A Review of Knowledge on the Effect of Key Disturbances on Aquatic Invertebrates and Fish in the South-west Forest Region of Western Australia

By

P. Horwitz[1], E. Jasinska[1], E. Fairhurst[2] and J.A. Davis[2]

[1] Centre for Ecosystem Management, Edith Cowan University, Joondalup, Western Australia 6027
[2] School of Biological Science, Murdoch University, Murdoch, Western Australia 6150

A Report Prepared for

ENVIRONMENT AUSTRALIA
Environment Forest Taskforce

October 1997

1. INTRODUCTION, RATIONALE AND APPROACH

The present report is a review of the knowledge of the effects of key disturbances on the aquatic invertebrates and fish in the south-west forest region of Western Australia. The aims of the review were to:

A) review and collate all available information on the impact of disturbances, including single and multiple disturbance effects, on species and communities of aquatic macroinvertebrates and fish;

B) where information is available, describe the recovery of species and communities from the disturbance and identify management actions which will ameliorate the negative impacts of disturbances on species and communities;

C) where appropriate, provide summary statements of the best available knowledge;

D) identify gaps in knowledge on the subject of impacts of disturbances and recommend directions for future research;

E) provide recommendations for the management of aquatic invertebrates and fish with regard to each disturbance type.

The area/region covered by this review includes the high rainfal region of south-west Australia, principally that area defined for the Regional Forest Agreement (the bioregions of Jarrah and Warren). This review also draws on information which has been compiled for locations adjacent to these two bioregions, for the following reasons:

• similar threatening processes are likely to be operative both outside and inside these bioregions;
• forests occur outside these two bioregions (for instance tuart forests and pine forests), and
• populations of species may occur across the nominal bioregional boundaries.

As such, forest management issues in adjacent locations are relevant and applicable, and where knowledge has been gathered on species and processes from outside the bioregions, that knowledge is relevant to a review of this nature. For instance, this review includes information found for macroinvertebrates and fish on the Swan Coastal Plain (SCP); several recognised taxa and communities are regarded as threatened from the northern part of the SCP, where groundwater abstraction, pine plantations, and urbanisation have combined to pose a threat to their existence. Throughout the report this study region will be referred to as the “Regional Forest Agreement study area”, or “RFA”.

Statement of limitations

The authors of this report are grateful for having been given the opportunity to compile a review of this nature, and for the chance to provide their interpretations of existing information on the subject matter. However, the review has been compiled under extreme constraints of time (only six weeks were allowed from the commencement of the contract), effectively restricting the authors' ability to critically reflect on the content of numerous, and often complex pieces of information, to gain access to obscure literature, to consult with busy people, and to gain access to confidential reports. While the authors stand by their interpretations and conclusions, they reserved the right to review the document prior to its publication in any form, electronic or otherwise. The authors also requested that the document not be altered editorially or otherwise without their expressed consent.

The authors of this report have not attempted to draw an *a priori* qualitative distinction between the information content of published and refereed information, published but unrefereed reports, unpublished reports, and personal observations or personal communications. In other words, for the review *per se* we intend to present a state of the knowledge as it is held by practitioners experienced in aquatic macroinvertebrate and fish issues in south-west Australia (see also Section 3.3).

Approach

Information for the present report came from the personal libraries of the authors, and was supplemented by literature made available from individual researchers, theses from Environmental Management, Edith Cowan University (Joondalup Campus); Environmental Sciences, Murdoch University; and Department of Zoology, The University of Western Australia. Additional published reports, unpublished reports and scientific papers were obtained from the libraries of the Western Australian Department of Conservation and Land Management and Department of Environmental Protection. We are particularly grateful to Dr. Peter Davies for providing us with a selection of reports undertaken by Streamtec, Natural Systems Research, and the Aquatic Research Laboratory of The University of Western Australia.

The following authorities were consulted during the course of the review: Dr. Mark Harvey (Western Australian Museum), Dr. Peter Davies, Dr. Don Edward, Dr. Brenton Knott, Dr. Andrew Storey (University of Western Australia), Dr. Stuart Halse, Mr. John Blyth, Mrs. Val English (from the Department of Conservation and Land Management), Mr David Morgan, Mr Gavin Sarre, and Dr Howard Gill in the Freshwater Fish Group (Murdoch University), Ms. Kerry Trayler (Water and Rivers Commission), Dr. Mark Lund (Edith Cowan University) and Dr. Stuart Bunn (Griffith University). Dr Stuart Halse also provided critical comments on an earlier draft of the report. We are grateful for their time; readers of the report should however recognise that these authorities are in no way responsible for errors of fact or judgement, or for omissions of key information sources, should such appear herein.

Finally, and where appropriate, unpublished data held by the authors were synthesised for use in the report.

From all these sources, information was collated and summarised under a series of disturbance headings, with each heading dealing with a major disturbance category (where categories were provided to us by the Environment Forest Taskforce of Environment Australia, as a table of disturbance categories). Specific references to responses by individual species were noted where available, as were responses at the community level.

2. DISTURBANCES

2.1 FIRE

State of knowledge
Studies on the effects of fire on aquatic invertebrates in the RFA have been much neglected. Major reports, reviews and symposia on the effects of fire on natural ecosystems in Western Australia have typically failed to address even the potential effects of fire on aquatic animals (although they may include issues such as effects of fire on water resources). For example, major fire-management-related publications, such as Ford (1985), Gill (1986), Lewis *et al.* (1994) do not contain any comments on the impact of fire on aquatic macroinvertebrates and fish. The omission of the effects of fire on aquatic faunas from those and similar reports reflects a dearth of research in this area, and a failure to adequately incorporate aquatic values into fire management procedures. Several recent publications have sought to rectify this situation; this section brings together the information in published and unpublished works, adding potential but uninvestigated topics where appropriate.

Effects of fire on invertebrates of streams and wetlands
The immediate impacts of fire include heating, exposure and loss of soil moisture, with fires of high intensity exacerbating these effects. Overheating of water can cause the death of aquatic macroinvertebrates and fish as many pools in which these organisms are found are shallow (Horwitz, 1994a; Gill, pers. comm.). Burning of the dried sections of temporary streams may kill drought-resistant eggs, and other drought resistant stages, which may be oversummering in the dried stream bed, although this has yet to be experimentally tested.

Drainage of permanent pools for fire fighting purposes would have a negative impact on the survival of aquatic animals which use the pools as summer refuges (Trayler *et al*., 1996). For instance, many of the species living in temporary streams of the south-west do not have drought resistant stages, for example crangonyctoid amphipods, phreatoicid isopods, and some fish; some of these survive dry summers by retreating to permanent pools that remain along the waterway.

The longer term effects of fire in and adjacent to wetlands and waterways are many and varied and include the following.

- The loss of substantial amounts of organic material (litter) from the surface of the soil, would technically reduce the amount of coarse particulate organic matter entering the aquatic system (Horwitz, 1994a). The headwaters of south-west Australian streams, with canopy and riparian vegetation intact, are recognised as being heterotrophic, i.e. where the primary source of food for these aquatic ecosystems is from forest debris, such as leaves and wood, and other organic matter derived from terrestrial vegetation (Bunn and Davies, 1990).

- The removal of shading would promote greater photosynthetic production in the aquatic systems as well as increasing the temperature of the water; all this combined with increased surface drainage into the stream may lead to a temporary dominance of, or increase in, autotrophy (Horwitz, 1994a).

- High frequency of burning may alter and/or reduce the amount of riparian vegetation (Pen, 1993; Balla, 1994) and therefore alter and/or reduce important fish habitat (See 2.10 Clearing). Reduction in suitable habitat/cover increases the amount of predation and/or competition on native species by introduced fish species (See 2.6 Introduced Species).

- Repeated burning in and adjacent to wetlands will reduce vegetative debris at the soil level, exposing the soils to seasonal drying, and reducing the ability of wetlands to edaphically control fire in their own right.

- On steeper slopes removal of soil litter may also lead to the erosion of underlying mineral soils (Horwitz, 1994a). This effect would be exacerbated by extensive fires which leave soils exposed in the following winter.

- A temporary decrease in evapotranspiration and reduced interception of rain (due to removal of live leaves) may result in the rise in water table (Fleay, 1985) but this may be off-set by lower infiltration rates due to the facilitation of surface drainage *via* the hydrophobic properties of ash, the removal of the soil litter and understorey vegetation by fire (especially in the case of high topographic relief).

Thus, overall, the effects of fire include (at least temporarily): altered physicochemistry of the water, altered hydrological regimes, a shift towards autotrophy, and a change in the relative proportions of species in the aquatic faunal assemblges.

Effects of fire on invertebrates of peat swamps (and organic mound springs i.e. tumulus springs)

The immediate and longer term effects of fire in peat swamps and tumulus springs (see Criticaly Threatened Ecological Communities in section 3.1) include loss of peat and other soil organics, exposure and loss of soil moisture, heating, loss of soil, and changed hydrological regimes. The seasonality and fires of high intensity may exacerbate these effects, which are detailed below.

- Burning of peat swamps especially under dry conditions has resulted in substantial removal of peat (Horwitz, 1995; Horwitz *et al*, 1997). Since peat acts like a sponge, soaking up water and releasing it slowly when conditions dry up, it has been hypothesised that peatlands ameliorate the effects of seasonal drying by providing moist microclimates year round (Horwitz *et al*., 1997). Burning also removes surface organic material, the build up of which normally leads to peat production (Horwitz, 1994a; 1995); thus the accumulation of peat can be substantially slowed or even stopped by regular burning, reducing the future availability of permanently moist habitats. Consequently, it has been hypothesised that fires which result in the loss of peat have the potential to enhance seasonal aridity in far south-west Australia.

- Fires of high intensity during the dry season can penetrate deeply into the peat, with the direct heat killing fauna (which oversummer by burying into the permanently moist deeper layers of peat, ie. the parastacid crayfishes, native fishes (see below), crayfish burrow fauna) or other invertebrates which retreat to these sources of permanent moisture over summer.

- Destruction of drought resistant eggs and other drought resistant stages of taxa such as chydorid cladocerans (these may comprise over 10 species in a single swamp and a major food source for native fish, Smith, 1996; Knott and Jasinska 1995). Bog-dwelling dragon-flies in the Petalauridae and Synthemidae families are further examples of aquatic species threatened by summer or autumn burns of peatlands (Trayler *et al.*, 1996).

- tumulus springs (organic mound springs) provide permanent springs/seepages but their above ground vegetation and thick layers of peat extending between the various spring outflow points are often dry in summer and can result in an extremely hot fire. The absence of larger, fully aquatic crustacean fauna from the tumulus springs at Muchea may well represent a kill of this fauna by intense fire(s), since hot fires are known to have occurred at the Muchea tumulus springs on several occasions in the past 60 years (Jasinska unpubl. data).

- Burning of peat may also change the local hydrology by creating more surface pools in the landscape, or improving drainage over sandy soils, thus altering the proportional occurrence of aquatic species (Horwitz, 1995; Horwitz *et al*., 1997b).

Specific observations of effects of fire on individual species and communities

Crayfish burrow fauna

Horwitz (1994) described the results of the effects of a prescription burn on the fauna inhabiting the burrows of the freshwater crayfish *Engaewa subcoerulea* in a low shrubland (mixed heaths and sedges) near Inlet River. The site did not contain surface water, but the *Engaewa* burrows reached the water table and contained aquatic invertebrates. The soils were sandy with a limited amount of organic material in the soil profile. One section of the site (on one side of a track) was burnt in May 1993. Both burnt and unburned areas of the site were sampled before the fire in April 1993, and after the fire, in July and October 1993.

Water table readings taken in April 1993 and July 1993 (following the fire in May) registered a differential rise in the water table, with increases being greater in burnt areas. The temperatures of burrow water in the unburnt shrubland were more buffered from temperature extremes than those in the burnt shrubland.

In the burrows of *Engaewa subcoerulea* on each side of the track, 15 taxa of aquatic invertebrates were recorded in total. The burnt and unburnt sections had 11 taxa in common, with each section having 2 additional taxa not found on the other side of the track. One of the species found only in the unburnt section was an undescribed freshwater worm, *Telmatodrilus* sp. The difference in the distribution of the four species of aquatic invertebrates between the burnt and unburnt areas, and the proportional representation of all other species, resulted in a clear separation between burnt and unburnt assemblages in ordinational space. Different assemblages could have been the result of changes in their food supply and physicochemistry of the water in the burrow inducing the fauna to move from or to the interstitial habitat surrounding the burrows.

Aquatic root mat communities in caves

Information on the effects of fire on the aquatic root mat communities (see Criticaly Threatened Ecological Communities in section 3.1) is available for one of the nine sites known to contain them (Jasinska unpubl. data). The tuart forest above and upstream of Carpark Cave at Yanchep National Park was burnt by high intensity fire in 1991. The subterranean stream is for most part 2-3 cm deep with 10-15 cm deeper channels near the stream edges into which the root mats grow, and stream flow ranges from 2 cm/sec to 20 cm/sec in deeper channels and narrower stream sections.

Following the fire, a drop in the stream level was observed by the emergence of the upper sections of root mats that were normally submerged. In addition, a decrease in stream flow was indicated by an increase in the deposition of organic debris (mainly of root mat origin) along the stream bed, which previously had only sandy bottom. These changes appeared to be consistent, but larger than, the changes expected seasonally.

The root mats remained alive following the fire but, in contrast to those in the other four caves at Yanchep National Park, no new growth was produced on these root mats for two years following the fire. The lack of growth of root mats resulted in the reduction of their overall biomass in the stream (to about half of the original extent) probably due to overgrazing by the invertebrates.

All of the invertebrate species originally present in the root mats survived the fire, but examination of the relative proportions of the various taxa in years following the fire revealed greater numbers of nematodes and *Gomphodella* aff. *maia* (Ostracoda) and lower numbers of an undescribed species of janirid isopods (a Gondwanan relictual group) than recorded prior to the fire.

Effects of fire on individual species of fish

Lepidogalaxias salamandroides and *Galaxiella nigrostriata* aestivate in the substrate of ephemeral pools in the peatlands and shrublands during summer (Pusey and Edward, 1990; Pen *et al*., 1993b). These organically rich soils burn readily (Trayler *et al*., 1996) and therefore fuel reduction burns carried out during these summer periods when the soil is dry may result in a loss of these aestivating fish (Morgan pers. comm.). In 1995 a fire burnt through an area of peatflats and shrublands in the D'Entrecasteaux National Park. A number of pools (connected to a stream) in this area were covered with ash and debris after the fire. Lower numbers of fish (*Lepidogalaxias salamandroides, Galaxiella nigrostriata, Edelia vittata, Nannatherina balstoni* and *Bostockia porosa*) than expected were recorded from these pools; approximately one month later fish numbers had returned to the previous higher levels (Gill, pers. comm.).

Recommendations

1. Management burns should be conducted only if maps identifying the extent of organosol terrains, their erosion status and their hazard, have been produced (Horwitz *et al.*, 1997b).

2. Management burns should be conducted only when field tests prior to lighting fires specifically target the moisture levels of organosols at a representative number of sites (Horwitz *et al.*, 1997b). As a rule, prescribed burning should not be carried out during late spring, summer nor autumn when the soil is dry (Trayler *et al*., 1996). All fuel reduction burns over peatlands, including organic mound springs (tumulus springs) should be of very low intensity so that the actual peat is not burnt and the animals seeking refuge in the peat are not killed by the heat.

3. Only small-scale controllable prescription burns at strategic locations should be conducted (Horwitz *et al.*, 1997b) to minimise indiscriminant damage to wetland processes.

4. Maps identifying sites with known locally endemic species [such as Fig. 5 in Wardell-Johnson and Horwitz (1996)] should be used by fire managers to reduce further the risk of fire mis-management.

5. Permanent pools left along waterways during the dry seasons must not be used as a source of water for fire fighting purposes because they represent the only means of surviving drought for many of the stream species which are endemic to the RFA (Trayler *et al*., 1996). Positions of new waterpoints should be carefully monitored. Permanent pools should not be deepened and/or used as sources of water for fighting fires.

6. Frequency of burning should be managed in order to a) retain functions of the riparian vegetation (maintenance of organic debris in wetlands, shading etc.), b) to allow organic material to accumulate in moist areas, and c) to retain actively growing root mats in cave streams.

2.2 LOGGING

State of knowledge

Studies on the impacts of logging on the faunas of streams in south-west Australian forests have been carried out since the 1980s. These studies have concentrated on the effects on water quality and quantity, and on macroinvertebrates. Little or no information exists on the impacts of these practices on fish. Secondary disturbances sometimes resulting from logging include sedimentation and salinization which are also attributable to land clearing. Therefore, where commercial harvesting of trees was not the principal cause of such secondary disturbances, the consequent effects on fishes and on macroinvertebrates in cleared areas, are addressed in Section 2.10 Clearing.

The categories of effects of logging are now well defined: the major impacts being sedimentation, increased salinities and reduced inputs of organic debris, such as leaves, into the streams which constitute the principal energy sources in undisturbed forest stream ecosystems (Bunn and Davies, 1990; Halse and Blyth, 1992). Shifts in the overall community structure in forest streams have been documented over several years for a number of catchments both affected and unaffected by logging. These studies have demonstrated that:

- compared to sites without forestry activity, macroinvertebrate communities at upland logged sites declined in their mean richness, mean total abundances and overall composition of the fauna, and that this was mainly attributable to the immediate effects of periods of high loads of inorganic sediment (Growns and Davis, 1994);
- the invertebrate fauna in streams of the southern forests can be affected by logging activities up to 8 years following the logging activities (Growns and Davis, 1991, 1994); and
- value of leaving adequate buffer strips along stream-lines to ameliorate the greatest of short-term impacts: high levels of sedimentation of the streams (Halse and Blyth, 1992).

Despite the fact that the impacts on individual species have not been specifically investigated and the taxonomic identity and the life histories of many of the aquatic invertebrates are still poorly known (Growns and Davis, 1994), it is possible to name aquatic invertebrate taxa which can respond negatively or positively to the effects of clearfall logging (Table 1).

It is now well recognised that even within a catchment the invertebrates of lowland waters differ substantially from those of the headwater sections (Storey *et al*., 1990; Growns, 1992). Furthermore the upland sites of different catchments may have distinct faunas while the faunas of the downstream sections (lowland sites) are more similar to each other than they are to upland sites (ARL Reports 9 and 13, 1988; Storey *et al*., 1990). Consequently, the lowland section of a river cannot be considered as a reservoir of invertebrate species for future recolonisations of mis-managed upland waters. Upland poorly-defined waterways, shrublands, and heathlands are attributed less protection from logging and other forest practices than lowland waterways.

There appear to be no studies that have examined the impacts of logging operations on nearby peat swamps and wetlands associated with shrublands and heathlands in the RFA. Yet these types of wetlands are recognised as containing high levels of locally restricted invertebrates including many relictual and still undescribed species. Any logging activity may result in the increasing incidence of colonisation of nearby swamps or waterways by invasive, or weedy, native or introduced aquatic plant species, and altering the local hydrology, and accordingly altering the assemblages of macroinvertebrates (Horwitz, 1994a). Horwitz (1994a) examined two sites where upland peaty seepages had been exposed to logging activities, and although he found a high species richness compared to other sites which had not been exposed to these disturbances, he found no restricted endemic species at the sites (which was unusual), and found a higher proportion of widespread and common species.

Table 1. Species which responded to sedimentation and/or clearfelling episodes from the study of Growns (1992), in which he commented on species which either increased or decreased in abundance following clearfelling (x). Species which decreased, and where Growns considered the species to have responded negatively to high levels of suspended solids, are denoted “ss” in this table. Other comments are given where appropriate.

Species/taxon	Common name	Increase	Decrease	Comments
Platyhelminthes	(flatworms)	**x**		
Australiobates sp.	(aquatic mite)		**ss**	
Oxus sp.	(aquatic mite)		**ss**	
Candonocypris novaezelandiae	(seed shrimp)		**ss**	
Hurleya sp. nov.	(amphipod)	**x**		
Newmanoperla exigua	(stonefly)	**x**		Due to univoltine life cycle?

Baetis soror	(mayfly)		**ss**	(but not present at control site)
Paramerina levidensis	(non-biting midge)	**x**		
Tanypodinae sp. 3	(non-biting midge)		**ss**	
Ceratopogonidae sp. 7	(biting midge)	**x**		
Ceratopogonidae sp. 13	(biting midge)		**x**	disappeared after clearfelling
Dolichopodidae sp. 1	(dipteran)	**x**		never found in uncleared sites
Empididae sp. 1	(dipteran)		**ss**	
Taschorema pallescens	(caddis fly)		**ss**	disappeared after clearfelling
Diplectrona sp.	(caddis fly)		**ss**	filter feeder
Leptoceridae Indet. gen 10.	(caddis fly)	**x**		(but not present at control site)

The discussion below deals with sedimentation, salinity, temperature, hydrological change and changes in inputs of allochthonous material, following a logging episode. It should be recognised that many of these effects act together (rarely is only one singularly responsible for the response). Similarly, it is easy to construct an argument for the effects or the absence of effects, by not making explicit reference to differences between catchments, degree of buffer zone left intact, extent of the post-logging silvicultural burn, and so on. Cumulative effects of one disturbance following another have not been investigated. In general, it can be hypothesised that in order to survive the *in situ* effects of logging adjacent to a watercourse, an organism must be tolerant to changes in salinity, sedimentation, and the amount of CPOM and FPOM in the system, changed water levels, and interactions between all of these. Current knowledge on this, especially with regard to individual species and specific impacts on their biology, is woefully depauperate. Nevertheless, existing research results provide clues to what types of studies are required in the near future, and which species are indicative of change following disturbance from logging, for certain parts of the RFA.

Experimental pre- and post- logging examination of sedimentation, salinity and hydrological change has been carried out in several catchments in and adjacent to the study region. In the main, only the studies undertaken in the southern forests around Manjimup have been related to their effects on the biota, the particular topic of this review. There is an urgent need to relate existing hydrological studies in the northern and central sections of the RFA region (e. g. Anson *et al*., 1988; Bell *et al*., 1988) to the riparian and aquatic biota.

Effects on stream invertebrates

Hydrological changes

Hydrological changes are likely to be variable depending on the geology and geomorphology of the catchment, the intensity of the logging event, the extent of buffer zone retained about a wetland or waterway, the degree to which any post-logging fires have penetrated the buffer, and so on. Logging is often accompanied by an increase in stream flows and elevation in the water table for two to three years after logging, with streamflow volumes approximately doubling in these years. In the high and intermediate rainfall zones, the increases corresponded to about 10% of rainfall, whereas in the low rainfall zone the increase was less than 5% of rainfall (Steering Committee for Research on Land Use and Water Supply, 1987).

Sedimentation

The sources of sediment inputs into streams during logging operations include road construction (reported to be a major source of sediment; Halse and Blyth, 1992), run-off from service roads, especially unsealed roads (reported to be a major source of sediment particularly during heavy rains; see ARL Report 2, 1986; Doeg and Koehn, 1990), and increased surface run-off following the clearing of vegetation (Halse and Blyth, 1992).

The effects of sedimentation on the aquatic invertebrates are related to smothering and a change in the energetics of the systems towards eutrophication:

- Increased sediment levels can block the gills of some fauna and kill directly (Halse and Blyth, 1992), or clog the nets of filter feeders such as *Diplectrona* sp. (Growns and Davis, 1994);
- Sediment can block the interstitial spaces in the stream bed. The stream bed interstices in sections of upland streams remain permanently wet even when there is no surface water and they represent an important refuge from drought for phreatoicid isopods (B. Knott pers. comm.), some species of ostracods (E. J. Jasinska pers. obs.) and doubtless many more species of aquatic invertebrates, since the strategies of dealing with drought still remains unknown for many species endemic to the RFA.

- Sediment can carpet the organic matter (leaf litter etc.) of the stream bed producing anoxic conditions in the smothered organic layer and reduce its availability as a major food resource to the stream fauna (Halse and Blyth, 1992).
- Increased fine particulate organic matter can lead to eutrophication (Borg *et al*., 1988a; Doeg and Koehn, 1990; Halse and Blyth, 1992). The increase in primary production combined with the altered availability of allochthonous matter would be likely to produce changes in community composition (ARL Report 13, 1988; Halse and Blyth, 1992).

Borg *et al.* (1988a) compared the effectiveness of 50 m and 100 m buffers in reducing sedimentation in streams from logging activities and found no difference between the effectiveness of these two buffer widths. However, they did not discuss or explain the reason why in the odd sample the sediment concentrations were very high (up to 5 times more than in other samples).

Gazey (1994) studied the effects of sedimentation on four headwater streams of the North Dandalup River system, situated in the northern jarrah forest approximately 100 km south of Perth. Soils were lateritic gravel, in a relatively undisturbed catchment (although the area had been selectively logged in the past). The purpose of the study was to experimentally introduce sediment into a stream in such a way that it might mimic a sedimentation event following logging or clearing. Gazey described the impacts of sediment addition on macroinvertebrate faunas for up to four weeks following the disturbance, and where responses were deemed to be sufficiently clear cut, grouped those responses into one of four categories listed below.

i) Species missing from impacted sites but present in "before impact" and control sites: *Glacidorbis occidentalis, Uroctena* sp.*, Nyungara bunni, Tanytarsini* sp. V13.
ii) Species with clearly reduced abundance 4 weeks after the addition of sediment (compared to "before impact" and control sites): *Neboissophlebia occidentalis* (stonefly), *Ablabesmyia* sp. V10 (non-biting midge), *Thienemanniella* sp. V19 (non-biting midge), *Riethia* sp. V4 (non-biting midge), *Tanytarsus* spp. (non-biting midge), *Rheotanytarsus* sp. V18 (non-biting midge), Empididae sp. B (fly larvae), *Taschorema pallescens* (caddis fly).
iii) Species with clearly reduced abundance (compared to "before impact" and control sites) 33 hours after the addition of sediment only – ie. four weeks later their numbers had recovered *Limnophyes* sp. (chironomid) commented on in text, ?*Zavrelimyia* sp. V20 (chironomid), and *Hyperoedesipus plumosus* (isopod).
iv) Species which abundance clearly increased four weeks after the addition of sediment (compared to "before impact" and control sites): *Stictocladius uniserialis*, *Stenochironomus* complex V17 (appeared only at the impacted sites – 4 weeks after the impact) (both chironomids).

<u>Salinity</u>
Concentrations of salts (as measured by flow-weighted annual stream salinities) can increase in logged catchments for a variable period of years after logging, and often by an order of magnitude (see Borg *et al.* 1987, Borg *et al.* 1988a, Steering Committee for Research on Land Use and Water Supply, 1987). Questions of the degree to which buffer strips limit the influence of logging on salinities, and the degree of influence of local geology, are still contested, and it is very difficult to generalise on the subject, particularly given the fact that the only critical data for the subject comes from around Manjimup. For instance, although increases in salinity of about 50 mg/L to 150 mg/L Total Soluble Salts following logging are almost the norm for such studies (Steering Committee for Research on Land Use and Water Supply, 1987), in one catchment reported by Borg *et al.* (1987; Yerraminnup South), stream salinity was actually reduced by logging, which exemplifies the importance of accounting for differences in geology in different logged areas (see also Doeg and Koehn, 1990). Also, Borg *et al*. (1987) found that for streams adjacent to logged coups, 100 m buffers were still insufficient in preventing a rise is salinity. However, there is some evidence that a 100 m buffer will reduce the period that salinities remain elevated from 15 years (as estimated by Borg *et al.*, 1988b), to approximately 8 years as documented by Growns and Davis (1991).

The gradual increases in salinities are likely to be a cause (or contribute to several causes) of long term alterations in macroinvertebrate community structure. Supporting evidence for this is indicated by Growns (1992), Growns and Davis (1991, 1994) and K. M. Trayler (unpubl. data), indicating potential intolerance and/or sensitivity of the macroinvertebrate fauna to relatively small rises in salinity. Common reference is made to fact that the rises in annual flow-weighted stream salinities detected in catchment studies, are below the limit from high quality drinking water (500 mg/l; see for instance Abbott and Christensen, 1994). While this may be so, it must be stressed that the limit for drinking water may not match the tolerance limits for aquatic organisms. In fact, one would expect there to be faunal suites adapted to waters of extremely low salinity that would be stressed by prolonged but small elevations in salinty: in the order of 50-150 mg/L.

<u>Temperature</u>
Increased water temperature owing to lack of shading after clearfelling effects the life cycles of many animals (Halse and Blyth, 1992). Temperature regimes in waterways adjacent to logging will be influenced by the degree to which riparian vegetation has been removed or altered in its structure. The effects of changed temperatures can be best assessed empirically by focussing research on known temperature regimes, then examining the individual faunal components for lethal effects of temperatures. This critical research remains to be done for the south-west

Australian fauna, although we now have a list of important and/or potential susceptible taxa which could be tested (see Section 3.1).

Allochthony: leaf and woody debris following logging
Width of buffer zones and extent of damage to the riparian vegetation caused by logging and post-logging fires will strongly influence the amount of organic material found in the watercourse. The issue of woody debris *per se* has not been evaluated in south-west Australian river systems. Deposition of logging debris can affect the fauna by changing the stream profile (Halse and Blyth, 1992). However, Beesley (1996) showed that large logging debris is beneficial to the stream ecosystem by providing substrate/shelter for some aquatic invertebrates.

Halse and Blyth (1992) hypothesised that in the absence of a large buffer zone there would be a decrease in the input of litter from the surrounding forest and therefore a reduction in the food source for the aquatic communities. This, in part, would be due to the removal of the riparian vegetation and a subsequent decline of litter fall from it, until it regenerates. On the other hand, Growns and Davis (1991) documented an increase in the amount of coarse and fine particulate organic materials in clearfelled streams without a buffer zone, compared to those in the undisturbed and buffer streams. However, the comparative nutritional value and degree of utilization by the aquatic communities of this latter source of organic matter remains to be evaluated.

Other changes to faunal composition of waterways as a result of forestry activity are dealt with in Sections 2.4 and 2.11.

Recommendations

1. Removal of timber must be undertaken carefully, without widespread exposure of soil which leads to run off and sedimentation in waterways. The best approach here will be the selective removal of one tree at a time, leaving lower strata of the forest, and the soil, intact. Technology to enable such exploitation is available. Removal of trees should be confined to the dry season to reduce potential for sedimentation (Borg *et al*., 1988a; Doeg and Koehn, 1990).

2. Further research:
   - Studies into the life history strategies (reproductive and oversummering strategies) and tolerances to salinities, sedimentation and changed hydrological regimes of key aquatic invertebrates of the RFA. Key invertebrates include locally restricted species, species known to be susceptible, or species likely to be vulnerable.
   - An independent study on the effectiveness of different buffer strips, under a variety of topographic (high *vs* low relief) and geological conditions, in ameliorating the effects of logging on stream ecosystems in the RFA is still required.

3. Improved positioning of roads, especially unsealed road and diversion of road run-off from streams is required to reduce sediment inputs into streams (ARL Report 2, 1986).

4. All drainage lines (as marked on CALM 1:50000 map and interpreted through aerial photography) should be protected by retaining all vegetation (Wardell-Johnson *et al*., 1991).

5. All seepage sites and valley headwaters should be protected (not logged) since they are most likely to still contain many undiscovered and susceptible endemics (Wardell-Johnson *et al*., 1991).

6. The road reserves may be reduced to increase the width of buffer strips along streams (Wardell-Johnson *et al*., 1991).

7. The transgression of buffer zones should be avoided, i.e. no tree removal, no cutting a path across a stream for shortcuts, no post-logging fire in buffer strip etc. It is crucial that buffer zones and riparian zone retain their integrity. Logging contractors should receive relevant training in ecology.

8. There is a need for research on the effect of forestry practices on fish species of the south-west. For example, nothing is known of the effects of sedimentation on fish, particularly on larval stages and eggs (i.e. effect of sedimentation on egg deposition sites).

2.3 OTHER FOREST MANAGEMENT PRACTICES

Other Forest Management Practices relevant to aquatic organisms include Roading, Pest Control, Fire, Recreation, Harvesting. Effects of these are discussed in relevant sections.

2.4 PEST CONTROL

State of knowledge
Pesticides have been used heavily in south-west Australia since the 1940s. It was only in mid-1987, following the 'beef residue crisis' (where high residues of DDT were detected in a consignment of beef imported from Australia), that State governments completely banned all remaining uses of DDT and removed all registered agricultural uses for the other common organochloride insecticides, namely dieldrin, heptachlor and chlordane. Since late 1988, the only registered use for heptachlor, chlordane, aldrin and dieldrin is as termiticides in the building industry (Rutherford, 1989). Nevertheless, many other pesticides are still being used and are likely to present a hazard to non-target animals. A Report on "The toxicity of pesticides to wildlife" by the Western Australian Department of Agriculture lists five pages of various pesticides and their toxicity rating according to the species LD_{50} or LC_{50} [where the lethal dose (LD) or lethal concentration (LC) of a chemical is determined for a species when 50% of the animals subjected to the dose or concentration die]. Of these pesticides, many are listed as having highly toxic effects (LC_{50} of less than 0.5 mg/L) on fish and aquatic fauna (WA Department of Agriculture, 1988). It is important to note that this information is based on European and American species and it treats fish and aquatic invertebrates as one group and does not differentiate between different species. Yet, different species have different sensitivities/tolerance levels/LC_{50} with regard to pesticides (Cairns and Niederlehner, 1994). Also, the compounding effects of other factors such as temperature are not included in the LC_{50} toxicities.

Pesticides are classified into the following categories (after Rutherford, 1989 and WA Department of Agriculture, 1988).

Herbicides – weed control; herbicides which are considered to be soil persistent are relatively few but they include diuron, ethidimuron (ureas), atrazine, hexazinone (triazines), bromacil (uracils) and chlorsulphuron (sulphonylureas).

Fungicides – control of fungal diseases; fungicides are important in horticultural industries, and considerable use is still made of older inorganic fungicides (sulphur and copper), as well as more modern synthetic organic chemicals. Mercury-based fungicides are ecotoxic and extremely persistent but have not been used in WA for some years. Other fungicides are generally biodegradable, are of short persistence and relatively insoluble in water.

Insecticides – control of insects, nematodes and mites; inorganic insecticides include arsenic and sulphur. Organochlorines are largely insoluble in water, soluble in lipid materials, resist biodegradation and are readily bioaccumulated. The other types of organic insecticides are much more water soluble, biodegradable and less persistent. The more long-lasting of organophosphates have half-lives measured in weeks.

Miscellaneous pesticides include: algicides, fumigants, molluscicides, rodenticides, and plant growth regulators. Based on the European and American information (WA Department of Agriculture, 1988) a considerable number of pesticides from each of these four categories are known to have highly toxic effects on fish and aquatic fauna.

High levels of pesticides have been noted repeatedly in aquatic animals in rivers of the RFA (Atkins, 1982; unpublished data from various sources in Rutherford, 1989). Apart from the few studies on the effects of mosquito/midge-control-pesticides on non-target organisms (Davis *et al*., 1988b; Davis *et al*., 1990; Trayler and Davis, 1996), there is a severe lack of research into the impacts of pesticides on fish and aquatic invertebrates of the RFA. Thus, the effects of specific pesticides on the biology of nearly all native aquatic species in the RFA or on their community structure in the RFA remain unknown.

Uses of Pesticides in RFA
Rutherford (1989) provides a thorough review of the use patterns (at the time of the publication of the Report) of pesticides in Western Australia, identifying actual and potential environmental impacts for each type of use. The main points relevant to the RFA aquatic biota together with referenced impacts observed in other studies are summarised below. Spills resulting from storage, transport or inappropriate disposal are possible in the RFA region where activities occur in or through forests, or in urban or agricultural areas immediately adjacent to forests.

<u>Forestry Protection</u>
Herbicides may be used: to maintain fire breaks, for thinning developing stands of hardwood to the correct density, to control regrowth of unwanted tree species, to kill pasture plants prior to planting eucalypt and plant seedlings in reafforestation areas of catchments. Nurseries' use of pesticides is significant: small quantities of nine herbicides,

ten insecticides and several fungicides are used to protect the nursery stock. There exists the potential for contamination of ground water and waterways with pesticides *via* drainage and wind-drift.

Manufacture, Transport and Storage.
One company based at Kwinana manufactures pesticide active constituents. Under the original owners and operators, the manufacturing plant caused significant contamination of groundwater in the area with 2, 4, 5-T and 2,3-D phenoxy herbicides. The latter was still being manufactured together with other pesticides in 1989. Large quantities of pesticides are stored (warehouses, stores and on farms) and transported in Western Australia. Potential for environmental damage is high in the event of a major spill.

Agricultural Use.
Predominantly broadacre (cereal, legume, or oilseed cropping and usually associated with livestock grazing on rainfed pastures) and horticulture. Broadacre land typically receives one herbicide application per year; horticultural land receives multiple pesticide applications every year. Contamination of ground water and waterways with pesticides occurs by drainage from agricultural land or from dumping of dip solutions directly into waterways, used in animal husbandry for the control of ectoparasites. Atkins (1982) noted that filling and cleaning of tractor operated spraying equipment was carried out next to the Preston River and would have contributed to the contamination of the river. In addition pesticide containers were carelessly disposed of near the orchardists pumping sites by the same river. He noted that crop-spraying activities appeared to be producing a spray drift, which travelled a considerable distance to watercourses. Davis *et al*., (1988a) measured levels of organochlorine pesticides in trout caught in their study of Serpentine River and Gooralong Brook. The concentrations measured in trout far exceeded those allowed for human consumption (NH&MRC 1978 standard): DDT (3.3-6.2 mg/L) and dieldrin (0.2-0.7 mg/L). Several native species including *Tandanus bostocki*, *Galaxias occidentalis*, *Edelia vittata* and *Bostockia porosa*, co-occur with trout in this river but the effects of pesticides on the biology of these species is not known.

Midge Control.
Until the late 1980s mosquito/midge control involved the use of tempos granules (larvicide) during summer. Then the treatment became less effective due to increasing resistance to this pesticide in the target chironomid species *Polypedilum nubifer* (Davis *et al*., 1988b). More recently pyriproxyfen has been trialled to control the emergence of adult chironomids (Davis *et al*., 1990; Trayler and Davis, 1996). Lund and Chester (1991) also conducted a study into reducing the numbers of the nuisance chironomids by reducing the nutrient levels in a wetland by the application of alum (aluminium sulphate). However, the application was too short term to reduce the algal blooms and therefore the numbers of midges. Temephos was suspected killing non-target species of invertebrates (Rutherford, 1989). Trayler and Davis (1996) showed that Pyriproxyfen applied at the rate used to control the emergence of chironomids had no observable immediate effects on the non-target cladoceran species *Daphnia carinata*. However, 14-day life cycle tests, revealed that the pesticide reduced the reproductive output in this cladoceran by as much as 80%. Rates of emergence of the non-target species of mayfly *Tasmanocoenis tillyardi* appeared to be affected after 13 days following the application of the pesticide. The application of alum had no obvious effect on most of the aquatic invertebrates, except the numbers of rotifers and a species of cyclopoid copepod noticeably decreased 13 days following the application (Lund and Chester, 1991).

Other Pest and Weed Control.
Channels that supply water for use in irrigated dairy pastures and drainage channels are often sprayed with herbicides to prevent weed growth, which reduces the efficiency of the channel. A range of all pesticide types is used on bowling greens and golf courses especially, leading to groundwater and waterways contamination.

Termiticides are used specifically to protect wooden power poles and in pre-treatment of new domestic and commercial buildings. Many commercial and domestic premises are regularly treated with insecticides for the control of cockroaches, silverfish, fleas, ticks and spiders. Waterway contamination occurs particularly from the treatment of power poles, and for groundwater and wetland contamination from built up areas.

Argentine ants have been found in many areas of the RFA particularly in the high rainfall areas. These were treated since 1940s with dieldrin, then since 1970s with heptachlor and in the agricultural areas (after 1985) with chlorpyrifos. The treatment with the organochlorine pesticides was stopped in 1987/88. The use of dieldrin, and heptachlor has, like pest control operations, contributed to organochlorine residues being found in groundwater and wetlands. Garland and Davies (1986) found that the use of heptachlor at Herdsman Lake has caused significant though transitory reductions in aquatic invertebrate numbers.

Recommendations

1. A broad-scale survey needs to be undertaken to establish the levels of pesticides which exist in the aquatic environment in the RFA region.

2. Ecotoxicological testing (in the light of 1. above) needs to be carried out on selected aquatic species (for instance those from endangered communities, or rare and threatened aquatic invertebrates, and all the native freshwater fishes) to enable accurate predictions of the effects of pesticides on the biology of these species and on the ecology of whole communities. The LC_{50} ecotoxicological testing is not adequate because it gives little insight to the effects of sublethal concentrations of pesticides on the aquatic biota (Trayler and Davis, 1996). Yet in the aquatic environments of the RFA the levels of pesticides have often been detected above the environmentally acceptable concentrations (which are considerably lower than the LC_{50} for most aquatic species). The above proposed ecotoxicological testing should then be used to set meaningful water quality standards for acceptable concentrations of various pesticides in waterways so that appropriate pesticides may be used in the RFA to preserve the native aquatic biota.

3. Ecotoxicological monitoring also should be implemented to monitor stress levels (from pesticides) in threatened communities and rare and endangered species before the environmental changes caused by "sublethal" levels of pesticides become irreversible. The technique of evaluating the effects of sublethal concentrations of pesticides by measuring the changes in the energy allocation to various body functions in aquatic animals would be suitable for both of the recommendations above. The technique utilises the compensatory physiological responses of animals to toxic substances (or other forms of environmental stress) which, temporarily, prevents changes in mortality and/or reproduction (Wall and Hanmer, 1987; Calow, 1991; Cairns *et al*., 1993).

4. Application methods should be reviewed and steps taken to reduce inputs to the rivers (Atkins, 1982).

5. Steps should be taken to educate farmers and contractors in the correct use of pesticides and disposal of empty containers (Atkins, 1982).

2.5 GRAZING

Grazing by (mainly) cattle has been practiced in some forested parts of south-west Australia for up to 150 years. Earlier graziers moved their cattle from inland forested parts to the far southern and coastal region of the state and this may have been associated with firing to promote vegetative growth and thus food. Superphosphate application in other cleared areas was, and still is, also used to promote vegetative growth. In flowing water systems, grazing and trampling by stock reduces the extent of riparian vegetation coverage (Pen, 1993; Balla, 1994) and therefore degrades fish habitat, amongst other things (See 2.10 Clearing), and the destruction of riparian vegetation increases erosion and therefore sediment loads entering water bodies. Eutrophication of water bodies can occur when animal wastes are washed into waterways (see 2.17 Interacting Disturbances). Therefore the effects of grazing by cattle on macroinvertebrate and fish communities will be a combination of the physical effects of trampling, soil compaction and erosion, with clearing of native vegetation, eutrophication, and fire, and they are likely to be locally profound. No specific studies have been identified which delineate the effects of each of these potential impacts.

Horwitz (1994a) discussed the potential effects of grazing cattle on non-flowing wetland ecosystems in the Southern Forest Region. He suggested that the physical effects of trampling, apart from directly effecting organisms and their habitats, altered soil structure with a concomitant hydrological effect that leads to increased erosion of soils. The addition of urine and faeces adds nutrients directly to the water and soil in a soluble form, leading to symptoms of eutrophication and degradation of water quality. Horwitz argued that these effects are unlikely to be conducive to the continued existence of endemic or rare species, and are likely to favour more common elements of the freshwater fauna which he found at sites where grazing occurred (such as the crustaceans *Austrochiltonia* spp., *Palaemonetes australis*, species in cosmopolitan genera of aquatic mites and species of chironomid midges).

ARL (1992) demonstrated that nutrient levels and salinity of permanent lakes of the south coast correlated highly with macroinvertebrate community structure. Lakes of the region which had been, or still are, subjected to agricultural land practices, contain suites of macroinvertebrate faunas which are characteristic of eutrophic wetlands on the Swan Coastal Plain. These macroinvertebrate species are widespread and common in their occurrence.

In a study of distribution of fish in the Busselton - Walpole region, Morgan *et al*. (1996) found no ammocoete beds (belonging to the lamprey *Geotria australis*) in parts of streams running through cleared agricultural land, where it is believed that agricultural run-off and increased inflow have adversely altered the composition of the substrate. Similarly, *Galaxiella munda* has a distribution in the south-west corner of the state, and in the same study (Morgan *et al*., 1996), this species was absent or rare in many streams occurring in areas used for grazing.

Recommendations

1. Restrict stock access to exclude them from water bodies and riparian vegetation.

2. Enhance and maintain riparian vegetation zones (riparian vegetation can reduce and filter run-off from pastures and therefore reduce input of animal wastes).

3. See also Recommendations: 2.10 Clearing

2.6 INTRODUCED SPECIES

Introduced species in south-west Australia which are likely to influence native aquatic macroinvertebrates and fish assemblages include disease causing organisms, parasites and symbionts, macroinvertebrate species, a variety of fish species, kookaburras, pigs and other feral vertebrates, microflora, and weeds. Disease causing organisms are covered in Section 2.7; specific issues relating to some of these other groups is presented separately, below, where information exists.

Lawrence (1993) and Horwitz (1994b) have summarised the possible impacts of the translocation of aquatic animals in waterways, and commented that their effects on native ecosystems can be extreme. Specifically translocations of organisms may lead to:

- a loss of genetic diversity (*via* intra and interspecific hybridisation and mix of genetically distinct strains);
- the introduction of other species;
- alteration of habitats for native species;
- massive biomass shifts;
- alteration of community structure; and
- elimination other species through competition, predation or habitat exclusion by aggressive behaviour.

These impacts lead to degradation of aquatic systems and loss of aquatic values. Lawrence (1993) and Horwitz (1994b) also provide a list of aquatic organisms introduced into aquatic waters of south-west Australia and their probable origins.

Lawrence (1993) notes that when viewed in the international context, Western Australia has relatively few introduced species or pathogens. This may be attributed to the general isolation of WA water bodies from the remainder of Australia's aquatic environment. As in the terrestrial situation this isolation has the potential to enable a higher degree of quarantine for the Western Australian region.

<u>Parasites and symbionts</u>
Pathogens (diseases), parasites, symbionts, and other incidental species can be incidentally introduced when translocations occur. Possibly the most serious of these are diseases (see Section 2.7). Other (not intentionally translocated) aquatic organisms arrive this way too. The temnocephalan flat worm *Temnocephala minor* is widespread on the yabbie (*Cherax destructor*) from Eastern Australia. This ectoparasitic/commensal (the exact energetics of the association are still incompletely known) worm has now been isolated from marron (*Cherax tenuimanus*) in aquaculture ponds in Western Australia and also from marron being bred in Japan.

In addition, a number of fish parasites such as the fish louse, *Argulus* and the anchor worm, *Lernaea cyprinacea* were imported through fish introductions and are now common in several indigenous Australian fishes (Arthington, 1991).

<u>Macroinvertebrate Species</u>
The concern raised over the translocation of different strains of native species stems from the likelihood that if within state translocations continued unabated then the known strains would interbreed and significant genetic and morphological variation would be "lost, or made unavailable" by hybridisation (Horwitz, 1990). Sadly the circumstantial evidence indicates that this is already occurring for an endemic strain/sub-species of marron (*Cherax tenuimanus*) in Margaret River.

Cave communities can be threatened by translocated crayfish which invade and cause trophic changes to unique communities. An invasion of a cave by translocated yabbies (*Cherax destructor*) has been described by Jasinska *et al.* (1993).

Other aquatic species known to have been introduced and subsequently persisted in waterways include the aquatic snails *Lymnaea columella* and *Physa acuta*. In addition, the planorbid gastropod snail *Helisoma* sp. has been identified in wetlands of the Swan Coastal Plain and is likely to also occur in pools of rivers in the RFA (Davis, pers. comm.). These taxa are likely to have been accidental escapees from home aquaria (in the case of the snails), or introduced for aquacultural purposes (for the brine shrimp). Impacts on native macroinvertebrates and fish, resulting from these invasions, have not been examined.

Fish

There is evidence to implicate introduced fish species in the decline in abundance of several native fish populations. In addition, introduced and translocated species may transfer disease (See 2.7 Disease). Translocated and exotic fish species are widespread in the waterways of the south-west and there is increasing anecdotal evidence that these introduced species have a serious impact upon the distribution of our native fish fauna (see Morgan *et al*., 1995). Other circumstantial evidence implicates introduced fish in the changed structure of macroinvertebrate communities.

At the turn of the century numerous attempts were made to stock the waters of the south-west with large exotic freshwater food and sport fish. By 1918 the redfin perch was recognised as a widespread, successful introduction; these still thrive in large permanent waters (Lane and McComb, 1988). Of additional concern is the translocation of the piscivorous species *Macquaria ambigua* (Golden Perch) and *Bidyanus bidyanus* (Silver Perch) to the catchments surrounding the peat flats of the D'Entrecasteaux National Park. These species may threaten the already restricted distribution of the four native species endemic to this region (Trayler *et al.*, 1996).

Another reason for introducing fish relates to their potential for pest control. The predator *Gambusia*, for example, was introduced into Australia from South America to control mosquitoes; it is now resident more or less throughout the south-west, and abundant in some lakes on the Swan Coastal Plain. Effects on fauna of this fish seem to vary from site to site. Reduction in riparian vegetation can lead to increased abundances of the introduced fish, *Gambusia holbrooki*, as this species prefers sunny, light environments and warmer temperatures (Gill, pers. comm.). In addition, reduction in habitat cover increases predation on native species by introduced species such as *G. holbrooki* and redfin perch. (See 2.17 Interactions).

In most cases the critical research has not been performed to link the presence of an introduced fish with its potential effects. Where introductions are deliberately sanctioned by government agencies (for instance the stocking of trout), continuing this practice in the absence of critical information is seen as a clear abrogation of duty to protect native biodiversity. The evidence, listed below, for the effects of introduced fish species on individual native fish species is therefore varied, but largely circumstantial.

- *Edelia vittata* is absent from areas of the Murray River that contain substantial numbers of redfin perch (Hutchison, 1991).

- *Galaxiella munda* is absent and *Edelia vittata* and *Bostockia porosa* have reduced abundances in areas upstream of Big Brook Dam that contain large populations of the introduced redfin perch and *Gambusia holbrooki* (Morgan and Gill, 1995). Morgan *et al*. (1995) were unable to locate *G. munda* within the headwaters of Lefroy Brook where it was once found in abundance (Pen *et al*., 1991). This was attributed to the introduction of Redfin Perch, *Perca fluviatalis*, to Big Brook Dam during an exceptionally dry period when the reservoir was the only source of permanent water in the Lefroy region. In addition, the drainage of permanent pools for fire fighting purposes is also problematic to the survival of these species. The circumstantial evidence for these effects are substantial, even if the mechanisms of the interactions (and the role of habitat disturbance) are not entirely understood. (See 2.17 Interacting Disturbances).

- The requirement of the non-aestivating native fish species *Nannatherina balstoni* and *Galaxiella munda* for permanent water during dry periods makes them particularly vulnerable to predation by other fishes, as well as habitat alteration. The effect of predation on these species is enhanced when they are forced to retreat to permanent pools and streams during summer and autumn.

- *Galaxias occidentalis, Edelia vittata* and *Bostockia porosa* are absent in remnant pools in the south branch of the Collie River that contain large numbers of redfin perch and that had little cover (Morgan *et al*., 1995) (See 2.17 Interacting Disturbances).

- *Galaxias occidentalis, Edelia vittata* and *Bostockia porosa* are absent/rare in the lakes of the south-west which contain large numbers of *Gambusia holbrooki*, although they are abundant in nearby streams and lakes which do not contain this species (Morgan *et al*., 1996).

- *Galaxias occidentalis, Edelia vittata* and *Bostockia porosa* are only abundant in lakes, pools and streams at the RGC Mineral Sands wetlands that contained large amounts of cover and low numbers of *Gambusia holbrooki*

(Hambleton *et al*., 1996). Aggressive behaviour by *G. holbrooki*, including fin-nipping, has been observed towards native species in these wetlands and in aquaria (Hambleton *et al*., 1996).

Alteration of Natural Habitats

Some species are known to physically alter the habitat, and the most pronounced of these is the European carp which can move sediment and alter vegetation patterns.

Alteration of Macroinvertebrate Community Structure

The *Trophic cascade theory,* or the *theory of biomanipulation* when it is applied to manage waterways, is based on the principle that food webs are irrevocably linked and altering one component can have ripple effects throughout the community. In waterways with high densities of *Gambusia*, community structure changes to assemblages dominated by species which are not palatable or can evade, *Gambusia* predation. A simple calculation can be made to demonstrate the enormity of fish predation on macroinvertebrate assemblages. For a lake on the Swan Coastal Plain, of known areal extent, where the average number of *Gambusia* per m^2 was estimated, and assuming an average weight of 0.5 g for each fish, a total biomass of these fish in this lake was calculated (Horwitz, 1994b). Applying the rule that 90% of the biomass is lost as energy, moving from one trophic level to the next, means that ten tonnes represents one tenth of the biomass of food eaten by the *Gambusia*. This then represents one hundred tonnes of macroinvertebrates and zooplankton in one lake consumed. A similar calculation can be performed for any of the predatory introduced fishes. Impacts should be noticeable at both the species and the community level provided that baseline data are available to determine pre-predation conditions.

Gambusia holbrooki is described as an opportunistic carnivore, given its capacity to alter its feeding behaviour when the abundance of potential prey changes; this capacity can lead to the elimination or at least great reduction in numbers of fauna such as copepods and cladocerans (Pen *et al.,* 1993b). This is particularly relevant in areas where the explosive population increases in its numbers occur in late spring to mid summer. Balla and Davis (1993) also regard the effects of *Gambusia* predation to be significant in wetlands on the Swan Coastal Plain.

Pen and Potter (1992) examined the gut contents of Redfin Perch from the Collie River, and reported substantial changes in feeding patterns as the size of the fish increases. The diet shifted from predominantly planktonic crustaceans to benthic invertebrates, with decapod crustaceans constituting between 55% and 88% of the volume of food ingested by larger fish (>120 mm in length). The species of shrimp *Palaemonetes australis,* and crayfish *Cherax quinquecarinatus* and *C. tenuimanus* made up this decapod component.

Recommendations

1. The recommendations given in Lawrence (1993) are relevant in this context, namely:
   - the use of a local species should be investigates before promoting the translocation of non-local species for the same purpose;
   - it is reasonable to assume that a translocated species will eventually escape and plans to contain the inevitable escape should be mandatory as part of any translocation proposal;
   - if translocations are the only available option after all other alternatives have been exhaustively considered then the species should be introduced as infection free fertile eggs or quarantined and certified (by an independent qualified pathologist) to be disease, parasite and symbiont free.

2. Urgent research is required to investigate the interactive effects of introduced species with other key disturbance factors, principally those resulting in eutrophication and salinisation.

3. There needs to be an increased level of recognition amongst government agencies that introduced fish can have a significant impact on aquatic macroinvertebrates, and other aquatic life (and not just native fish).

2.7 DISEASE

The presence of pathogens, and the occurrence of disease outbreaks in native populations of aquatic macroinvertebrates and native fish have not been reported in the literature, and no published information exists as to the role that diseases play in population regulation of these species in the south-west Australia. This says little about the impact of diseases - it only states an absence of information. However, there are two relevant but minor clarifications which need to be made.

Firstly, there is the potential for diseases to be introduced into the region through the translocation of aquatic organisms. Introduced and translocated aquatic organisms may harbour pathogens detrimental to indigenous fish (Arthington, 1991; Lawrence, 1993). At least two feral species in the south-west have the potential to bring with them unwanted diseases; goldfish can harbour the bacterium *Aeromonas salmonicida* causing goldfish ulcer disease. Redfin perch harbour epizootic haematopoietic necrosis virus which is pathogenic to native species and commercial species as well. This virus has spread to cultured rainbow trout and has been found to be highly pathogenic to several indigenous Australian fishes, and the state of Victoria has banned the translocation of redfin (Arthington, 1991). Both of the above diseases are in Australian populations already (Langdon, 1989). Another potentially debilitating disease is the crayfish-plague fungal disease *Aphanomyces astaci* which, although not yet recorded from Australia, is highly pathogenic to Australian species of freshwater crayfish (Unestam, 1975).

Secondly, conditions under which native and/or introduced species are held may be conducive to the outbreak and spread of disease. Some pathogens of freshwater crayfish have been detected in freshwater crayfishes under aquaculture conditions in Australia. Experience elsewhere suggests that fish and crayfish are rendered susceptible to diseases by stress, such as that caused by a combination of high stocking densities and poor water quality. It is not beyond the realms of possibility, therefore, that wild populations may have suffered in the past from outbreaks of undefined diseases where water quality has deteriorated markedly. Such an hypothesis needs to be considered in any discussion of the disturbance ecology of aquatic organisms since outbreaks of diseases may be symptomatic of poor ecosystem health resulting from other human induced disturbances like the eutrophication of waterways. Pathological investigations will be required in future to determine the extent to which diseases are operative in the decline of fish and invertebrates in inland waters of south-west Australia.

Finally, another disease likely to influence aquatic organisms is vegetative dieback caused by *Phytophthora cinnamomi*. Hydrological change, fire, dieback and logging might all combine to significantly alter aquatic habitats; research has not been done to elucidate such effects.

Recommendations

1 Develop the expertise to assess the disease status of native invertebrates and fish in inland waters of south-west Australia, particularly in association with other disturbances likely to stress aquatic organisms.

2. Strict quarantine protocols must be enforced for any introductions or translocations, an they should only be considered subject to health certification.

3. Dieback should be regarded as having at least a potential impact on aquatic habitats.

2.8 HARVESTING

No native fish species is commercially fished and only one species, the freshwater cobbler *Tandanus bostocki*, is sought by recreational anglers (Morgan *et al*., 1996). There are no data available on the effect of fishing pressure on this species, however, due to the relatively low numbers taken by anglers, and the high abundance of this species in many rivers (Morgan *et al*., 1996), recreational fishing is unlikely to have had much impact.

Populations of the freshwater crayfish marron (*Cherax tenuimanus*) have been subjected to often intensive fishing pressure predominantly for recreational pursuits, or even for collection of brood stock. Overfishing, combined with drought, and the degradation of habitat and water quality have resulted in significant declines in the distributions of this species in several river systems within the RFA (Morrissy and Fellows, 1990; Nickoll, 1996). Such declines have prompted a two year moratorium on the recreational harvesting of marron, and following the removal of the moratorium, more stringent regulations on permissible fishing practices in certain rivers, and smaller bag limits (see Morrissy, 1992). Fishing for this species is likely to be strongly related to concepts of remoteness (where populations of larger marron still exist in waterways with intact and relatively good water quality), and accessibility (where remote sites can be accessed through four-wheel drive trails, fire breaks, or other smaller roads) (Horwitz, unpubl. obs.). The construction of such accesses (for forestry, control of fire, etc.) is therefore likely to be strongly influential on initial declines of marron stocks due to overfishing.

Recommendations

1. The role played by roads, snig tracks and fire breaks in the behaviour of fishers, and the extent to which remote stocks of marron can be accessed, needs to be investigated.

2. see Section 2.9 Recreation

2.9 RECREATION

Relevant recreational activities in the RFA include fishing for native and introduced species (see also 2.8 Harvesting), hunting for ducks, and vehicular damage to aquatic systems caused by off-road vehicles (see also 2.11 Roading). It is feasible that all, or any combination of these activities, can take place at the same time (see also 2.17 Interacting Disturbances). (It should be remembered that duck shooting for the purposes of hunting was made illegal after 1989.)

Lund *et al*. (1991) conducted investigations into whether lead from duck shooting and/or from road run off was acting as a source of lead in an alkaline wetland ecosystem. A polluted urban wetland and a relatively undisturbed wetland were also studied for comparison. They found that lead concentrations in sediments did not differ significantly between lake Wannamal and Thomson's lake, and they apparently represented natural background levels. However, Lake Monger sediments were contaminated and the main sources seem to be run-off from the near-by freeway in urban Perth. They suggested that availability of the lead shot to ecosystem components depended on the solubility of the shot; lead is highly insoluble between pH 6 and pH 8. Outside of this pH range it is marginally soluble but this solubility decreases in the presence of high concentrations of calcium ions. The results indicated that lead shot entering Lake Wannamal remained in metal form and did not cycle in the ecosystem - the shot appeared to be insoluble under the alkaline and hardwater conditions of this lake. Macroinvertebrates accumulated lead to low concentrations and no evidence was found of biomagnification. Lead concentrations were only slightly higher in macroinvertebrates in Lake Monger than in the other lakes, providing an indication that lead uptake was poor even in a contaminated lake.

Recreational fishing for native species has an obvious impact on the target species (See 2.8 Harvesting), but can also have an indirect, flow on effect to the composition of the aquatic communities through the removal of individuals and biomass from the local system. This may be particularly important since freshwater crayfish may constitute the largest proportion of total biomass for any animal species in unfished waterways of south-west Australia. These indirect or flow on effects have not been studied.

Exotic species have been illegally introduced into a number of waterways to enhance recreational fishing, for instance redfin perch into Big Brook (Gill, pers. comm.). (See 2.6 Introduced Species; 2.17 Interacting Disturbances).

The physical disturbances caused by recreationalists, in gaining access to waterways, or in the direct use of waterways, have not been investigated.

Recommendations

1. Effects of lead from duck shooting on aquatic faunas should be further investigated in the highly acidic dark-water wetlands which are common to south-west Australia and in which the solubilities of lead may be sufficiently high to impact on the resident communities.

2. The flow-on effects to the composition of the aquatic communities from the removal of marron (*Cherax tenuimanus*) should be investigated.

2.10 CLEARING

State of knowledge
Broad scale clearing of trees in south-west Australia has lead to salinisation. Many freshwater invertebrates of the RFA, especially those with Pangean or Gondwanan origins are highly intolerant of increases in salinity. The freshwater species, which disappear from salinised rivers, are replaced by estuarine forms or by forms known from the more saline athalassic waters which also colonise salinised lakes. Rehabilitation of salinised waters to their original fresh condition has proven to be an extremely difficult task, with little success thus far. For the majority of species including the rare obligatory freshwater invertebrates with Gondwanan or Pangean affinities the upper tolerance limits in terms of salinity are not known.

Eutrophication of waters initiated by the removal of shade and increased sediment inputs following land clearing is further exacerbated by agricultural activities. This process (in addition to salinisation) results in changes in the aquatic community structure and losses of species that require dystrophic, fresh waters for survival. In the event of a collapse of an algal bloom (a common occurrence in eutrophic waters) the severely anoxic conditions which develop kill much of the remaining aquatic fauna.

Effects of increased salinity
(see also 2.2 Logging)
It is now well recognised that large-scale tree clearing raises salinities. The principal mechanism for the extreme salinisation of inland rivers in the south-west being the rise of water table following removal of trees and consequent termination of loss of groundwater to the atmosphere *via* evapotranspiration. When the groundwater rises through salt-containing geological strata (common in the south-west of Australia), the salt is mobilised and the water rising nearer the ground surface becomes enriched with salt. Such salination of the groundwater results in the death of salt intolerant vegetation still remaining following the tree clearing. Subsequently the saline groundwater becomes even more concentrated due to increased evaporation.

A number of rivers in the south-west have significantly elevated salinities attributed to land clearing in their catchments, primarily for agriculture e.g. Swan-Avon, Blackwood, and the Warren (see for instance Collins and Barrett, 1980). Changes in the salinity may effect the distribution of fish in the river systems. For example, in the Swan/Avon, freshwater fish populations are becoming more restricted in their distributions as higher salinities become more wide spread while estuarine faunas move further inland (see below).

Williams *et al*. (1991) conducted surveys at several locations on the Blackwood River which has a clear longitudinal salinity profile: the upper reaches are more saline than the lower ones (except the lowermost station were tidal intrusion increases salinity). The locations on the Blackwood were chosen with the aim to investigate relationships between salinity and species composition. Apart from an obvious estuarine-riverine split there was no evidence of a longitudinal pattern of macroinvertebrate distribution although such a split may have been obscured by inadequate taxonomic knowledge of the fauna. Williams *et al*., (1991) provide lists of the macroinvertebrate species collected of which nearly all were insects. They suggested that either much of the riverine fauna may be more resistant and resilient to salinity change due to climatic history of the continent or the present fauna may represent halotolerant vestiges of previously more diverse riverine assemblages. The survey results also suggested that salinisation of the river, beyond causing the extinction of some particularly salt-intolerant species, had facilitated inland penetration of a few estuarine species.

Other observed effects of increasing salinisation of waters in the RFA include:

- In the rivers: replacement of the freshwater mussel (*Westralunio carteri*) by a brackish mussel (*Anticorbula amara*), and the upstream occurrence of the usually estuarine copepod (*Sulcanus conflictus*) (Williams, 1987).

- In the rivers: virtual disappearance of the crayfish (marron) *Cherax tenuimanus* from sections of rivers that now have unnaturally high salinities eg. the Blackwood (Morrissy, 1974, 1978b; Williams, 1987), although this is confounded with interacting effects of other disturbances.

- In Hotham River, where salinities recorded mostly exceeded upper limit of freshwater, Bunn and Davies (1992) recorded a low species richness of benthic invertebrates, but they were present in high densities of individual species; the authors argued that this situation was indicative of degraded river conditions. This river system was also affected by eutrophication (see the following subsection). Insects comprised only 14.5% of the invertebrate fauna while northern jarrah forests typically contain 70-80% of insects. Several species of insect larvae more typical of jarrah forests were recorded in August following the winter rains and were likely to represent faunal intrusion from headwater tributaries (Bunn and Davies, 1992).

- In Lake Toolibin, Doupè and Horwitz (1995) described the establishment of saline tolerant forms of macroinvertebrates representing widespread groups each with high dispersive powers. They further speculated that there may be a succession of species in the lake as salinities change through the seasons. In the lake, there was an absence of predominantly freshwater forms even though these were present in the nearby Lake Walbyring which still remains relatively fresh (Doupè and Horwitz, 1995).

- In general, from the data he accumulated, Horwitz (1997) surmised that faunas requiring waters with low ionic concentrations of salts are unlikely to be found in inland wetlands unless they are highly mobile and have other life history characteristics which enable them to capitalise on the sporadic occurrence of fresh waters.

- Edward *et al*. (1994) found in their survey of permanent lakes of the southern coast of south-west Australia that, although at all sites the salinity was well below the upper limit for potable water, the salinities appeared to be sufficiently high to cause loss of some, presumably salt-intolerant species. Lakes which had higher salinities and nutrient levels, contained fauna more typical of eutrophic Swan Coastal Plain (SCP) lakes, while overall, only about 30% of identified species were shared by SCP lakes (they list species recorded from other such studies).

Effects of increased nutrients
Concomitant with clearing of trees is the removal of shading, and increased surface drainage carrying nutrients into the waterways, lakes and swamps. These changes lead to eutrophication of waters, both fresh and saline. In agricultural areas the surface run-off is further enriched with fertilisers and/or manure.

The main sources of nutrients identified for some of the eutrophic permanent lakes along the south coast of WA (ARL Report 22, 1992) were (i) inputs of secondary treated sewage (Lake Powell *via* Five and Seven Mile creeks) and (ii) farming activities such as potato production (Lake Saide). In a survey of nutrient inputs from various land uses on the Darling Plateau, Gerritse *et al*. (1992) found that the greatest sources of nitrogen and phosphorus were from land used for orchards, determined to be about equal to those in unsewered residential areas in Perth with density of 10 houses per hectare.

In a survey of the Toby Inlet Catchment near Busselton, both nitrogen and phosphorus concentrations significantly correlated with rainfall patterns. Samples collected from the outfall of the Dunsborough Lakes development were highly enriched in both phosphorus and nitrogen (with the latter five times above the EPA standard). The macroinvertebrate fauna of the catchment was characterised by low species richness (about 25% of unimpacted forested streams) and the occurrence of many cosmopolitan species. The number of "sensitive species" such as plecopterans, trichopterans or ephemeropterans was very low, with the plecopterans absent altogether (Streamtec Report ST 268, 1997).

In eutrophic wetlands which have accumulated organic pollution, new species such as nuisance chironomids can appear (Pinder *et al.*, 1991).

Other examples of the effects of eutrophication are given in sections dealing with Grazing, Logging, Interactions.

Effects of toxic components of fertilisers
High concentrations of cadmium (Cd) are being introduced to the environment from fertilisers which contain rock phosphate. Such fertilisers contain from 18 to 91 ppm Cd, and 0.5 to 1.2 million tonnes of a single superphosphate is spread in WA, per annum. Cadmium enters the aquatic ecosystems in south-west Australia through soil movement (mainly on clay based soils) and leaching (sandy soils) (Chambers and Knott, 1996). A survey of 20 locations in the south-west where aquatic ecosystems contained marron (*Cherax tenuimanus*), revealed significant levels of Cd accumulation ranging from 0.06-6.0 (micrograms per gram wet tissue weight) for gill, 0.2-1.1 for hepatopancreas and 0.07-0.25 for abdominal muscle tissue. However, the measured concentrations of water from which the marron were collected did not exceed the 0.001 ppm (environmentally acceptable) standard. Accordingly it can be concluded that cadmium is not being sequestered in the aquatic ecosystem but is biologically available (Chambers and Knott, 1997).

Toxicity tests of cadmium on marron have been carried out by Chambers (1996a and 1996b).
For cadmium, copper and zinc toxicity in juvenile (3 month old) freshwater crayfish, *Cherax tenuimanus:* LC_{50}s following 96 hr exposures were 0.40 mgCd/L; 0.48 mgCu/L and 45.78 mgZn/L. For cadmium toxicity of juvenile compared to adult marron: 3 month old marron from Pemberton had LC50s of 0.40 mg Cd/L, while adult marron from the same region had LC50s of 17.9 mg Cd/L.

Urban pollution
Groundwater quality is reduced in all urban residential areas. The salinity is somewhat increased particularly chlorides and sulphates (the latter increases strongly in groundwater from unsewered urban areas). The data provided by Gerritse *et al.* (1990) show that DDT, lindane, dieldrin and chlordane are consistently detected, while aldrin and heptachlor are consistently not detected. Additionally, many other pesticides are used in garden and parks in urban areas. Where urban areas are built over catchments which supply water to vulnerable communities such as those of tumulus springs or aquatic root mat communities in caves, activities in the urban areas constitute a serious potential disturbance.

Clearance of Riparian Vegetation

Loss of riparian vegetation reduces important fish habitat (Jackson and Wager, 1993). Most of the available habitat in wetlands originates from the surrounding vegetation eg. fallen logs, leaves bark etc. It also becomes important as fish habitat during high water levels when inundated. Many native fishes such as *Nannatherina balstoni* use these areas of inundation as spawning and feeding grounds. The larvae of many species are associated with shallow areas of inundated vegetation. An important food source of the endemic fish, terrestrial invertebrates, originate from riparian vegetation (Morgan *et al*., 1996; Fairhurst, unpubl. data). It also acts as a buffer strip filtering chemicals and pasture effluent in run-off.

A study by Armstrong (1995) investigated the impacts of clearing of riparian and upslope vegetation from four upland creeks in the North Dandalup catchment, and comparisons between cleared and uncleared sections of the creeks were made using stream habitats as categories. Distinct faunal compositions were found between cleared and uncleared sites for five out of six habitats (the exception being the cobble habitat). Taxa which contributed to the differences included *Limnophyes* sp. and *Ablabesmyia* sp. A (both non-biting midges which were only present in uncleared riffle habitats). Gazey (1994) also identified the former species as being particularly sensitive to elevated sediment levels.
Armstrong (1995) attributed the changes in faunal composition to one or more of three factors:

i) different susceptibilities to increased sediment levels,
ii) changes in the energy base of the habitat, and/or
iii) within habitat variation, within a treatment (cleared) area.

He then tested, experimentally, the susceptibility of cobble habitat to artificially elevated sediment loads, comparing treatment (sediment added) sites to control (uncleared) and impacted (cleared sites). The results of these experiments confirmed the earlier observations: in the cobble habitat at sites with added sediment, no detectable effects were observed either at the species diversity level, or for groups of taxa hypothesised to be particularly sensitive. However, for this habitat he noted considerably fewer species and substantially depressed abundances in the cleared parts, where the aquatic plant *Potamogeton* sp. had been eliminated. He hypothesised that this plant provided habitat complexity amongst the cobbles for sheltering at the treatment site, but not at the cleared site. The main conclusion from this study was that the clearing of riparian vegetation alters the linkages between terrestrial and aquatic ecosystems, reducing biological water quality.

Effects on individual species of fish

Geotria australis

No ammocoete beds were found in parts of streams running through cleared agricultural land, where it is believed that agricultural run-off and increased inflow have adversely altered the composition of the substrate (Morgan *et al*., 1996).

Galaxiella munda, *Lepidogalaxias salamandroides*, *Galaxiella nigrostriata* and *Nannatherina balstoni*

These species were never found by Morgan *et al*. (1996) in cleared agricultural areas.

Recommendations

1. The upper tolerance limits to salinity of freshwater invertebrates with Pangean or Gondwanan lineages need to be determined.

2. More monitoring and maintenance of undamaged aquatic ecosystems is required (Williams, 1987).

3. The use of rock superphosphate in fertilisers needs to be reviewed in light of the high cadmium concentrations it contains and consequent toxic effects on the environment.

4. Aquatic biodiversity can be maintained and the values of waterways restored by:

    - retention or re-establishment of wide buffer zones (of native vegetation), fenced-off in grazing lands to prevent the invasion of livestock;

    - prevention of agricultural run-off from entering directly (prior to the removal of organics and fertilisers) into natural waters either *via* drainage along roads or in specifically designed channels are likely to prevent or reverse the eutrophication process;

    - enhancement and maintainance riparian vegetation zones where they exist and replace those that have been removed.

2.11 ROADING

Poor road designs where roads cross streams can result in barriers to the movement of fish (Halse and Blyth, 1992). Culverts may also provide barriers to the upstream migration of species. Road construction can cause erosion and increased sediment loads entering streams (see 2.2 Logging). In areas with frequent heavy traffic, greater quantities of lead (see 2.9 Recreation) and oils in run off may also enter waterways. Roading also can provide unwanted access to wetlands and waterways (see 2.8 Harvesting).

Two species of fish (*Lepidogalaxias salamandroides* and *Galaxiella nigrostriata*) aestivate in the substrate of ephemeral pools (Pusey, 1990; Pen *et al*., 1993a) along the south coast. Many macroinvertebrate species also can be found in interstitial waters of the pools, or associated with the burrows of freshwater crayfish in the genera *Cherax* and *Engaewa* which also live there. According to Morgan *et al*. (1996) these pools are often mistakenly considered by employees of government agencies (for instance the Department of CALM) to be devoid of aquatic fauna when they are dry during summer. The pools are sometimes destroyed or drastically altered when their substrate is used for ‘fill’, or the pools themselves are filled during routine road maintenance (Morgan *et al*., 1996). It is quite conceivable that such activities could result in a complete kill of individuals of these species in affected areas.

The effects of roading on sedimentation of waterways is discussed in Section 2.2 Logging.

Culverts in road crossings, where placed above stream level, create waterfalls which fully aquatic invertebrates and fishes are unable to cross. This can be particularly serious when fishes are prevented from migrating upstream to breed and thus prevented from breeding (Halse and Blyth, 1992). Some invertebrates may be likely to migrate upstream in search of permanent water to survive summer drought.

The position of new roads should be carefully established (Morgan *et al*., 1996)

Recommendations

1. Ephermal pools where fish aestivate and crayfishes oversummer in burrows should be protected and mapped. Government agencies involved in road construction should use these maps to avoid accidental destruction of these important habitats.

2. Creation of artificial water falls at road crossings by, for example, placing culverts above stream level should be actively discouraged or reversed since these prevent the upstream migration of some native fishes and macroinvertebrates which then can have serious, detrimental impacts on the species’ biology.

2.12 MINING/QUARRYING

State of knowledge

There is practically no freely available information on the impact of mining/quarrying on the aquatic biota, nor studies which established before and after impacts of mining activity. There are some studies that have been conducted which were not accessible to this review due to their confidential nature. The reports from one study dealing with the impacts of a gold mine residue area on the aquatic biota of a creek was easily accessible, and the results of this study are summarised here. Limited information on the downstream effects of bauxite mining highlight the prevalence of high levels of silt (Bunn *et al.* 1986). Peat mining may have a destructive impact on the fauna which normally inhabit the peat swamps (there is one relevant report on this subject which was not accessible during the time frame of this review). Apart from directly killing many of the resident species it would also alter the habitat by altering its hydrology and following peat mining one would expect a major change in the community structure and replacement of the original diverse peat swamp fauna with high densities of highly mobile cosmopolitan species.

Known impacts of mining on water quality in south-west Australia include:

- Coal mining near Collie: the pH of three of the lakes affected by mining at Collie ranged from 3.0 to 4.0. The acidification is due to sulfuric acid production from the oxidation of pyrites (FeS_2) which are common in the spoils of open-cut mining (Bartle and Riches, 1978).
- Bauxite mining: Bauxite residue disposal areas tend to have a pH of 10.5 to 11.5 and a high total level of water-soluble salts as well as very high free sodium concentrations (Olsen, 1978). Elevated levels of sediment might also characterise stream sites downstream of strip mining (see below).
- Gold mine (Boddington): the mining residue area, situated upstream of the Thirty-four Mile Brook did not seem to be having an effect on the brook (the water is impounded at the mine which is some distance from the creek); and the heavy metal concentrations were low. However, the mine did have a very detrimental effect on the brook by construction of a dam which was then filled with water from Hotham River and thus rendered the creek saline (Worsley Alumina Pty Ltd., 1987; Bunn and Davies, 1992; Streamtec Report ST26/97, 1997; P. Davies pers. comm.).

Bunn *et al.* (1986) recorded the silt tolerant mayfly *Tasmanocoenis tillyardi* only at sites in streams influenced by bauxite mining, showed that this association was highly significant, and stated that such a result indicates a higher level of sediment than at undisturbed sites. They argued that this was an exception in their study, where sites downstream from strip mining showed no consistent differences in community structure from other sites. They attributed this inability to detect effects of strip mining on the high degree of spatial variation in the composition of taxa found at undisturbed sites (see 3.1 Categories of Fauna).

Mining activity may cause disturbance to fish habitat, particularly if it involves water abstraction as has occurred in the south branch of the Collie River. (See 2.17 Interacting Disturbances).

Several leases for the mining of mineral sands exist in the south-west region including a sand mining lease on the boundary of D'Entrecasteaux National Park near Lake Jasper. This lake contains a highly diverse native fish fauna. Another sand mining lease covers an area adjacent to the Scott River National Park. This area represents the easternmost boundary of *Nannatherina balstoni*. (Morgan, pers. comm.). There is a risk of contamination of water bodies by effluent from the processing of mineral sands. Effluent from the processing of mineral sands is being discharged into a series of artificially created lakes at the RGC mineral sands wetlands in Capel. This series of interconnecting lakes was formed where mining pits intersected the groundwater table (Hambleton, 1996). The distribution of fish species within the wetlands may be partially explained by water quality problems attributable to the effluent discharge. Ammonia which is highly toxic to fish is discharged at the southern end of the wetland chain. No fish are present in the lake receiving direct effluent discharge, while only the highly tolerant, introduced species, *Gambusia holbrooki* is present in lakes close to the pollution source. Native fish are only present in a few lakes furthermost from the discharge (Hambleton, 1993).

Recommendations

1. Detailed studies on hydrological impacts should be conducted prior to any mining activities where water extraction occurs, or where other groundwater disturbances are likely to occur. Lowered water levels could impact on native fish by drying out important summer remnant pools. Also lowered water levels could impact on aestivating fish species. These fish burrow into the substrate and aestivate at the surface of the groundwater table.

2. The impacts of any water or chemical leakage from mines needs to be investigated by an independent organisation so that any impacts of these operations on the aquatic faunas of RFA can be learned and rectified. This is particularly important when considering the vast extent of mineral mining leases and mine sites in south-west Australia (map: p. 19 in Steering Committee for Research on Land Use and Water Supply, 1984).

3. Peat mining should be restricted to only highly degraded urban deposits where it is unlikely to result in the loss of diverse and important faunas.

13. WASTE DISPOSAL

State of knowledge
Waste disposal sites are well recognised as major sources of pollution. However, there are no freely available reports on the impacts of waste disposal sites on the aquatic biota of the RFA. We are aware of impact assessments having been conducted but the results are kept confidential.

Septic tanks on the Darling Plateau, in a medium density residential area were found by Gerritse *et al*., (1992) to lead to substantial inputs of nitrogen and phosphorus into the groundwater. However, the impact of this on the groundwater fauna of the Scarp or on the spring and creek fauna in nearby groundwater discharge areas has not been assessed.

Recommendations
1. Since waste disposal sites can be the sources of extreme pollution of waters by heavy metals and other chemicals, research on their impacts should be carried out in all potentially vulnerable instances by independent agencies. This would speedily improve our knowledge on this kind of disturbance on the aquatic biota of the RFA.

2. Septic tanks on the Darling Scarp have been shown to be a source of contamination of groundwater. The effect of this contamination on the poorly known but important (including Gondwanan relicts) aquatic invertebrates living in groundwater, springs and nearby creeks should be investigated.

2.14 DAMS

State of knowledge

The effects of disturbance on aquatic organisms above and below dams are many and varied. The principal disturbance relates to changed hydrological regimes by altering (usually reducing) downstream flows, reducing the magnitude and frequency of downstream flood events, and impounding waters upstream (so that waterways function as lentic rather than lotic systems). These changed hydrological regimes have significant implications for the movement of sediment in the dammed watercourse. Dams also provide a physical barrier to upstream or downstream migrations of species. Despite the large number of dams and reservoirs constructed on waterways within the RFA, their impacts on aquatic fauna have only been studied selectively and infrequently (see Recommendations). The review below briefly summarises the studies undertaken on the impact of dams on the aquatic macroinvertebrates and fish in or adjacent to the RFA region.

Effects of dams on stream invertebrates

Storey *et al.* (1991) examined the recovery of aquatic macroinvertebrate assemblages downstream of the Canning Dam, Western Australia. The slower flow rates immediately downstream of Canning Dam (2.6% of the original discharge at that site) resulted in reduced levels of dissolved oxygen, higher levels of organics, higher water temperatures, and infilling of interstitial spaces due to sedimentation. These changes resulted in a more frequent occurrence of macroinvertebrate collectors (in low flow conditions) and greater proportion of shredders (in the higher flows after rains) in the upper and middle reaches. Particularly common were species of oligochaetes, molluscs and chironomids. The authors regarded this changed macroinvertebrate faunal assemblage as one much like that of lowland rivers. At a site below the confluence with a major tributary, recovery of community occurred because the tributary could act as a source of increased discharge. The authors recommended that further studies were required to test the hypothesis that riverine faunas could recover from damming if a major tributary reinstated flows downstream of the dam.

Worsley Alumina Pty Ltd. (1984) found negative impacts on the macroinvertebrate fauna of sedimentation due to logging and dam construction. Sites downstream of the dam revealed reduced abundance, richness and overall diversity of species, and it was hypothesised that collectors and shredders were the main groups to have been affected, and that seasonality needs to be considered as part of the assessment (where impacts were discernible only at certain times). Freshwater mussels were used to check for levels of accumulation of trace metals but they were not standardised. The mayfly *Tasmonocoenis tillyardi* was proposed as an indicator of sedimentation when present in high numbers.

ARL no. 15 (1989) and Davis *et al*.(1988a) describe the results of several baseline studies in northern rivers flowing off the Darling Scarp; the studies were initiated to allow impact assessment of proposed dams on the rivers. No post impact results are available, or have been undertaken since (see Recommendations).

Effects of dams on fish

Dams, weirs and other obstructions, both natural and man-made, act as barriers to the migration of several native fish species. Aggregations of *Edelia vittata* and *Geotria australis,* and *Galaxias occidentalis,* have been observed at the base of dams and weirs during peak spawning periods, as fish attempt to move upstream to spawn (Pen *et al*., 1988; Pusey *et al*., 1989). Authors documenting such aggregations have suggested that the reproductive success of these species may be subsequently effected (Pen *et al*., 1988; Pusey *et al*., 1989). This is confirmed in part by an absence or a decline in numbers of some fish species in areas upstream of dams and weirs (Pen *et al*., 1988; Pusey *et al*., 1989; Morgan and Gill, 1995). (See also 2.17 Interacting Disturbances).

Big Brook Dam near Pemberton provided a good example of these issues. Attempts to allow for fish migrations upstream using fish ladders were unsuccessful (Pen *et al*., 1991). Significant reductions in the density of *Edelia vittata* and *Bostockia porosa* have been recorded in streams above the dam (Morgan and Gill, 1995); this decline is thought to have occurred through the construction of the dam combined with several other disturbance regimes (See 2.17 Interacting Disturbances). The construction of the dam has led to the elimination of *Galaxiella munda* in areas upstream of the dam and to a huge decline in abundance in areas below the dam.

The creation of large, deep essentially lentic environments favours many introduced species. This increases predation and/or competition on native species, resulting in substantial declines or elimination of some native species in areas upstream of dams. (See also 2.17 Interacting Disturbances).

Recommendations

1. Fish ladders need to be designed to ensure fish passage. Early designs are largely based on the requirements for strong swimming salmonoid species. There is a need to determine the swimming capabilities of the smaller native fish and design appropriate ladders for their capabilities.

2. Availability of baseline data: several studies are available for pre-disturbance conditions in catchments where dams have been scheduled for construction (see ARL Nos. 9, 10, 11, 12, 15, 16, 1988-1989). These baseline data are comparatively rare in the disturbance ecology of aquatic organisms in south-west Australia, and complimentary post-disturbance investigations where dams have been, or will be, constructed, are recommended.

3. Wherever possible flows downstream of dams should be maintained at rates similar to those found in the creek before the construction of the dam. Building dams upstream (rather than downstream) of a minor tributary has been shown to be an effective measure of reducing the negative impacts of dams on downstream communities.

2.15 GROUNDWATER ABSTRACTION

State of knowledge

Groundwater abstraction for agricultural, industrial (including mining) and domestic purposes results in the lowering of water tables and loss of permanently wet habitats for aquatic fish and invertebrates which lack the adaptations to withstand complete drying (Balla and Davis, 1993; Jasinska and Knott, 1991; Jasinska, 1997; Hopper *et al*., 1996). Temporary waters (also faunistically diverse but tend to harbour different suites of animals from those in permanent wetlands), likewise, are detrimentally affected by groundwater abstraction. Balla and Davis (1993) suggest that the rate of drying of temporary wetlands is naturally very slow (<2cm per day) which enables the invertebrates to lay eggs in flooded fringing vegetation to complete their life cycles before the wetland dries. They postulate that groundwater abstraction may increase the rate of natural drying perhaps to the level where some species will not be able to complete their life cycle. The water levels of several valuable wetlands on the Swan Coastal Plain are being artificially maintained by pumping ground water into them. Permanently moist, freshwater habitats including lakes, springs/seepages, subterranean waters (interstitial ground water, cave streams and pools, subterranean conduits), headwater streams and swamps (which have water year round whether in pools or crayfish burrows or in the form of water saturated peat) all constitute potential refuges for the remnants of Pangean and Gondwanan faunas which have evolved under cooler, darker and wetter conditions than present (Main and Main, 1991; Christensen, 1992; Hopper *et al*., 1996; Jasinska, 1997).

The vestiges of the wet-adapted, strictly freshwater Gondwanan and Pangean faunas are represented by many families (from a broad range of higher taxa), often monogeneric, and with very few surviving species. Since the break up of the southern hemisphere continent, Gondwana, Australia has drifted from the Antarctic circle into lower and drier latitudes progressively losing its wet and cool adapted biota which in the more arid parts of the continent sought refuges in ground waters and springs (Hopper *et al*., 1996; Jasinska, 1997). Tasmania, the lower south-east of Australia (particularly the cooler mountains) and the lower south-west of Australia were the last sections of the continent to be influenced by the drier climate. Therefore, compared to the rest of Australia, these wet southern regions contain more permanent freshwater habitats and consequently more of the Pangean and Gondwanan relicts.

During the 1990s especially, more intensive collecting of aquatic invertebrates from relatively undisturbed habitats that remain moist year round, including caves, interstitial habitats and crayfish burrows has led to the discovery of many Gondwanan relicts. The great majority of the newly discovered species, particularly the crustaceans, have not been formally described or listed as threatened (see 3.1 Categories of Fauna). Yet, these species have highly restricted distributions: some species are endemic to single sites, for instance the aquatic root mat communities in caves and tumulus springs (see SYNTHESIS, Section 3.1). These moist refuges can be highly inconspicuous (for example a spring, small swamp or a cave stream) the only criteria being relatively undisturbed history and the presence of permanent moisture throughout historical times.

Aside from acting as refuges for relictual species, permanently moist habitats have diverse and rich faunas which are distinct from those of those creeks and wetlands which dry out completely in summer (Edward *et al.*, 1994)

Observed impact of drying of a permanent cave stream containing threatened aquatic root mat community.

The threatened aquatic root mat cave communities contain faunas that are unusual compared to cave waters elsewhere in having high species numbers and high animal abundance. The aquatic community of each of these caves is sustained nutritionally by submerged tuart root mats which grow along the edges of the streams. These aquatic root mat faunas consist primarily of invertebrates, although the night fish (*Bostockia porosa*) also lives in at least one of the caves (Cabaret). Some of the species are endemic to these cave streams and, furthermore, a number of them are Gondwanan relicts (crangonyctoid amphipods and janirid isopods). The great majority of animals in the cave streams inhabit the root mat interstices with only a few species being more abundant in either the open water or in the sandy stream bed (Jasinska, 1990; Jasinska and Knott, 1991; Jasinska *et al*., 1996; Jasinska, 1997).

One of the threatened aquatic root mat cave communities (stream in Gilgie Cave) dried up for the first time in recorded history (~70 years, L. Bastian pers. comm.) in Autumn 1996 for about three months. Once the flow resumed, Gilgie Cave stream was re-sampled in November 1996 to document impacts of the drying, and to compare the assemblage to that found in other adjacent caves (Twilight, Carpark). Regrowth of root mat branches from dried root stumps and from roots buried in the sandy stream bed was very limited (and so sampling was restricted). About half the original number of species recolonised the root mats. However, these comprised mainly species derived from the interstitial fauna of the Gnangara Mound aquifer, the only larger invertebrate being the freshwater crayfish, *Cherax quinquecarinatus* which has the ability to burrow and to walk considerable distances over dried stream beds (Jasinska, 1996; 1997).

Recommendations

1. For aquatic fish and invertebrates inhabiting temporary wetlands the water requirements, such as the impacts of the rates of drying of the wetlands, and the minimum length of time the wetlands need to contain water for the species to complete their life cycles, need to be investigated.

2. There is an urgent need for objective, detailed and thorough assessments on the impacts of groundwater abstraction on water levels in areas containing mainly undisturbed, permanent water habitats.

3. The threatened the tumulus spring and aquatic root mat communities, particularly those on the Leeuwin-Naturaliste Ridge, are facing imminent extinction due to the progressively falling water table levels and stream flows in the caves. An adequate impact assessment of groundwater abstraction on these communities is urgently needed. The assessment would have to involve mapping of subterranean conduits and identifying the specific catchment areas for each of the caves or tumulus spring outcrops. The assessment should also investigate the interaction between rainfall, catchment vegetation (including pine plantations), local geology and the patterns of recharge and determine ways of returning the flows to adequate levels.

2.16 WEATHER EVENTS

See 2.17 Interacting Disturbances

2.17 INTERACTING DISTURBANCES

Mining/Quarrying, Irrigation/Groundwater Abstraction, Weather Events and Introduced Species

Groundwater abstraction, periods of extremely dry weather and introduced species may individually have significant effects on the fish fauna of the south-west region. The impact of these disturbances is often multiplied when they are interacting as has been observed in the south branch of the Collie River in recent years. Abstraction of water during extremely dry years can reduce water levels resulting in either complete drying out of the aquatic environment and the subsequent loss of fauna, or a significant reduction in suitable habitat and cover. This causes increased competition between fish and if introduced fish predators are present, increased predation on native species. There is potential for these interacting disturbances to have a significant negative effect on native fish populations in any systems that contain introduced fish and which may be subjected to lowered water levels due to water abstraction.

Morgan *et al.*(1995) describe the situation occurring for freshwater fish fauna of the pools of the south branch of the Collie River, during a period of extremely low water levels. During the summer months water levels in this part of the Collie River markedly decline and the river becomes converted into a series of unconnected pools which act as important refuges for populations of various aquatic organisms (Pen and Potter, unpubl. data). These pools dried rapidly during the summer of 1994/95, probably due to the combined effects of underground mining and groundwater abstraction during a period of little rainfall (Morgan *et al.*, 1995). In previous years, Western Collieries have compensated for water losses associated with mining activity and groundwater abstraction by maintaining a flow of mine discharge water into the river. During the spring of 1994/95, this policy was not adopted, and as a result, many of these remnant pools became completely dry (Morgan *et al.*, 1995). While some of these pools would probably always have dried out prior to mining activity, the drying out during this summer period was exacerbated by the combined effects of a very dry summer and mine water abstraction (Morgan *et al.*, 1995). The implications for three fish species, *Galaxias occidentalis, Bostockia porosa* and *Edelia vittata* included:

- Large numbers of these species would have died in the south branch of the Collie River in the summer of 1994/95, had they not been relocated.
- The marked reductions in water levels that occurred in the south branch of the Collie River led to increased fish densities, reduced available habitat and cover, and thus to increased predation on native species by the introduced redfin perch
- It should also be noted that while the native fish fauna appear to be unaffected by the acidic discharge water from this mine, an indirect effect of acidic discharge water occurs through changes in the invertebrate fauna. Pools downstream of the mine did not contain the freshwater prawn *Palaemonetes australis*, an important dietary component of the redfin perch. Morgan *et al*. (1995) stated that the absence of *P. australis* is almost certainly due to its ‘susceptibility’ to the acidic mine water that was discharged into that part of the system prior to spring 1994. The lack of this important invertebrate prey item could have led to increased predation by redfin perch on native fish.

Dams, Introduced Species and Weather Events
Fish monitoring at Big Brook Dam has provided relevant information for three species of native fish, *Galaxiella munda, Bostockia porosa* and *Edelia vittata* (Pen *et al*., 1988; 1991; Morgan and Gill, 1995). The evidence on the effect of these interacting disturbances relate to data obtained from fish monitoring conducted over several years after the construction of Big Brook Dam near Pemberton in 1986. This ongoing monitoring program is the only such program undertaken to study the effects of dams on fish populations in the south-west forest region, and as such, documents changes to the fish fauna which have important ramifications on future management decisions regarding the placement and design of such barriers. The changes to the aquatic environment after the dam construction has led to the increased abundance of predatory introduced fishes, which, coupled with a particularly dry summer, have led to the decline of several native fish species in this system. It is highly likely that these events have already, or may easily occur again in other systems, placing the future of certain native fish species, particularly *Galaxiella munda* under great threat.

The construction of Big Brook Dam in 1986 has led the elimination of *Galaxiella munda* in areas upstream of the dam and to a huge decline in abundance in areas below the dam (Morgan and Gill, 1995). This species is more common in lotic headwater streams than in lentic waters and it is thought that the lentic waters created by the dam have been detrimental to the survival of this species (Morgan and Gill, 1995). This species was found to be abundant in the headwaters above Big Brook Dam in the mid 1980s, but the study of Morgan and Gill (1995) recorded no *Galaxiella munda* in the headwaters of Big Brook above the dam and only one specimen in the brook below the dam. The disappearance of this species from Big Brook is probably due to both the unsuitability of the deep lentic environment created by the dam and by competition and/or predation by Redfin Perch (Morgan and Gill, 1995). During several recent dry years the reservoir immediately above the dam was the only upstream section to retain water during summer and autumn (Morgan *et al*., 1996). It was during this time that the redfin perch was introduced to the reservoir and has now become well established in this part of the system (Morgan *et al*., 1996). Dams and weirs form barriers to the migration of *Galaxiella munda* and therefore prevent recolonization of areas upstream (Pen *et al*., 1988). If a population is eliminated from these areas upstream as has occurred at Big Brook, there is no natural means of recruitment to these effected areas (Pen *et al*, 1988; Morgan and Gill, 1995). As this species is listed as restricted in the Australian Society of Fish Biology's list of Australian threatened fishes and is considered rare throughout much of its distribution, its decline in stream headwaters and tributaries (the only areas where it is found on occasion to be abundant) upstream of dams is of particular concern.

There has also been a marked decline in the numbers of *Edelia vittata* and *Bostockia porosa* occurring upstream of Big Brook Dam (Morgan and Gill, 1995). It is thought that predation and/or competition with redfin perch and *Gambusia holbrooki* have led to the reduction in numbers of these two species (Morgan and Gill, 1995) and that recruitment to the populations from unaffected downstream areas is prevented by the dam.

Dieback, Logging and Hydrological Change
The spread of dieback throughout a vegetation community may have significant effects on hydrological regimes. Logging may in itself cause such changes in hydrological regimes, but may also exacerbate the spread of dieback, further influencing hydrological regimes. The effects of such disturbances on aquatic macroinvertebrates and fish has not been investigated, and is unknown, although any change in hydrological regime will influence the composition of aquatic communities.

Weather Events, Eutrophication, Grazing, Clearing, Application of Fertiliser
Several examples of the influence of summer downpours on fish and macroinvertebrate faunas in rivers adjacent to agricultural areas, have been documented. For example:

1. Eutrophication and deoxygenation caused by summer storms washing large quantities of organic wastes (principally of sheep manure) into river pools, have resulted in massive fish kills in the Avon (Kendrick, 1976), and have been hypothesised for the decline of marron (*Cherax tenuimanus*) in the Blackwood (Horwitz and Nickoll, 1996).

2. In the Hotham River, following a summer thunderstorm, overland flow from the Hotham catchment washed considerable amounts of manure from livestock into the river system. A combination of high temperature and salinities, excessive organic matter and subsequent bacterial respiration caused severe oxygen depletion along the river. Farmers reported kills of marron along the river and in dams (Bunn and Davies, 1992).

3. Fish kills of black bream, trout and redfin perch in farm dams in the Manjimup/Pemberton area have occurred in gully dams due to eutrophication and subsequent deoxygenation caused by high inputs of animal wastes, and the introduced duckweed (Sarre, pers. comm.). These dams are built on streams in cleared, steep valleys and after heavy rains large amounts of animal waste were washed down into the dams.

2.18 SUMMARY

Table 2 presents a list of species which have been shown to, or hypothesized to, respond negatively to a particular disturbance event. The list has been constructed from the above review.

A similar list of species could be constructed to reflect species which respond positively to particular disturbances (as depicted in the text) (but time allowed for the review did not permit this synthesis).

Table 2: Species which have been shown to be, or hypothesized to be, detrimentally affected by one or more disturbances in the RFA region of south-west Australia. The table gives the species, the broad disturbance category, the section in the report where the details are given, and the nature of the report (UO = unpublished observations, UR = unpublished or published report, PA = popular article, RA = refereed scientific paper).

Species	**Disturbance**	**Section**	**Publ.**	**Details**
MOLLUSCS	**(mussels and snails)**			
Westralunio carteri	Clearing	10	RA	Salinisation
Glacidorbis occidentalis	Logging	2	UR	experimental introduction of sediment
Austroassiminea letha	Pesticides	Categories	RA	pesticide usage, restricted distriubtion
ACARINES	**(water mites)**			
Pseudohydra-phantes doegi	Salinity	Categories	RA	Drying and salinity
Acercella sp.	Salinity	Categories	RA	Drying and salinity
Australiobates sp.	Logging	2	UR	Sedimentation
Oxus sp	Logging	2	UR	Sedimentation
Notoaturinae gen. nov.	Logging/Clearing	Categories	UR	Siltation
Tartarothyas sp. nov.	Logging/Clearing	Categories	UR	Siltation
Tillia davisae	Logging/Clearing	Categories	UR	Siltation
Penemideopsis pusilla	Logging/Clearing	Categories	RA	Siltation
CLADOCERANS	**(water fleas)**			
Chydorid cladocerans	Fire	1	UR, RA	fire in wetlands
OSTRACODS	**(seed shrimps)**			
Candonocypris novaezelandiae	Logging	2	UR	Sedimentation
Gomphodella aff. *maia*	Groundwater abstraction	15	UO	Absence following drying
ISOPODS				
Hyperoedesipus plumosus	Logging	2	UR	experimental introduction of sediment
AMPHIPODS				
Uroctena sp	Logging	2	UR	experimental introduction of sediment
Austrochiltonia subtenuis	Groundwater abstraction	15	UO	Absence following drying
DECAPODS	**(shrimps and crayfish)**			
Cherax tenuimanus	Introduced species Clearing Interactions Harvesting	6 10 17 8	RA UR, PA, RA UR, PA, RA RA, PA, UR, UO	Predation by redfin perch Salinisation Eutrophication, drought, deoxygenation, etc overfishing
Cherax quinquecarinatus	Introduced species	6	RA	Predation by redfin perch
Engaewa sp. (WAM 182-94)	Logging	Categories	UR	Forestry activity
Palaemonetes australis	Introduced species Interacting Disturbances	6 17	RA UR	Predation by redfin perch Acid mine drainage

Table 2 (cont.)

CHIRONOMIDS	**(non-biting midges)**			
Limnophyes sp.	Clearing Logging	10 2	UR UR	sedimentation, clearance of riparian vegetation
Ablabesmyia sp. A or sp. V10	Clearing Logging	10 2	UR UR	sedimentation (including experimental studies), clearance of riparian vegetation
Tanypodinae sp. 3	Logging	2	UR	Sedimentation
Tanytarsini sp. V13	Logging	2	UR	experimental introduction of sediment
Zavrelimyia sp. V20	Logging	2	UR	experimental introduction of sediment
Thienemanniella sp. V19	Logging	2	UR	experimental introduction of sediment
Riethia sp. V4	Logging	2	UR	experimental introduction of sediment
Tanytarsus spp.	Logging	2	UR	experimental introduction of sediment
Rheotanytarsus sp. V18	Logging	2	UR	experimental introduction of sediment
Diplectrona sp	Logging	2	UR, RA	Sedimentation
ODONATANS	**(damselflies and dragonfles)**			
Petalauridae	Fire	1	RA	fire in wetlands
Synthemidae	Fire	1	RA	fire in wetlands
PLECOPTERA	**(stoneflies)**			
Nyungara bunni	Logging	2	UR	experimental introduction of sediment
EPHEMEROP-TERANS	**(mayflies)**			
Tasmanocoenis tillyardi	Pest Control	4	UR	Non-target species in midge control programmes
Baetis soror	Logging	2	UR	Sedimentation
Neboissophlebia occidentalis	Logging	2	UR	experimental introduction of sediment
DIPTERANS	**(other flies)**			
Empididae sp. 1	Logging	2	UR	Sedimentation
TRICHOPTERA	**(caddies flies)**			
Taschorema pallescens	Logging	2	UR	Sedimentation
Leptoceridae Indet. gen 10.	Logging	2	UR	Sedimentation

Table 2 (cont.)

FISH				
Lepidogalaxias salamandroides	Fire Roading	1 11	UO UR	Fire adjacent to pools Excavation or infilling for roads
Galaxiella nigrostriata	Fire Clearing Roading	1 10 11	UO UR UR	Fire adjacent to pools Clearing and agricultural activity Excavation or infilling for roads
Galaxiella munda	Grazing Clearing Introduced species Dams	5 10 6 14	UR UR RA, UR UR	Grazing, clearing and agricultural activity Redfin perch and Gambusia
Galaxias occidentalis	Interactions and Introduced species	17 6	UR UR	Redfin perch and Gambusia
Edelia vittata	Fire Introduced species Interacting disturbances	1 6 17	UO RA, UR UR	Fire adjacent to pools Redfin perch and Gambusia Dams, Introduced Species and Weather Events
Nannatherina balstoni	Fire Introduced species Clearing	1 6 10	UO UO UR	Fire adjacent to pools Vulnerable to predation Absent from waterways in cleared land
Bostockia porosa	Fire Introduced species Interacting disturbances	1 6 17	UO UR UR	Fire adjacent to pools Redfin perch and Gambusia Dams, Introduced Species and Weather Events
Geotria australis	Grazing Dams	5 14	UR RA	Substrate alteration due to agricultural activity Blocking spawning migrations

3. SYNTHESIS

3.1 CATEGORIES OF FAUNA AND THEIR SPECIFIC REQUIREMENTS

This section deals with the special attributes of faunal assemblages and individual taxa in the RFA, as they relate to disturbance ecology. In particular, the section provides details on:

- the types of habitats in which special aquatic fauna (assemblages of species, or individual species) are likely to be found,
- the assemblages or communities of aquatic fauna which are recognised as threatened,
- the individual taxa which are recognised or regarded as threatened,
- locally restricted (narrow range) endemic species, and
- species which have shown a negative response to one or more disturbances.

Moist habitats: Gondwanan sites and relictual and endemic aquatic species

All reasonably undisturbed, permanent or permanently moist, freshwater, habitats in south-west Australia, whether coastal flats, headwater streams, subterranean waters or peat swamps are potential refuges for Gondwanan relictual (Gondwanan and Pangean) aquatic species, and/or threatened taxa or communities.

Main (1996, following Main and Main, 1991) proposed specific characteristics of sites in south-west Australia in which Gondwanan elements might be found, and conserved:

1. unaffected by salinisation;
2. high rainfall areas with short summer drought;
3. topographically high south coastal areas subject to frequent mists, cloud and drizzle;
4. areas adjacent to granite rocks from which water is shed;
5. areas of impeded groundwater flow so producing winter wet swamps;
6. streams with extensive fresh headwater swamps and year round flow;
7. areas where vegetation can harvest water from fog or cloud by drip from leaves and stem flow e.g. tingle forest and south coast dunes and heath;
8. areas with southern or south-west aspect which are thus sheltered from summer insolation e.g. valley slopes and wet valley floors; and
9. areas of intact forest canopy under which the characteristic under storey shrubs and herbs occur;

to this list we can add:

10. springs and caves streams, or other expressions of interstitial or groundwater.

There are two important characteristics of these habitats which have been highlighted in the review so far:

<u>1. Adjacent wetlands can be quite distinct</u>

Headwater sites (see ARL reports for northern forest regions), and peatland and shrubland sites (see Horwitz, 1997 for southern wetlands), and cave faunas (see Jasinska, 1997) which are adjacent to each other, are frequently observed to have different suites of aquatic fauna. This can be expressed as high beta richness of aquatic fauna. This suggests that <u>each</u> wetland with these characteristics, to a certain degree, has a unique biodiversity conservation value in its own right, and requires particular management objectives to ensure that these values are not lost.

<u>2. Suites of wetlands can have high conservation value due to their total assemblages</u>

Simply on the basis of the alpha richness of aquatic macroinvertebrate faunas, suites of wetlands represent areas of high conservation value (see ARL Report 22, 1992 for permanent lakes of the south coast).

Ecological Communities Regarded as Threatened

The following communities in the South-west Botanical Province have been proposed for inclusion on the Department of CALM's threatened ecological community database, as of 7th August 1997, using their prioritised ranks.

<u>Already defined as Critically Threatened Ecological Communities</u>

Rank 3: Communities of tumulus springs (organic mound springs) central SCP (Perth to Gingin);

Tumulus springs consist of large volumes of peat build up (in the form of a mound) about a permanent point of groundwater discharge with the peat typically resting on a sandy substratum. The spring may issue either from a discrete vent on top of the mound or seep from the whole surface of the mound without a main outflow channel. The tumulus springs comprise discrete plant and animal communities which include endemic species and northern outlier populations of mesic species which now occur only in the wetter part of south-west Australia (Jasinska and Knott, 1994; Knott and Jasinska, 1997). The conservation of all Australian mound springs is under threat from three principal causes: groundwater abstraction from their source aquifers; physical destruction either by land clearing or cattle grazing; fire and invasion of exotic plant species (also see Sections 2.1 and 2.15).

Rank 6: Aquatic root mat community of the Swan Coastal Plain (Yanchep)
In south-west Australia permanent groundwater streams of caves in Yanchep National Park (YNP), contain root mats which serve as a primary food source for a faunal suite of unusually high species richness and abundance compared to subterranean groundwaters elsewhere (Jasinska, 1995, 1996; Jasinska *et al*., 1996; Jasinska and Knott, in press) (see 2.15 Groundwater Abstraction). The YNP cave streams include several endemic species (e.g. undescribed species of crangonyctoid amphipods).

Rank 11-14: Aquatic root mat community numbers (1-4) of the Leeuwin Naturaliste Ridge
Permanent groundwater streams also occur in caves in the Leeuwin Naturaliste Ridge. These aquatic root mats in the Leeuwin Naturaliste Ridge caves contain predominantly unpigmented fauna. Local groundwaters likewise contain zoogeographically important fauna including species endemic to the individual cave streams (e.g. undescribed species of bathynellid syncarid and crangonyctoid amphipods). The greatest, and imminent, threats to the root mat communities is the rapid disappearance of the cave water's source, and secondarily removal of the trees above the cave to which the root mats belong. Jasinska (1997) and Jasinska and Knott (in press) showed that the assemblages in each cave are relatively discrete.

Communities proposed, but with insufficient information at present:
Rank 83 *Baumea* wetlands of the Southern Jarrah Forest (Lake Muir system)
Rank 92 Relictual peat community (Lake Surprise) (South Coast Region)

Declared Threatened Fauna within or immediately adjacent to RFA region

Only one aquatic invertebrate is listed from the RFA under the provision of the Wildlife Conservation Act 1951 (WC Act)(but see Specially Protected Fauna below). No fish are listed (but see unofficial listings for fish below).

Mollusca

Austroassiminea letha, Cape Leeuwin Freshwater Snail.

Solem *et al*. (1982) regard this snail as a Gondwanan relict. Living (as opposed to fossil) specimens of *A. letha* were found at just three localities (despite extensive searching).

- Turner Brook, (ca. 34° 15’ 09’’S and 115° 03’ E), near Deepdene Cliffs, in seepage areas at the base of limestone cliffs, or in the litter near the creek banks in an area located only a few hundred metres from the creek mouth.
- Cosy Corner, Hamelin Bay, (ca. 34° 15’ 05’’S and 115° 01’ E), in grass tussocks on granite cliffs wet by seepage from the limestone-granite rock contact zone above and located less than 200 m from the beach.
- Ellen Brook just north of Margaret River (I) at the entrance to Meekadorabbie Cave (ca. 33° 54’ 36’’S and 114° 59’ 40’’E), Leeuwin-Naturaliste National Park on moss and algal covered limestone forming sides of the waterfall at the cave entrance and on the banks of the brook above it. (II) upstream from Ellensbrook homestead: in algae growing on the sides of concrete and wooden troughs carrying flowing water from Ellen Brook to the Ellensbrook homestead, under logs 2-3 m above water level, below and adjacent to the dam at Ellensbrook homestead (ca. 33° 54’ 10’’S and 114° 59’ 30’’E).

In all cases the water drains from areas of limestone. Live individuals were typically collected from actual seepage films or splash zones by small freshwater streams. All of these localities, although near the ocean, are well above stormwater marks and are not subject to seawater inundation (Solem *et al*., 1982). At the time of publication of the Solem *et al*. (1982) paper the Turner Brook site involved present and proposed agricultural areas subject to chemical spraying and/or fertiliser applications. The effects of such chemicals on the snails are still unknown. Solem *et al*. (1982) recommended a ban on chemical applications on the few hectares immediately involved in the seepage drainage through the known live snail area. However, such a ban might not suffice since many of the streams/springs on Leeuwin-Naturaliste Ridge flow underground for several kilometres in discrete conduits before emerging at the surface (E. J. Jasinska pers. obs.). Therefore, it is important to investigate the subterranean routes of the upstream sources of the few springs, streams and seepages that contain populations of this snail.

Other Specially Protected Fauna (aquatic species in the south-west)

The following taxa are recognised by state officials in the Department of CALM as being of conservation concern.

PRIORITY ONE (taxa with few, poorly known populations on threatened lands):

CRUSTACEA

1. *Daphnia occidentalis* [Cladocera], considered to be of Gondwanan origin. Found at two localities just south of Northcliffe in pools within apparently undisturbed swamps. These localities are close to the boundary between the karri forests and the alluvial plains dominated by heath and swamp vegetation (Benzie 1988; Horwitz, 1990).

2. *Calamoecia elongata* [Copepoda: Calanoida], found in three roadside pools between 6 and 7 km south of Northcliffe in the south-west and appears to favour temporary pools. These localities are also are close to the boundary between the karri forests and the alluvial plains dominated by heath and swamp vegetation (Bayly, 1979; Horwitz, 1990).

3. *Limnocythere porphyretica* [Ostracoda]. When listed it was known from only one locality, a roadside pool near Lake Grace township (outside of RFA) where at the time of collection (winter) the water was fresh (De Deckker, 1981; Horwitz, 1990). Since then the species has been found at two sites near Gascoyne Junction (Halse, pers. comm.) and on the Swan Coastal Plain.

PRIORITY TWO (Taxa with few, poorly known populations on conservation lands, or taxa with several, poorly known populations not on conservation lands)

ACARINA

1. *Pseudohydraphantes doegi* (Doeg's Water-mite), collected only from Poorginup Swamp (a peat swamp) (34° 33' S and 116° 44' E), in 1985 before the lake temporarily dried up in 1987. Pooriginup Swamp is the smallest, most fresh and most pristine of the lakes in the Lake Muir complex where the other lakes have become saline due to the clearing of natural vegetation around them for farmland (Harvey, 1987; Harvey, 1996). Recently the mite has been collected from the Shannon River (34° 50' 35'' S and 116° 22' 18'' E).

2. *Acercella* sp. (Poorginup Swamp Water-mite); this species is now described as *A. poorginup* (Harvey, 1996). Like *Pseudohydraphantes doegi*, *A. poorginup* has been collected only from Poorginup Swamp, in 1985 before the lake temporarily dried up in 1987, and has not been collected at any other site, despite a large collecting effort in the south-west over the recent years (Harvey, 1996).

The mites would be expected to survive the drying of a freshwater lake by being transferred to another nearby freshwater lake on their insect hosts (to which larval mites attach). However, the other wetlands in the Lake Muir compex may have become too saline for the larval mites (or the host insects) to utilize them as a permanent water refuge when Poorginup Swamp dried up. It is possible that both species have permanently disappeared from Poorginup Swamp (M. S. Harvey pers. comm.).

Both of these species are formally protected under the "closed season notice" under the provisions of the WC Act.

CRUSTACEA
1. *Fibulacamptus bisetosus*
This harpacticoid copepod has a very restricted distribution, and was recognised in this category following its unofficial listing in Horwitz (1990).

2. *Engaewa* sp. (WAM 182-94) [Decapoda: Parastacidae]
This new species of burrowing crayfish (Horwitz and Adams, in prep) has only been found where seepages occur in forested areas in the Walpole - Bow Bridge part of the RFA. It was first found in a clearfall coupe in water-filled tractor tyre ruts in May 1981 following recent logging and heavy rain, and never found again at that site, despite repeated searching. It was discovered again at two, possibly three, nearby locations during a survey of southern forest peatland and heathland sites in 1992 and 1993 (Horwitz, 1994a). All forest near or in the likely range of this species must be surveyed adequately prior to any logging activity. For locations where the species occurs, logging should never be undertaken near or in headwater or seepage areas and logging or roading machinery should never be taken near or in seepage areas. The effects of fire on peat habitats needs urgent consideration (by modifying fire prescription practises and developing a protocol for action if peat fires commence and further research). Threats to the taxon are considered to be clearfall logging through headwater/seepage areas; cattle trampling and degradation of peaty seepages (these threats are based on similar responses by species elsewhere in Australia). Inappropriate fire management activities may also have detrimental effects. For these reasons, this species is regarded by Horwitz (1995) as being of "conservation concern".
Despite being registered in 1995 by the same agency which authorises and conducts logging activities, and to the authors' knowledge, no surveys of logging coups in the area have been undertaken for the species.

<u>PRIORITY FOUR (Taxa in need of monitoring)</u>
CRUSTACEA
Cherax tenuimanus Margaret River subspecies. (Margaret River Marron) [Decapoda: Parastacidae].
This "subspecies" (not yet formally described taxonomically) is threatened by habitat alteration, overfishing, and genetic pollution (by hybridization).

Horwitz and Nickoll (1996) make the case that *all* marron should be regarded as threatened in natural waterways for the same three reasons:

- habitat and water quality degradation,
- the possibility for genetic pollution to take place, and
- the depletion of stock through overfishing (either in the form of legal recreational fishing or illicit stock removal).

The spread of the yabby is constantly referred to as a potential activity to threaten marron, either directly or by the introduction of disease, and these issues are yet to be fully evaluated. The entire species was recorded by Horwitz (1995) as being of conservation concern not because the species as a whole is likely to become extinct, but because range contractions in the wild, and genetic pollution, may result in the loss of genetic material.

There has been a significant retreat of marron stocks downwards, from the upper reaches of major rivers in the south-west (Morrissy 1978). The security of remaining marron stock is of concern because of increasing nutrient and salt pollution, from agricultural areas, and increasing multiple use of the forested downstream catchments (see Morrissy 1978), and the overfishing of marron stock.

MOLLUSCA

Westralunio carteri (river and lake mussel)

Substantial declines in the distribution of this species within water courses of the south-west have been observed.

Other macroinvertebrate species in need of conservation attention

1. A species of crangonyctoid amphipod (gen. nov., sp. nov.) until the early 1990s was present in high numbers in the sandy, groundwater pools of Crystal Cave at Yanchep National Park. The species is endemic to this one cave, and when most of the groundwater pools in Crystal Cave dried up over the last few years the population of this relictual species was reduced to fewer than 20 individuals (Jasinska, unpubl. data). These amphipods feed microbial growths associated with wood or tree roots and on fine detritus, and are killed by water temperatures of ~28°C and higher.

2. Western petalura dragonfly *Petalura hesperia*

This species is rare in south-west Australia and should be regarded as threatened. Disturbances such as fire which burns peat, and clearing of understorey, and any mechanism which reduces soil moisture (such as prescription burning, see Section 2.1) may threaten its continued existence at a local site. The following information is adapted from Barrett (1996):

This species is the largest dragonfly species in Western Australia and the fourth largest in the world. It was discovered in Lesmurdie in 1957. Species in the Family Petalauridae can be considered to be Gondwanan relicts (indicated by the little morphological variability amongst patchily distributed species). It is reported to have an extremely long larval period, up to five or six years, spent in burrows in boggy marshes. In Western Australia it occurs (has been sighted) along the eastern fringe of the Darling Scarp, usually associated with headwaters of permanent water bodies, but restricted to freshly oxygenated waters of boggy marshes or seepages. Authorities believe that extensive under and overstorey vegetation types are essential to maintain moist soils and provide roots and peripheral vegetation amongst which the larvae can burrow.

3. Water mites

The following five species can be regarded as being in need of conservation attention. Information is adapted from that provided by Dr Mark Harvey (Western Australian Museum, pers. comm.). The life-cycle of water mites involves a parasitic phase on an insect host, yet the identity of the insect species which act as host is still unknown for all the south-west Australian water mites. The water mite fauna of south-west Australia shows high levels of endemicity and includes both Pangean and Gondwanan relicts. To protect these mites effectively, research into the identity and requirements of their insect hosts needs to be carried out.

•*Larri laffa* – a Pangean relict, collected from Poorginup Swamp (in 1985), Lake William in West Cape Howe National Park (35° 05' S and 117° 36' E) and a roadside pool, Chesapeake Road near crossing of Gardiner River (34° 48' S and 116° 10' E).

•Notoaturinae gen. nov., sp. nov., *Tartarothyas* sp. nov. are both Pangean relicts, collected only from Carey Brook, and are likely to be vulnerable to siltation.

•*Tillia davisae* – collected only from Serpentine River, interstitial waters, and therefore likely to be vulnerable to siltation.

•*Penemideopsis pusilla* – collected only from Gooralong Brook, west of Jarrahdale (32° 20'S and 116° 03' E), rare, interstitial and therefore likely to be vulnerable to siltation (Harvey, 1996).

4. Stoneflies

A stonefly nymph collected from Mingenew in 1963, and placed into museum curation, was described by Hynes and Bunn (1984) as a species of *Dinotoperla*. It has not been collected since, despite searches for it, and should be considered for listing as a threatened taxon. This species is included here because its distributional range might conceivably extend south from Mingenew into the northern part of the RFA.

Status of south-west Australian inland fishes

Species included on the Australian Society for Fish Biology's list of Australian threatened fishes

Lepidogalaxias salamandroides Mees, 1961 (Salamanderfish)

Classed as Restricted in the Australian Society for Fish Biology's list of Australian threatened fishes. A large part of the area in which this species occurs is in the D'Entrecasteaux National Park (Morgan *et al.,* 1996).

Galaxiella nigrostriata Shipway, 1953 (Black-stripe minnow).

Classed as Restricted in the Australian Society for Fish Biology's list of Australian threatened fishes. A large part of the area in which this species occurs is in National Park (Morgan *et al*., 1996). [Disjunct populations recorded from a small pool near Bunbury and at Gingin (Morgan *et al.,* 1996)].

Nannatherina balstoni Regan, 1906 (Balston's pygmy perch)

Has been proposed for inclusion in the vulnerable category in the Australian Society for Fish Biology's list of Australian threatened fishes. A large part of the area in which this species occurs is in National Park (Morgan *et al*., 1996). Isolated population also occurring at Gingin (Morgan *et al.,* 1996)

Galaxiella munda McDowall, 1978 (Western mud minnow)

Classed as Restricted in the Australian Society for Fish Biology's list of Australian threatened fishes.

Not included on the Australian Society for Fish Biology's list of Australian threatened fishes

Edelia vittata Castelnau, 1873 (Western pygmy perch)

Galaxias occidentalis Ogilby, 1900 (Western minnow)

Bostockia porosa Castelnau, 1873 (Nightfish)

Tandanus bostocki Whitley, 1944 (Freshwater cobbler)

Geotria australis Gray, 1851 (Pouched lamprey)

Locally restricted (narrow range) endemics

Table 3 presents summary data for selected species of macroinvertebrate which are known to be restricted in their distribution to a narrow geographical range. It must be recognised that this list is by no means complete. These species are at one end of a taxonomic certainty continuum: they are a subset of the species which are taxonomically well known, for which a reasonable effort has been expended to determine their distributions, or where they would have been expected to be found in surveys. Only taxonomically well-known species (formally described, or in the process of being formally described) are included in this section. This process then includes only a small fraction of possible species which could be expected to be classed as locally restricted in their distribution, since taxonomic coverage of many groups is insufficiently detailed.

These species are also at one end of the distributional or geographic range spectrum. Distributions of any aquatic organism might be global, or cosmopolitan, or Australia-wide, or south-west Australia, or a local region within south-west Australia, or at a single site only. Narrow range endemics have been defined by Horwitz (1997) as those species restricted to a location or area within a bioregion (in that instance, the Warren Bioregion). The size of the area is somewhat arbitrary, but for this exercise a range of less than 100 km has been selected.

These species are vulnerable to disturbances simply due to their distributionally rare status. Species in this section overlap with species mentioned in the above section on threatened taxa, for this very reason. Trayler *et al.* (1996) showed that a high proportion of species identified as locally endemic in the Warren Bioregion were found in a nature reserve or national park, but that this should be no reason for complacency as such reserves were not inviolate; in fact some human induced disturbances to wetlands were operable (like management fires). The same might apply to the whole of the RFA, although the proportion of species reserved is lower for the whole region.

Species in Table 3 can be ascribed to one or more of the special habitats (1-10) mentioned above. Where aspects of their habitat were known in sufficient detail, sites for all species conformed to habitat characteristics 1 (not affected by salinisation) and 9 (intact canopy cover; except for species found in pools on granite rock). The listed taxa are mostly known (or hypothesised to have Gondwanan ancestry). In general terms this confirms the theory that these types of habitat are likely to contain special elements of south-west Australian fauna.

Table 3. Selected invertebrate fauna found in aquatic habitats within the RFA region (or immediately adjacent to it) which are regarded to be locally restricted in their distribution [see Trayler *et al.* (1996) and Horwitz (1997)]. Habitat refers to one or more of the Gondwanan habitats (1-10, see Section XX of this report, where n/a = habitat which does not fall into one of these categories, and nk = habitat not known). Reservation status refers to their presence or absence in a Nature Reserve or National Park within the region. Table adapted from Trayler *et al.* (1996) and Horwitz (1997) to include the RFA region. See text for more explanation.

Species[1]	Source	Habitat	Reservation	Distribution or location
ACARINA				
Tartarothyas sp. nov.		2, 6	-	Carey Brook
Tillia davisae		6?	?	Serpentine R.
Penemideopsis pusilla		6?	?	Gooralong Brook
Pseudohydraphantes doegi	12	2, 5	+	Shannon/Lake Muir
Notoaturinae gen. nov		2, 6	?	Carey Brook
Acercella. poorginup	12	5	?	Lake Muir region
CRUSTACEA				
Kapcypridopsus asymmetra De Deckker	4	nk	+	Albany
Ilyodromus candonites De Decker	4	3, 4	+	
Calamoecia elongata Bayly	7	2, 5	+	Northcliffe
Hemiboeckella powellensis Bayly	8	2	+	Lake Powell
Boeckella geniculata Bayly	7	2, 5	+	
Biapertura imitatoria Smirnov	7	3, 4	+	Mt Chudalup
Daphnia occidentalis Benzie	7	2, 5	+	Northcliffe
Uroctena whadjukia			-	Wungong System
Uroctena yellandi	10		-	Armadale
Protocrangonyx frontinalis	10	6, 10		Lesmurdie
Totgammarus eximius	10	2, 5, 7	-	Scott River
Engaewa subcoerulea Riek	5	2, 5, 7	+	Shannon
Engaewa reducta Riek	5	2, 5, 7, 10	+	Dunsborough
Engaewa sp. nov 1	9	2, 5, 10	+	Walpole
Engaewa sp. nov 2	9	2, 5, 7	-	Margaret River
Cherax glaber	10	2, 5, 7		Augusta to Dunsborough
INSECTA				
Kosrheithrus boorarus Neboiss	2	2, 6	-	Carey Brook
OLIGOCHAETA				
Astacopsidrilus novus	11	10?	-	Lesmurdie Falls

[1] Fully described species, or species for which reliable taxonomic data are available.

Sources: 2, Growns and Davis (1994); 4, Bayly (1982); 5, Horwitz (1994a); 7, Bayly (1992); 8, Bayly (1979); 9, Horwitz and Adams (in prep.); 10 Horwitz *et al*. (1997a); 11, Pinder and Brinkhurst (1997); 12, Harvey (1996).

Summary Points and Recommendations

1. All reasonably undisturbed, freshwater or permanently moist habitats in south-western Australia (for instance headwater streams, springs, caves streams or peat swamps) are potential refuges for Gondwanan relictual (Gondwanan and Pangean) aquatic species. The great majority of relictual taxa collected from these habitats still remain to be described and many such sites have not yet been surveyed for fauna. Therefore, the reasonably undisturbed, freshwater, habitats within forested ecosystems should all have a management status which emphasises rigorous preservation of biodiversity and ecosystem functioning, at least until the status of the inhabitant fauna of each such site is assessed.

2. The identification, description management and identification of important but vulnerable communities in the South-western Botanical Province have been much facilitated through the threatened communities program within CALM, but there is much to do on these matters, even in the RFA region. It is very important that the threatened communities program continue and be expanded. Legislative support is seen as essential (see point 3 below).

3. Key habitats contain threatened fauna. The current legislative support for threatened fauna is considered to be inadequate for the longterm conservation of aquatic biodiversity. Several issues need urgent attention, and the RFA process is an appropriate mechanism to ensure that such issues are translated to policy and mandatory practice. For instance, according to a recent Supreme Court of Western Australia ruling (17 June 1997), the Western Australian Government through its relevant agency (CALM) is not bound with respect to fauna by the provisions of the Wildlife Conservation Act 1950, and is therefore not obliged to protect fauna, whether listed or not. This gives relevant government departments the oportunity to lower the priority of managing threatened species or communities. This is clearly unacceptable in terms of forest management in Western Australia, since the agency responsible for timber exploitation is also the one responsible for biodiversity conservation. The legislative obligation must extend to protect biodiversity. Also, aquatic fauna might be considered relevant to many pieces of legislation in Western Australia, and to jurisdictional interests of many government departments. The jurisdictional authority, however, is not at all clear, to the extent that obvious regulatory failings become evident. For instance, one government department presently sanctions the release of introduced predators (trout) into waterways of tracts of land managed by another department where nature conservation is the primary objective. In legislative terms, waterways must be considered as a part of Nature Reserves and/or National Parks, and interagency interests must not override such objectives.

4. Since many of the aquatic Gondwanan relicts live in areas of active groundwater discharge, they are particularly vulnerable to disturbances involving the groundwater source (aquifer, recharge areas and subterranean conduits which, especially in karst areas, carry water in discrete channels to the surface discharge area). The disturbances include groundwater abstraction, pollution of groundwaters either from agricultural, urban or industrial sources. This is a pressing problem in the rapidly developing Leeuwin-Naturaliste region in particular. Therefore, it is a matter of some urgency to determine the subterranean drainage, source aquifers and their catchment areas for the caves and freshwater discharge areas known to contain species restricted to these Leeuwin-Naturaliste sites (also see sections 10, 13 and 15).

3.2 OTHER ISSUES TO NOTE

Granite Inselbergs

Granite monadnocks or inselbergs (resistant, elevated igneous outcrops) in the RFA serve as water catchments due to their impervious nature, and ready runoff. Aquatic habitats therefore exist in small depressions on the rocks (commonly referred to as granite pools), or in wetland areas around their bases. Both types of habitat are known to harbour a potentially important macroinvertebrate fauna (in some cases the habitats are surrounded by cleared land; in other cases their moisture retension properties have acted for extrememly long periods of time to enable some taxa to avoid seasonal aridity; in yet other cases, the pools are fresh but surrounding wetland systems are saline). In some cases the fauna found on them, or associated with them fits the categories given above (local endemics, threatened species, Gondwanan relicts, etc.). The fragility of these habitats, and some of the disturbances to them, are described fully in papers in a special issue of the Journal of the Royal Society of Western Australia, which is due for publication shortly.

Biotic Integrity Indices, and Monitoring River Health

Biotic integrity indices have been developed for families of aquatic macroinvertebrates in wetlands of the Swan Coastal Plain, south-west Australia, with a view to providing a numerical assessment of local disturbance (Davis, Trayler and Chessman, manuscript in prep.). The index is based on a similar approach developed for stream invertebrates in south-eastern Australia (Chessman 1995). This index is a composite index and does not necessarily distinguish between forms of disturbance. Nevertheless, it does provide a summary of the susceptibility of different families to a range of disturbances, and for any wetland under examination, can provide a preliminary, rapid indication of the condition of a waterway, where that assessment in required by management (see Chessman, 1995).

Similarly, the AUSRIVAS programme has established monitoring sites on rivers in south-west Australia. Like the approach taken above, this will not give disturbance specific details about community change, or response by taxa, although some post hoc guesswork might establish caustation. The purpose of the programme has been to construct models of river health. This approach requires the establishment of a large database containing both biological and environmental information about sites that represent unimpaired or least disturbed conditions (reference sites). The database is used to a develop a predictive model that matches a set of environmental variables to biological conditions. When environmental measurements are made at a new site, the model is used predict the new site's expected biological condition. A comparison of the actual biological condition at the new site with predicted conditions allows an assessment of the condition of the new site to be made. Early interpretations of constructed models for Western Australia as a whole, are currently being evaluated (Smith *et al.* in prep).

3.3 KNOWLEDGE GAPS AND ASSOCIATED ISSUES

Overall coverage of disturbance types, and the issue of publication
Table 4 summarises the reference sources (reports and refereed papers) which have been used for each of the major disturbances for aquatic macroinvertebrates and fish. The Table shows that some disturbances have received less attention by research or survey, than others. In particular:

- the effects of logging on fish,
- the effects of mining activity on all aquatic life,
- the effects of waste disposal/drainage on all aquatic life, and
- the effects of groundwater abstraction on fish,

are conspicuously poorly treated in the literature or in the knowledge base in general.

Consideration of Table 4 raises the issue of publication credibility, access to information and the status of unpublished and/or unrefereed reports, or anecdotal information. These are complex issues, and we do not intend to deal with them at length here. The approach taken in this report is that all information gathered by trained aquatic ecologists should be taken as authorative for the purposes of providing a synthesis of the status of knowledge. The translation of this information to management practices is a different, slightly more complex issue. In general we take the approach that government agencies responsible for the management of any environmental matter should develop a protocol which ensures that all relevant information is incorporated into the decision making process *in some way*. This includes anecdotal and observation information, reports (published or unpublished, often referred to as the grey literature) for government agencies and private companies, and refereed publications. Government agencies should make such protocols explicit; in other words they should make it quite clear from where information has come which leads to a particular decision, and why other forms of information have not been considered. Consistency will also be important; applying a rule that excludes external or independent unpublished material, but includes governmental unpublished material, will lead to unequal relationships amongst the scientific fraternity, and hamper the dialogue on which successful science thrives.

Other knowledge gaps are identified in recommendations in each section, or in other parts of the text.

Table 4. Sources of information: published papers, published and unpublished reports referred to in the text for the principle disturbance categories. The main issue for which a references was cited is indicated in square brackets.

Topic	FIRE	LOGGING	PEST CONTROL
Aquatic invertebrates	1. Bunn and Davies (1990) [heterotrophic streams] 2. Horwitz (1994a) [general] 3. Horwitz (1995) [crayfish] 4. Trayler *et al.* (1996) [general] 5. Wardell-Johnson and Horwitz (1996) [crayfish]	1. ARL Report 13 (1988) [overview] 2. Bunn and Davies (1990) [heterotrophy of forest streams] 3. Bunn and Davies (1992) 4. Gazey (1994) [sedimentation] 5. Growns (1992) 6. Growns and Davis (1991) 7. Growns and Davis (1994) 8. Halse and Blyth (1992) [overview] 9. Horwitz (1994a) [peat swamps] 10. Trayler *et al.* (1996) 11. Wardell-Johnson *et al.* (1991) [overview]	1. ARL Report 12 (1988) [community structure downstream of orchards] 2. Davis *et al.* (1988a) [pesticide levels] 3. Davis *et al.* (1988b) [midge control: non-target species] 4. Davis *et al.* (1990) [midge control: non-target species] 5. Garland and Davis (1986) [coastal lake community structure] 6. Lund and Chester (1991) [midge control: alum application] 7. Rutherford (1989) [overview] 8. Trayler and Davis (1996) [midge control: non-target species] 9. WA Department of Agriculture (1988) [LC_{50} values]
Assessment techniques/ desriptions of disturbance /management	1. Fleay (1985) [effects on water tables] 2. Ford (1985) [overview; nothing on aquatic faunas] 3. Gill (1986) [overview; nothing on aquatic faunas] 4. Horwitz, (1994a) 5. Horwitz *et al.* (1997) [peat swamps] 6. Lewis *et al.* (1994) [overview; nothing on aquatic faunas],	1. Abbott and Christensen (1994) [overview] 2. ARL Report 2 (1986) [sedimentation] 3. Beesley (1996) [large woody debris] 4. Borg *et al.* (1987) [sedimentation, salinity] 5. Borg *et al.* (1988a) [sedimentation, salinity] 6. Borg *et al.* (1988b) [sedimentation, salinity] 7. Calver *et al.* (1996) [overview] 8. Doeg and Koehn, (1990) [overview] 9. Growns (1992) 10. Halse and Blyth (1992) [overview] 11. Steering Committee for Research on Land Use and Water Supply (1987) [hydrological changes] 12. Wardell-Johnson *et al.* (1991) [overview]	1. ARL Report 14 (1990) [use of FW mussel in detecting Pesticides] 2. Atkins (1982)[residues in river] 3. Gerritse *et al.* (1990) [groundwater quality] 4. Rutherford (1989) [overview]
Fish	1. Balla (1994) [riparian habitats] 2. Horwitz (1994a) [general] 3. Pen (1993) [riparian habitats] 4. Pusey and Edward (1990) [aestivation]; 5. Pen *et al.*, (1993a) [aestivation]; 6. Trayler *et al.* (1997) [general]	1. Halse and Blyth (1992) [overview]	1. Davis *et al.* (1988a) [pesticide levels] 2. Pusey *et al.* (1989) [*Gambusia affinis*] 3. Rutherford (1989) [overview] 4. WA Department of Agriculture (1988) [LC_{50} values]

Table 4. (cont.)

Topic	INTRODUCED SPECIES/ DISEASE	HARVESTING/ RECREATION	CLEARING (rural & urban) and GRAZING
Aquatic invertebrates	1. Balla and Davis (1993) [coastal plain wetlands] 2. Horwitz (1990) [crayfish, hybridisation] 3. Horwitz (1994b) [overview] 4. Horwitz (1995) [crayfish] 5. Horwitz and Nickoll (1996) [crayfish] 6. Lawrence (1993) [overview] 7. Trayler *et al.* (1996) [overview]	1. Horwitz and Nickoll (1996) [crayfish: fishing] 2. Lund *et al.* (1991) [lead accumulation from duck shooting] 3. Morrissy and Fellows (1990) [crayfish: fishing] 4. Morrissy (1992) [crayfish: fishing] 5. Nickoll (1996) [crayfish: fishing]	1. ARL Report 2 (1986) [roads] 2. ARL Report 22 (1992) [salinization, nutrient, sewerage and agricultural runoff: impact on lakes] 3. Armstrong (1995) [riparian and upslope vegetation, sedimentation] 4. Bunn and Davies (1992) [salinization, eutrophication] 5. Balla and Davis (1993) [coastal plain wetlands: eutrophication] 6. Chambers and Knott (1997) [Cadmium inputs and toxicity, crayfish] 7. Doupé and Horwitz (1995) [wetland salinization] 8. Edward *et al.* (1994) [wetland low level salinization and eutrophication] 9. Froend and McComb (1991) [wetland salinization and eutrophication] 10. Horwitz (1994a) [overview, grazing] 11. Horwitz (1997) [salinization] 12. Kendrick (1976) [river salinization] 13. Morrissy (1974) [salinization, crayfish] 14. Morrissy (1978b) [salinization, crayfish] 15. Pinder *et al.* (1991) [eutrophication] 16. Streamtec Report ST 268 (1997) [river eutrophication] 17. Trayler *et al.* (1996) [overview] 18. Williams (1987) [river salinization] 19. Williams *et al.* (1991) [river salinization]
Assessment techniques/ desriptions of disturbance /management	1. Balla and Davis (1993) [overview: coastal plain wetlands] 2. Horwitz (1994b) [overview] 3. Pen and Potter (1992) [predation by fish] 4. Pen *et al.* (1993b) [predation by fish]		1. Chambers and Knott (1996) [cadmium in fertilizers] 2. Collins and Barrett (1980) 3. Gerritse *et al.* (1990) [groundwater quality: urban polution] 4. Gerritse *et al.* (1992) [groundwater quality: nutrient inputs] 5. Hodgkin (1978)
Fish	1. Arthington, 1991) [fish parasites, disease] 2. Davis *et al.* (1988a) [records from Serpentine River system] 3. Hambleton *et al.* (1996) [Gambusia: aggression] 4. Horwitz (1994b) [overview] 5. Hutchison (1991) [red fin perch] 6. Lane and McComb (1988) [red fin perch] 7. Lawrence (1993) [overview] 8. Morgan and Gill (1995) [predation: low water levels] 9. Morgan *et al.* (1995) [predation: low water levels] 10. Trayler *et al.* (1996) [overview]	1. Morgan *et al.* (1996) [fishing]	1. Balla (1994) [grazing: riparian habitats] 2. Halse and Blyth (1992) [roads] 3. Jackson and Wager (1993) [grazing: riparian habitats] 4. Morgan *et al.* (1996) [grazing, agricultural clearing, riparian habitats, roads] 5. Pen (1993) [grazing: riparian habitats]

Topic	MINING	DAMS	WASTE DISPOSAL
Aquatic invertebrates in general	1. Bunn *et al.* (1986) [sedimentation, bauxite mining] 2. Bunn and Davies (1992) [gold mininig]	1. Abbott and Christensen (1994) [recovery from slow flow] 2. ARL Report 15 (1989) [dam pre-construction data] 3. Davis *et al.* (1988a) [dam pre-construction data] 4. Storey *et al.* (1991) [downstream recovery of assemblages] 5. Worsley Alumina Pty Ltd. (1984) [dam construction]	

Table 4. (cont.)

Topic	MINING	DAMS	WASTE DISPOSAL
Assessment techniques/ desriptions of disturbance /management	1. Bartle and Riches (1978) [coal mining: acidification of water] 2. Olsen, 1978 [alkalinisation, sedimentation, high salts in residue disposal areas]. 3. Streamtec Report ST26/97 (1997) [gold mining] 4. Worsley Alumina Pty Ltd. (1987) [gold mining]		1. Gerritse *et al.* (1992) [septic tank leakage]
Fish	1. Hambleton (1996) [mineral sands]	1. Morgan and Gill (1995) [physical obstruction to migration] 2. Pen *et al.* (1988) [physical obstruction to migration] 3. Pen *et al.* (1991) [fish ladders] 4. Pusey *et al.* (1989) [physical obstruction to migration]	

Topic	IRRIGATION/ GROUNDWATER ABSTRACTION	Other characteristics of the fauna or the habitats relevant to conservation and management
Aquatic invertebrates in general	1. Balla and Davis (1993) [drying rates in wetlands] 2. Christensen (1992) [moist refugia for relicts] 3. Edward *et al.* (1994) [high diversity in pristine permanent waters] 4. Hopper *et al.* (1996).[moist refugia for relicts] 5. Jasinska (1995,1996, 1997) [cave faunas – drying effects, groundwater fluctuations; moist refugia for relicts] 6. Jasinska and Knott (1991, in press) [cave faunas – drying effects, groundwater fluctuations; moist refugia for relicts] 7. Main and Main (1991)).[moist refugia for relicts] 8. Solem *et al.* (1982).[moist refugia for relicts: *Austroassiminea letha*]	1. ARL Reports 9, 11, 12 and 13 (1988) [distribution in rivers] 2. ARL Report 22 (1992) [distribution in permanent lakes] 3. Balla and Davis (1993) [distribution in coastal plain wetlands] 4. Bayly (1979) [specially protected fauna: *Calamoecia elongata*] 5. Benzie (1988) [specially protected fauna: *Daphnia occidentalis*] 6. Davis *et al.* (1988a) [distribution in river] 7. Davies (1993) 8. De Deckker (1981) [specially protected fauna: *Limnocythere porphyretica*] 9. Edward *et al.* (1994) [distribution in permanent lakes] 10. Growns (1992) [distribution in rivers] 11. Harvey (1987, 1996) [specially protected fauna: water mites] 12. Horwitz (1990, 1994a, 1997) [specially protected fauna: crustaceans; regional endemism] 13. Horwitz (1995) [specially protected fauna: *Cherax tenuimanus*, *Engaewa* sp. (WAM 182-94)] 14. Horwitz *et al.* (1997b) [moist microhabitats] 15. Jasinska (1997) [threatened communities: aquatic root mat cave communities] 16. Jasinska and Knott (1994) [threatened communities: tumulus springs] 17. Jasinska and Knott (in press) [threatened communities: aquatic root mat cave communities] 18. Knott and Jasinska (1997) [threatened communities: tumulus springs] 19. Main (1996) [moist refugia] 20. Solem *et al.* (1982).[threatened species: *Austroassiminea letha*] 21. Storey *et al.* (1990) 22. Trayler *et al.* (1996) [endemism] 23. Wardell-Johnson and Horwitz (1996) [maps of endemics]
Assessment techniques/ desriptions of disturbance /management		
Fish		1. Balla and Davis (1993) [distribution in coastal plain wetlands] 2. Davis *et al.* (1988a) [distribution in river] 3. Hambleton *et al*. (1996) [distributions and biology] 4. Smith (1996) [*Galaxiella nigrostriata*, diet and biology] 5. Pen *et al*. (1991) [biology, distribution]

Pre-disturbance conditions, baselines for determining change

A major problem encountered in preparing such a review has been the dearth of literature or referable studies which document pre-disturbance conditions for water quality, and the composition of aquatic macroinvertebrates and fish. In addition, we have only just begun to record the significance of relictual endemic species which are geographically restricted in their distribution. Calver *et al.* (1996) summarised the relatedness of these two issues, thus:

> The relictual, endemic species with poor powers of dispersal are particularly prone to disturbances such as logging, road construction and prescription burning. It is surely essential that thorough surveys are undertaken at a scale commensurate with the chance of finding relictual endemic and vulnerable faunas, prior to clearfelling operations, road constructions and further prescription burns. Monitoring is ineffectual without predisturbance information and some form of BACI would be highly appropriate in this context.

The importance of pre-disturbance condition is made even more crucial by the recognition of the great spatial heterogeneity and patchiness, throughout the forested part of south-west Australia. Given the heterogeneous nature of south-west Australian flora and fauna (Wardell-Johnson and Horwitz, 1996), and the unique characteristics of each wetland (which conform to special site characteristics, see Section 3.1), simple application of management regimes determined from one set of research results to another location, or a whole region, may be quite inappropriate. Pre-disturbance or pre-logging conditions are therefore essential wherever disturbance is planned.

Calls for pre-logging surveys in the past have been met with claims that proponents of the calls simply "want to know everything before doing anything", and "the costs in undertaking such exercises would be prohibitive". These claims undervalue both the resource which is being commercially exploited, and the biodiversity in areas affected by the disturbance. We, like other scientists, view the acquistion of pre-disturbance information, where such data are required for the elucidation of the effects of the disturbance on the species or habitat in question, as absolutely essential.

Ironically, water agencies in the mid-late 1980s had the considerable foresight to implement pre-disturbance surveys of river systems in the forested region on the Darling Scarp south-east of Perth, in order to evaluate the effects of future dams. Given that the construction of dams has commenced, a monitoring programme should be instigated now to get post-disturbance data.

Disturbance ecology, threatened species and management

Often in environmental reports or surveys comments are made to the effect that "no species (aquatic), listed as rare or endangered, were present", and that attention in management terms need not consider conservation of biodiversity. Such statements are deceptive, since a great number of aquatic species in the south-west are restricted in their distribution, and in some cases obviously threatened, but only 1 species of invertebrate is officially listed as threatened and only a further 9 are recognised as in need of special protection. The three main reasons for this discrepancy are (a) very poor taxonomic knowledge of the fauna - many species need to be described but there are very few people who have the expertise and the time to carry out the descriptions; and (b) the process of listing a species as threatened is time consuming and few people who work with these faunas would be able to find the time to prepare the information so that a species can be listed as threatened (or in need of protection); and c) the listing process demands critical information which, as this report shows, is rarely detailed enough to unequivocally determine whether a species responds negatively to a particular set of human induced disturbances.

Similarly, the statement that "no species has become extinct from forest management practices" is used whenever conservation concerns are raised regarding such practices. The authors regard such statements as effective obfuscation only. Extinction is the endpoint of a long process of decline in population numbers, and it makes little sense to use extinction as an indicator of the effectiveness of a management practices. Our knowledge on extinction is also severely constrained by the fauna we know; in other words there may be fauna which have become extinct which have never been recognised by the scientific process. Rather than make the statement above, we believe that it would be more sensible to use threatened species or communities, or special taxa (see Table 3) or species which can show a decline (see Table 2), as indicators of the appropriateness of management practices. Hopefully, this report will be useful in this regard.

Tolerance levels of individual species

One of the major frustrations to disturbance ecologists and managers alike is the lack of crucial data on species' tolerance and sensitivity to specific components of the disturbance. For instance, we might argue that an important species (for instance one of the species listed in Table 3) shows a negative response to elevated levels of suspended sediment in the water column following clearing in the catchment. The usual question then, is how much sediment will that species tolerate? Crucial data are required to answer this question. With the exception of perhaps some ecotoxicological work done on pesticide response for selected native invertebrates, none of this crucial data exists.

Other kinds of impacts which have not been addressed in the studies of the aquatic fauna of the RFA
Unless where stated in the text of this report, the effects of the following disturbances on aquatic macroinvertebrates and fish have not been treated: drainage and filling; aquatic weeds; sewerage and septic disposal systems; sanitary landfill and liquid waste disposal sites; industrial effluent pits and lagoons, mine waste disposal sites; heavy metal toxicity (other than cadmium).

3.4 SUMMARY: KEY POINTS

1. Aquatic habitats and their fauna in south-west Australia (in particular, the high rainfall zone or RFA) show special, interesting and vulnerable characteristics.

2. An extensive set of disturbances operate in the RFA, and most of them do not operate in isolation from one another.

3. Severity of the disturbance cannot be gauged by a review of this nature due to absence of information, the heterogeneous nature of both the fauna and the severity of the disturbance event itself, and the influence of interacting disturbances as above.

4. Crucial data are not available for individual species. Experimental data on single issue disturbances are not available. Interacting disturbances have not been evaluated experimentally due to their complexity. Research is required to improve this situation. Research examining impacts beyond the short-term, with a specific objective of testing the recovery or otherwise of ecological communities to known and quantified disturbances, is urgently required.

5. What is available? We have presented a series of critical habitats, critical species and communities, and species which show negative responses to known disturbance events, all of which will enable us to evaluate the importance of disturbances in the future.

6. Recommendations, predominantly dealing with research requirements, and some management practices, are given throughout the report.

4. REFERENCES

Abbott, I. and P. Christensen (1994). Application of ecological and evolutionary principles to forest management in Western Australia. Australian Forestry 57(3): 109-122.

Anson, B., Loh, I., Bell, R. and J. Bartle (1988). The hydrologic effects of reforestation in the Darling Range, Western Australia. Water Authority of Western Australia, Water Resources Directorate, Report No. WS 15.

ARL Report 2 (1986). Stream biological study: Stinton Creek 1984/85, results and recommendations. Report 2 to The Water Authority of Western Australia.

ARL Report 9 (1988). North Dandalup stream fauna study, results and recommendations 1985-1987. Aquatic Research Laboratory Report 9 to The Water Authority of Western Australia.

ARL Report 10 (1988). Aquatic Research Laboratory Report 10 to The Water Authority of Western Australia.

ARL Report 11 (1988). Lower Canning River. Stream fauna study: results and recommendations 1984-1987. Aquatic Research Laboratory Report 11 to The Water Authority of Western Australia.

ARL Report 12 (1988). Stinton Creek stream fauna study: results and recommendations 1984-1987. Aquatic Research Laboratory Report 12 to The Water Authority of Western Australia.

ARL Report 13 (1988). Biological monitoring in catchments of the northern jarrah forest and Swan Coastal Plain. Aquatic Research Laboratory Report 13 to The Water Authority of Western Australia.

ARL Report 14 (1990). Aquatic Research Laboratory Report 10 to The Water Authority of Western Australia.

ARL Report 15 (1989). Canning Reservoir Catchment - Lower Canning River Catchment - Serpentine River/Gooralong Brook Catchments - Dirk Brook Catchment - North Dandalup Pipihead Dam Catchment. Results and Recommendations. Aquatic Research Laboratory Report 15 to The Water Authority of Western Australia.

ARL Report 16 (1989). Stream fauna study. Lower North Dandalup River Catchment. Results and Recommendations. Aquatic Research Laboratory Report 16 to The Water Authority of Western Australia.

ARL Report 22 (1992). Survey of the macroinvertebrate fauna and water chemistry of permanent lakes of the south coast of Western Australia. Aquatic Research Laboratory Report 22 to Department of Conservation and Land Management.

Armstrong, K. (1995). Connectedness between ecosystems: the consequences of the removal of riparian linkages for instream macroinvertebrate communities. Honours Thesis, Zoology Department, University of Western Australia, Perth.

Arthington, A. H. (1991). Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. Canadian Journal of Fisheries and Aquatic Science 48: 33-43.

Atkins, R. P. (1982). Organochlorine pesticide residues in the Preston River, W. A. Report to the Leschenault Inlet Management Authority.

Balla, S. A. (1994). Wetlands of the Swan Coastal Plain. Volume 1. Their nature and management. Water Authority of Western Australia and the Department of Environmental Protection, Perth.

Balla, S A, and J. A. Davis (1993). Wetlands of the Swan Coastal Plain. Volume 5. Managing Perth's wetlands to conserve aquatic fauna. Water Authority of Western Australia and Environmental Protection Authority of Western Australia, Perth.

Barrett, M. D. (1996). Identification of significant habitats occupied by the Western Petalura dragonfly, Petalura hesperia, in the south-west of Western Australia. Report to the Australian Heritage Commission. Australian Government Publishing Service, Canberra.

Bartle, J. R. and J. R. H. Riches (1978). Rehabilitation after mining in the Collie Coalfield. Pp1-5. Rehabilitation of mined lands in Western Australia. In: Proceedings of a meeting held in Perth on 11th October 1978, WAIT, Bentley.

Bayly, I. A. E. (1979). Further contributions to a knowledge of the centropagid genera *Boeckella*, *Hemiboeckella* and *Calamoecia* (athalassic calanoid copepods). Australian Journal of Marine and Freshwater Research 30: 103-27.

Bayly, I. A. E. (1982). Invertebrate Fauna and Ecology of Temporary Pools on Granite Outcrops in Southern Western Australia. Australian Journal of Marine and Freshwater Research, 33: 599-606.

Beesley, L. S. (1996). The ecological significance of large woody debris in the sandy river systems of the Swan Coastal Plain. Honours thesis, The University of Western Australia. Perth.

Bell, R. W., Anson, B. and I. C. Loh (1988). Groundwater response to reforestation in the Darling Range of Western Australia. Water Authority of Western Australia, Water Resources Directorate, Report No. WS 24.

Benzie, J. A. H. (1988). The systematics of Australian *Daphnia* (Cladocera: Daphniidae). Species descriptions and keys. Hydrobiologia 166: 95-161.

Borg, H., Hordacre, A. and F. Batini (1988a). Effects of logging in stream and river buffers on water courses and water quality in the southern forest of Western Australia. Aust. For. 51(2): 98-105.

Borg, H., Stoneman, G. L. and C. G. Ward (1987). Stream and groundwater response to logging and subsequent regeneration in the southern forest of Western Australia: results from four catchments. Department of Conservation and Management. Technical Report 16.

Borg, H., Stoneman, G. L. and C. G. Ward (1988b). The effects of logging and regeneration on groundwater, streamflow and stream salinity in the southern forest of Western Australia. Journal of Hydrology 99: 253-270.

Bunn, S. E. and P. M. Davies (1990). Why is the stream fauna of south-west Australia so impoverished? Hydrobiologia 194: 169-176.

Bunn, S. E. and P. M. Davies (1992). Community structure of the macroinvertebrate fauna and water quality of a saline river system in south-west Australia. Hydrobiologia 248: 143-160.

Bunn, S. E., Edward, D. H. and N. R. Loneragan (1986). Spatial and temporal variation in the macroinvertebrate fauna of streams of the northern jarrah forest, Western Australia: community structure. Freshwater Biology 16: 67-91.

Cairns, J., Jr., McCromick, P. V. and B. R. Niederlehner (1993). A proposed framework for developing indicators of ecosystem health. Hydrobiologia 263:1-44.

Cairns, J., Jr. and B. R. Niederlehner (1994). Ecological toxicity testing: scale, complexity and relevance. Lewis Publishers, Boca Raton. pp1-10.

Calow, P. (1991). Mini-Review: Physiological costs of combating chemical toxicants: ecological implications. Comp. Biochem. Physiol. 100C:3-6.

Calver, M. C., Hobbs, R. J., Horwitz, P. and Main, A. R. (1996). Science, principles and forest management: a response to Abbott and Christensen. *Australian Forestry* 48.

Chambers, M. G. (1996a). Acute cadmium, copper and zinc toxicity in the juvenile freshwater crayfish, *Cherax tenuimanus* (Smith, 1912). In: program and abstract book of the International Symposium on Environmental Chemistry and Toxicology, Sydney (INTERSECT), Australia. July 14-18, 1996.

Chambers, M. G. (1996b). Comparative 96-hr LC50s for CdCl2 in juvenile and adult freshwater crayfish, *Cherax tenuimanus* (Smith, 1912). Abstracts of the SETAC 17th Annual Meeting, Partnerships for the Environment: Science, Education, and Policy. 17-21 November 1996 Washington, DC p.189.

Chambers, M. G. and B. Knott (1996). Cadmium in aquatic ecosystems of Western Australia. In: 7th Annual Combined Biological Sciences Meeting Perth, 1996 (Proceedings).

Chambers, M. G. and B. Knott (1997). Cadmium in aquatic ecosystems of Western Australia. In: Trace Metals in the Aquatic Environment; Fourth International Conference 19-23 May, Kuala Lumpur, Malaysia. p44.

Chessman, B. C. (1995). Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and biotic index. Australian Journal of Ecology 20(1): 122-129.

Christensen, P. (1992). The Karri forest. Department of Conservation and Land Management. 188p.

Collins, P. D. K. and D. F. Barrett (1980). Shannon, Warren and Donnelly River basins water resources survey. W. A. Public Works Department, Water Resources Branch Report No. 6.

Davies, P. M. (1993). Ecosystem ecology of upland streams of the northern jarrah forest, Western Australia. Ph. D. thesis, The University of Western Australia, Perth.

Davis, J. A., Barmuta, L. A. and S. A. Balla (1988a). Serpentine River and Gooralong Brook Aquatic Fauna Study. Report to The Water Authority of Western Australia. School of Biological and Environmental Science, Murdoch University, Perth.

Davis, J A, Harrington, S A, and A. M. Pinder (1988b). Investigations into more effective control of nuisance chironomids (midges) in Metropolitan wetlands, Perth, Western Australia.

Davis, J. A., Pinder, A. M., Trayler, K. M. and S. A. Harrington (1990). Towards more effective control of nuisance chironomids (midges) in metropolitan wetlands, Perth, W.A. Murdoch University. Prepared for The Midge Research Steering Committee.

De Deckker, P. (1981). Taxonomic notes on some Australian ostracods with descriptions of new species. Zoologica Scripta 10: 37-55.

Doeg, T. J. and J. D. Koehn (1990). A review of Australian studies on the effects of forestry practices on aquatic values. SSP Technical Report No. 5 No. Fisheries Division, Department of Conservation and Environment, Victoria.

Doupé, R. G. and P. Horwitz (1995). The value of macroinvertebrate assemblages for determining priorities in wetland rehabilitation: a case study from Lake Toolibin, Western Australia. Journal of the Royal Society of Western Australia 78: 33-38.

Edward, D. H., Gazey, P. and Davies, P. M. (1994). Invertebrate community structure related to physico-chemical parameters of permanent lakes of the south coast of Western Australia. Journal of the Royal Society of Western Australia 77: 51-63.

Fleay, B. J. (1985). Water Catchments and Fire Management in the Northern Jarrah Forest. In: Ford, J. [editor] Fire ecology and management in Western Australian ecosystems: proceedings of a symposium held in Perth on 10-11 May. WAIT Environmental Studies Group Report no. 14. 221 pages.

Ford, J. [editor] (1985). Fire ecology and management in Western Australian ecosystems: proceedings of a symposium held in Perth on 10-11 May. WAIT Environmental Studies Group Report no. 14.

Froend, R. and McComb, A.J. (1991).

Garland, M. E. and J. A. Davis (1986). Herdsman Lake Pesticide Study. Report for the Department of Conservation and Land Management, The State Planning Commission and The Department of Agriculture. School of Environmental and Life Sciences, Murdoch University, Perth.

Gazey, P. (1994). The response of benthic macroinvertebrates to sediment addition in northern jarrah forest headwater streams. Post-Graduate Diploma thesis. The University of Western Australia, Perth.

Gerritse, R. G., Adeney, J. A. and L. E. Bates (1992). Nutrient inputs from various land uses on the Darling Plateau in Western Australia – results of a survey. CSIRO Division of Water Resources, Divisional Report 92/3.

Gerritse, R. G., Barber, C. and J. A. Adeney (1990). The impact of residential urban ares on groundwater quality: Swan Coastal Plain, Western Australia. CSIRO Water Resources Series No. 3.

Gill, A. M. (1986). Research for the fire management of Western Australian State forests and conservation reserves. Department of Conservation and Land Management, Western Australia, Technical Report no. 12.

Growns, I. O. (1992). Macroinvertebrate community structure in the streams of the southern forests of Western Australia: The influence of seasonality, longitudinal gradients and forestry activities. PhD Thesis, Murdoch University, Perth.

Growns, I. O. and J. A. Davis (1991). Comparision of the macroinvertebrate communities in streams in logged and undisturbed catchments 8 years after harvesting. Australian Journal Marine Freshwater Research 42: 689-706.

Growns, I. O. and J. A. Davis (1994). Effects of Forestry Activities (Clearfelling) on Stream Macroinvertebrate Fauna in South-western Australia. Australian Journal of Marine and Freshwater Research 45: 963-975.

Halse, S. A. and J. D. Blyth (1992). Aquatic fauna of the karri forest. In: Research on the impacts of forest managemnt in south-west Western Autralia. CALM Occasional Paper No. 2/92, July 1992. Como: Department of Conservation and Land Management, Western Australia

Hambleton, S., Gill, H., Morgan, D. and I. Potter (1996) The distribution and biology of freshwater fish in the RGC Wetlands, Capel, Western Australia. Fish Research Group Murdoch University. Technical Report No. 34.

Harvey, M. S. (1987). New and little-known species of the water mite genera *Tartarothyas*, *Pseudohydryphantes* and *Cyclohydryphantes* from Australia (Chelicerata: Actinedida: Hydryphantidae). Memoirs of the Museum of Victoria 48: 107-122.

Harvey, M. S. (1996). A review of the water mite family Pionidae in Australia (Acarina: Hygrobatoidea). Records of the Western Australian Museum 17: 361-393.

Hodgkin (1978)

Hopper, S. D., Harvey, M. S., Chappill, J. A., Main, A. R. and B. Y. Main (1996). The Western Australian biota as Gondwanan heritage - a review. In: Gondwanan Heritage: Past, Present and Future of the Western Australian Biota (eds S. D. Hopper, J. A. Chappill, M. S. Harvey and A. George). Surrey Beatty and Sons, Chipping Norton 1-46.

Horwitz, P. (1990). The conservation status of Australian freshwater Crustacea, with a provisional list of threatened species, habitats and potentially threatening processes. Report Series 14. Australian National Parks and Wildlife Service, Canberra.

Horwitz, P. (1994a). Patterns of endemism of the freshwater fauna in far southern peatlands and shrublands, Western Australia. Report prepared for the Australian Heritage Commission and Heritage Council of Western Australia. Environmental Management Commissioned Report 1994-04. Edith Cowan University.

Horwitz, P. (1994b). The translocation of aquatic organisms in south-western Australia: a review and some prescriptions. In: Feral Fauna of South-west Australia (eds. R. Siewert, N. Robinson and P. Horwitz). Conservation Council of Western Australia. Perth.

Horwitz, P. (1995). Conservation status of Australian freshwater crayfish: review and update. Freshwater Crayfish 10: 70-80.

Horwitz, P. (1997). Comparative endemism and richness of the aquatic invertebrate fauna in peatlands and shrubland of far south-west Australia. Memoirs of the Museum of Victoria.

Horwitz, P. and M. Adams (manuscript). The systematics, biogeography and conservation status of species in the freshwater crayfish *Engaewa* Riek (Decapoda: Parastacidae) from south-west Australia. Monograph to be submitted to Invertebrate Taxonomy.

Horwitz, P., Jones, D. and S. Judd (1997a). A database of the freshwater and terrestrial Crustacea of inland south-west Western Australia. Accompanying report prepared for the Environment Forests Task Force of Environment Australia.

Horwitz, P. and R. Nickoll (1996). Marron as a flagships for river restoration in south-west Australia and the role of marron-growing industries. Pp. 37-40. In: Proceedings of Open Seminar - Marron Growers Association of Western Australia 25 May 1996.

Horwitz, P., Pemberton, M. and Ryder, D. (1997b, in press). Catastrophic loss of organic carbon from a management fire in a peatland in south-west Australia. Proceedings of INTECOL V. (eds. A.J. McComb and J.A. Davis). Gleneagles Press, Adelaide.

Hutchison, M. J. (1991). Distribution patterns of the redfin perch *Perca fluviatilis* Linnaeus and the western pigmy perch *Edelia vittata* Castelnau in the Murray River System Western Australia. Records of the Western Australian Museum 15: 295-301.

Hynes, H. B. N. and S. E. Bunn (1984). The Stoneflies (Plecoptera) of Western Australia. Australian Journal of Zoology 32: 97-107.

Jackson and Wager (1993)

Jasinska, E. J. (1990) Root mat ecosystem in an epiphreatic stream, Cabaret Cave, Yanchep National Park. Honours thesis. Murdoch University, Perth.

Jasinska, E. J. (1995). Water Requirements of Cave Dwelling Fauna in the Yanchep Area. Appendix 3. In: Review of Proposed Changes to Environmental Conditions, Gnangara Mound Groundwater Resources (Section 46). Water Authority of WA, Perth. Pp. 113-119.

Jasinska, E. J. (1996). Monitoring of cave stream invertebrates at Yanchep National Park, W. A. Annual Report to the Water and Rivers Commission. Department of Zoology, The University of Western Australia, Perth.

Jasinska, E. J. (1997). Faunae of aquatic root mats in caves of south-western Australia: origins and ecology. PhD thesis, The University of Western Australia, Perth. In review.

Jasinska, E. J. and B. Knott (1991). Stability of root mat ecosystem in a groundwater stream, Cabaret Cave, Yanchep National Park, WA. Australian National Parks and Wildlife Service, Canberra. Endangered Species Project No. 46.

Jasinska, E. J. and B. Knott (1994). Aquatic fauna in Gnangara Mound discharge areas of the Ellen Brook catchment, WA. Report to the Water Authority of WA. Department of Zoology, The University of Western Australia, Perth.

Jasinska, E. J. and B. Knott (in press). Root mat driven faunas in cave waters. In: Ecosystems of the World – Subterranean Biota (eds H. Wilkens, D. C. Culver and W. F. Humphreys). Elsevier Science B.V., Amsterdam.

Jasinska, E. J., Knott, B. and A. J. McComb (1996). Root mats in ground water: a fauna-rich cave habitat. Journal of North American Benthological Society 15: 508-519.

Jasinska, E. J., Knott, B. and N. Poulter (1993). Spread of the introduced yabby, *Cherax* sp. [Crustacea:Decapoda:Parastacidae], beyond the natural range of freshwater crayfishes in Western Australia. Journal of the Royal Society of Western Australia 76: 67-69.

Kendrick, G. W. (1976). The Avon: faunal and other notes on a dying river in south-west Australia. Western Australian Naturalist 13: 97-114.

Knott, B. and E. J. Jasinska (1996). Melaleuca Swamp and Edgecombe Spring, Ellenbrook, Western Australia. Report to the Water and Rivers Commission. Department of Zoology, The University of Western Australia.

Knott, B. and E. J. Jasinska (1997). Mound Springs of Australia. In: Studies in Crenology (ed. L. Botosaneanu). Blackhuys Publ., Leiden. Pp.23-38.

Lane, J. A. K. and A. J. McComb (1988). Western Australian wetlands. In: The conservation of Australian wetlands (eds A. J. McComb and P. S. Lake). Pp.127-146. Surrey Beatty and Sons Pty. Ltd., Chipping Norton.

Langdon, J. S. (1989). Disease risks of fish introductions and translocations. In: Introduced and Translocated Fishes and their Ecological Effects (ed. D. A. Pollard). Bureau of Rural Resoources, Proceedings No. 8: 98-107.

Lawrence, C. (1993). The introduction and translocation of fish, crustaceans and molluscs in Western Australia. Fisheries management paper No. 58. Fisheries Department of Western Australia.

Lewis, A. A., Cheney, N. P. and D. Bell (1994). Report of the Fire Review Panel: conducting a review of the Department of Conservation and Land Management (CALM) prescribed burning policy and practices and wildfire threat analysis as required in the Ministerial conditions set for the implementation of amendments to the 1987 conditions on the regional plans and the WACAP ERMP. Department of Conservation and Land Management.

Lund, M. A. and E. T. Chester (1991). The use of aluminium sulphate to control algal blooms and chironomids in Jackadder Lake, Western Australia. Verh. Internat. Verein. Limnol. 24: 1129-1133.

Lund, M., Davis, J. and F. Murray (1991). The fate of lead from duck shooting and road runoff in three Western Australian wetlands. Australian Journal of Marine and Freshwater Research 42: 139-149.

Main, A. R. (1996). Forest reservations: an overview. Journal of the Royal Society of Western Australia 79: 301-304.

Main, A. R. and B. Y. Main (1991). Report on the Southern Forest Region of Western Australia. Report to The Australian Heritage Commission, Canberra.

Morgan, D. and H. Gill (1995). The effect of Big Brook Dam during drought on the fish communities of the Lefroy and Big Brooks. Report to the Water and Rivers Commission. Fish Research Group. Murdoch University.

Morgan, D., Gill, H. and I. Potter (1996). The distribution of freshwater fish in the south-west corner of Australia. (Water Resource Technical Series No. WRT4). Water and Rivers Commission.

Morgan, D., Potter, I. and H. Gill (1995). The freshwater fish fauna of the pools of the south branch of the Collie River, during a period of extremely low water levels. Report to the Water Authority of Western Australia. Freshwater Fish Group Murdoch University.

Morrissy, N. M. (1974). Reversed longitudinal salinity profile of a major river in the south-west of Western Australia. Aust. J. Mar. Freshwat. Res. 25:327-335.

Morrissy, N. M. (1978a). The amateur marron fishery in Western Australia. Fish. Res. Bull. West. Aust. 21: 1-44.

Morrissy, N. M. (1978b). The past and present distribution of marron *Cherax tenuimanus* (Smith) in Western Australia. Fisheries Research Bulletin Western Australia 22: 1-38.

Morrissy, N. M. (1992). Management of the marron (*Cherax tenuimanus*) fishery in Western Australia. Finnish Fisheries Research 14: 61-68.

Morrissy, N. M. and G. Cassells (1992). The spread of the introduced yabby *Cherax albidus* Clark, 1936 in Western Australia. Fisheries Research Report No. 92.

Morrissy, N. M. and C. J. Fellows (1990). The recreational marron fishery in Western Australia, summarized research statistics, 1971-1987. Fisheries Research Report No. 87.

Nickoll, R. (1996). An investigation into the use of the freshwater crayfish Marron (*Cherax tenuimanus*) as a Flagship for the Restoration of the Blackwood River. Honours thesis. Edith Cowan University, Joondalup.

Olsen, D. P. (1978). Bauxite residue rehabilitation at Alcoa of Australia Ltd. Pp. 117-119. In: Proceedings of a meeting held in Perth on 11th October 1978, WAIT, Bentley.

Pen, L. (1993). Fringing vegetation of the Lower Collie and Brunswick Rivers 1992. Report to the Leschenault Inlet Management Authority. Waterways Commission Report No. 37.

Pen, L. J., Gill, H. S., Humphries, P. and I. C. Potter (1993a). Biology of the black-stripe minnow *Galaxiella nigrostriata*, including comparisons with the other two *Galaxiella* species. Journal of Fish Biology 42: 847-863.

Pen, L. J., Hilliard, R. W. and I. C. Potter (1988). The Effect of Big Brook Dam and the Pemberton Weir on the migration of native fish. Report to the Water Authority of Western Australia, Perth.

Pen, L. J. and I. C. Potter (1992). Seasonal and size-related changes in the diet of perch, *Perca fluviatilis* L., in the shallows of an Australian river, and their implications for the conservation of indigenous teleosts. Aquatic Conservation: Marine and Freshwater Ecosystems 2: 243-253.

Pen, L. J., Potter, I. C. and M. C. Calver (1993b). Comparisons of the food niches of three native and two introduced fish species in an Australian River. Environmental Biology of Fishes 36: 167-82.

Pen, L. J., Potter, I. C. and R. W. Hilliard (1991). Biology of *Galaxiella munda* McDowall (Teleostei: Galaxiidae), incuding a comparison of the reproductive strategies of this and three other local species. Journal of Fish Biology 39: 717-731.

Pinder, A. M., and R. O. Brinkhurst (1997). Review of the Phreodrillidae (Annelida: Oligocheta: Tubificida) of Australia. Invertebrate Taxonomy 11: 443-523.

Pinder, A. M., Trayler, K. M. and Davis J. A. (1991). Chironomid control in Perth wetlands: final report and recommendations. Murdoch University, Perth, Western Australia.

Pusey, B. J. and D. H. Edward (1990). Structure of fish assemblages in waters of the southern acid peat flats, south-west Australia. Australian Journal of Marine and Freshwater Research 41: 721-734.

Pusey, B. J., Storey, A. W., Davies, P. M. and D. H. Edward (1989). Spatial variation in fish communities in two South-west Australian river systems. Journal of the Royal Society of Western Australia 71(2 & 3): 69-75.

Rutherford, P. A. (1989). Monitoring Pesticides – A Review. Report to the Environmental Protection Auhority. EPA Bulletin 407.

Smith, K. (1996). An outlying population of *Galaxiella nigrostriata* (Pisces: Galaxiidae) at Melaleuca, Park, Western Australia: Causes and effects of habitat fragmentation. Honours thesis, The University of Westen Australia, Perth.

Smith, M., Kay, W. R., Edward, D. H., Papas, P. J., Richardson, K. St. J., Simpson, J. C., Pinder, A. M., Cale, D. J., Horwitz, P. H. J., Davis, J. A., Yung, F. H., Norris, R. H. and S. A. Halse (in prep). AUSRIVAS: Using macroinvertebrates to assess ecological condition of rivers in Western Australia.

Solem, A., Girardi, E.-L., Slack-Smith, S. and G. W. Kendrick (1982). *Austroassiminea letha* gen. nov., sp. nov., a rare and endangered prosobranch snail from south-west Australia

(Mollusca: Prosobranchia: Assimineidae). Journal of the Royal Society of Western Australia 65(4): 119-129.

Steering Committee for Research on Land Use and Water Supply (1984). Bauxite Mining in the Jarrah Forest: Impact and Rehabilitation. Department of Conservation and Environment, Perth , WA. Bulletin 169.

Steering Committee for Research on Land Use and Water Supply (1987). The impact of logging on the Water Resources of the Southern Forests, Western Australia. Water Authority of Western Australia, Report No. WH41.

Storey, A. W., Bunn, S. E., Davies, P. M. and D. H. Edward (1990). Classification of the macroinvertebrate fauna of two river systems in south-western Australia in relation to physical and chemical parameters. Regulated Rivers: Research & Management 5: 217-232.

Storey, A. W., Edward, D. H. and P. Gazey (1991). Recovery of aquatic macroinvertebrate assemblages downstream of the Canning Dam, Western Australia. Regulated Rivers: Research & Management: 6: 213-224.

Streamtec Pty Ltd Ecological Consultants (1997). Toby inlet aquatic study. Report ST 268 Feb. 1997 to the Toby Inlet Catchment Group.

Streamtec Pty Ltd Ecological Consultants (1997). Heavy metal levels in marron (*Cherax tenuimanus*) collected from D1 reservoir, Boddington. Boddington Gold Mine Report ST 26/97.

Trayler, K. M. and J. A. Davis (1996). Sensitivity of *Daphnia carinata* Sensu Lato to the Insect Growth Regulator, Pyriproxyfen. Ecotoxicology and Environmental Safety 33: 154-156.

Trayler, K. M., Davis, J. A., Horwitz, P. and D. Morgan (1996). Aquatic fauna of the Warren bioregion, south-west Western Australia: Does reservation guarantee preservation? Journal of the Royal Society of Western Australia 79: 281-291.

Unestam, T. (1975). Defence reactions in and susceptibility of Australian and New Guinean freshwater crayfish to European-crayfish-plague fungus. Australian Journal of Experimental Biology 53: 349-359.

WA Department of Agriculture (1988). The toxicity of pesticides to wildlife. Prepared by Brain, K. and B. O'Connor, Pesticide Section, Western Australian Department of Agriculture. Miscellaneous Publication No. 8/88.

Wall, T. M. and R. W. Hanmer (1987). Biological testing to control toxic water pollutants. Journal WPCF 59:7-12.

Wardell-Johnson, G., Hewett, P. J., & Woods, Y. C. (1991). Retaining remnant mature forest for nature conservation: a review of the system of road, river and stream zones in the karri forest. In A review of road, river and stream zones in south west forests, (pp. 6-22). Manjimup: Lands and Forest Commission.

Wardell-Johnson, G. and P. Horwitz (1996) Conserving biodiversity and the recognition of heterogeneity in ancient landscapes: a case study from south-west Australia. Forest Ecology and Management 85(1-3): 219-238.

Williams, W. D. (1987). Salinization of Rivers and Streams: An Important Environmental Hazard. Ambio 16(4): 180-185.

Williams, W. D., Taaffe, R. G., and A. J. Boulton, (1991). Longitudinal distribution of macroinvertebrates in two rivers subject to salinization. Hydrobiologia 210: 151-160.

Worsley Alumina Pty Ltd (1984). Aquatic Biological Baseline and Monitoring Investigation. Report by Natural Systems Research Pty. Ltd. for Worsley Alumina Pty. Ltd

Worsley Alumina Pty Ltd (1987). Boddington Gold Mine Environmental Management Program. Report by Kinhill Stearns/BHP Engineering for Worsley Alumina Pty. Ltd.