. Growns of the School of Biological and Environmental Science, Murdoch University is currently being written up (discussed under **Impacts of timber harvesting**).

The Fisheries Department has a general research and monitoring program for *Cherax tenuimanus*, led by N.M. Morrissy, but no specific research is being done in the karri forest.

A considerable amount of research has been undertaken recently on the invertebrates of jarrah forest streams (Bunn 1986a,b, 1988a,b,c; Bunn *et al.* 1986; Storey and Edward 1989; Storey *et al.* 1990, 1991).

Impacts of timber harvesting

Growns is about to submit his PhD. He has addressed two questions: (1) whether timber harvesting affects aquatic invertebrate communities in karri forest streams, and (2) whether the communities differ between first and higher-order streams. He worked on Carey Brook and the Department of Conservation and Land Management altered its timber harvesting program in the area to provide appropriate logged and unlogged areas for short-term studies. Some of the paired catchments studied by the Steering Committee for Research on Land Use and Water Supply (1987) were also examined to provide a long-term perspective (Growns and Davis 1991).

Some of the research being conducted in the jarrah forest by the Aquatic Research Laboratory at the University of Western Australia will also provide useful information about the effect of logging on aquatic invertebrates. This includes PhD studies by P. Davies on community structure and function in relation to autotrophy/heterotrophy and by L. Lebel on trichopterans, as well as studies cited under the previous **Aquatic invertebrates** section.

HIGH PRIORITY ADDITIONAL RESEARCH REQUIREMENTS

The five research topics involving karri forest streams that should receive highest priority are:

Inventory of aquatic invertebrates - the first step in devising a conservation strategy for stream fauna in the karri forest is finding out what animals occur where and determining their conservation status. There is a need for broad-scale surveys to document the fauna of karri forest streams and to establish which species are endemic, how restricted their distribution is and which parts of the stream system they inhabit. It is essential that animals are named in this type of work; voucher collections have very limited value and, hence, the work must have a taxonomic component.

Impact of logging on aquatic communities - just as important as undertaking an inventory, is the need to quantify further the impact of timber harvesting and subsequent regeneration on the biota of karri forests streams. This study could be undertaken in conjunction with an inventory. Growns and Davis (1991) have shown that changes in community composition persist at least eight years when areas adjacent to streams are harvested without a buffer. The main issues to be addressed are: (1) whether Growns and Davis' (1991) results are typical of karri forest streams or reflect peculiarities of their sites, (2) which species, if any, disappear from streams as a result of harvesting adjacent forest, (3) how long changes in community composition persist, and (4) how wide buffers must be to prevent given levels of change. The results of the inventory could be used to determine which streams require full protection and which streams could be allowed to have a period of perturbation. Buffer widths could be set accordingly.

Sources of energy input - management of karri forest streams is dependent on understanding how they function. A study of energy flow through the stream system, in particular identifying the major sources of energy input and documenting how the community is structured around energy transfer through the system, would provide much of the required information. Direct studies of the effect of timber harvesting and regeneration are essential and have the advantage of producing results fairly quickly but usually provide limited information about why particular results are obtained. Longer-term studies, in conjunction with direct studies of the effect of harvesting, will provide a better scientific basis for the design of buffer systems, harvesting prescriptions and stream management guidelines.

Structure and composition of stream substrata - as noted under **Forest Management**, input of sediment in streams as a result of land disturbance occurs as occasional short-term events. The effects on stream fauna will largely depend on two sets of factors:

(1) whether fine sediment penetrates the stream bed, how long it remains and whether it changes the structure or composition of the bed.

(2) whether the stream fauna is dependent in some way on interstitial features of the stream bed such as:

  (a) interstitial spaces free of fine inorganic sediment, which certain species may move through at a stage in their life history or use as refugia in dry periods;

  (b) high organic: inorganic ratio in fine material to act as a food source for collectors-gatherers.

The extent of sediment input and its effect on the stream fauna could be addressed comparatively simply using established methods of collecting cores from stream beds and by subsequent analysis of the fauna present at different depths in relation to bed structure and composition.

Life cycles and spawning in fish - management of fish species, like other animals, requires knowledge of life cycles. This information is currently lacking for *Galaxiella nigrostriata, Tandanus bostocki*, and *Nannatherina balstoni* and should be collected.

Even for species with known life-cycles, information about spawning behaviour, egg development and hatching are not available and in most cases the spawning areas are not known. Because recruitment is such a critical phase of the life cycle it is important that there is a systematic study of the spawning areas and early development of the native fish of the karri forest.

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