Improved Management of Exotic Aquatic Fauna: R&D for Australian Rivers

Occasional Paper 04/95

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December 1995

Published by:

The Land and Water Resources Research and Development Corporation

Land and Water Resources Research and Development Corporation
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Publication data:

Arthington, Angela H. and Blühdorn, David R. (1995) Improved management of exotic aquatic fauna: R&D for Australian rivers. LWRRDC Occasional Paper No. 4/95.

ISSN: 1320-0992
ISBN: 0 642 20609 0

Design: rba Graphic Design, Canberra

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1.0 Introduction

1.1 Background and Aims of the Review

This report presents the findings of a project to review R & D requirements concerning exotic aquatic biota and their significance in the improved management and monitoring of Australian inland waters. The review forms part of a portfolio of studies commissioned by the Land and Water Resources Research and Development Corporation as part of the "River Processes and Management Program".

The report is confined to exotic freshwater fishes, and invertebrates (Crustacea, Mollusca and various parasitic taxa), where the term exotic is taken to mean species that are not naturally found in Australian waters. The problems that may arise when indigenous Australian species are moved from areas where they occur naturally to basins where they do not occur now, or have never occurred historically, are also briefly outlined.

Although directed to problems in freshwater environments, the review draws attention to the extension of range of some essentially freshwater species into estuarine and more saline systems, and the implications for management and monitoring of rivers.

The aims of the study are the following:

1. To develop an assessment of issues concerning exotic fauna in Australian freshwater ecosystems.
2. To provide a report suitable for publication on the topic of exotic biota in Australian freshwater ecosystems, presenting a summary of problem species, economic and environmental costs of their presence in Australia, and a list of research and development priorities.

1.2. Research Methods

The report has been prepared using the following methods.

- Reviews of published literature, reports, working papers and other materials, primarily on exotic freshwater biota in Australia but including key papers from the international literature;
- Meetings and discussions with relevant State and Territory Government agencies, consultants, research groups and practitioners in the fields of freshwater ecology and resource management;
- Distribution of a questionnaire to gain an assessment of the problems and research requirements on this topic in Australia; and
- Distribution of a draft document for comment and revision before preparation of the Final Report.

1.3 Definitions

The following terms are used throughout the report.

Established:	an introduced species which has established a self-maintaining population.
Invasive:	a species which has the ability to become established in natural or semi-natural waters.
Exotic:	a species not naturally found in Australian waters.
Indigenous:	a species indigenous (native) to Australia.
Introduced:	an exotic or indigenous species released into an area in which it does not naturally occur.
Translocated:	a species, usually indigenous, moved to an area beyond its natural range. This term may also be used to describe the movement of an established exotic species to a new area.

2.0 Invertebrates

2.1 Introduction

Invertebrates have so far been neglected in the study of introduced freshwater species in Australia compared to the attention given to them in marine systems. Pollard and Hutchings (1990) have provided a comprehensive review of exotic marine invertebrates in the Australian region and discussed the regulation and control of such introductions. Although poorly documented, freshwater invertebrates introduced from other countries have been shown to cause severe medical, veterinary and economic problems, and may also have adverse effects on indigenous biota and freshwater ecosystems.

Williams (1980) presented information on some of the more significant exotic taxa, but a full review of exotic freshwater invertebrates in Australia does not appear to have been attempted. One of the recommendations of this study is that such a review should be commissioned.

The aim of this chapter is to indicate some of the more important types of introductions and identify gaps in the current R & D effort in Australia. As with all of the taxa discussed in this report, there has been very little research on the ecological impacts of introduced freshwater invertebrates.

The local and interstate translocation of freshwater invertebrates is a related issue and is probably equally significant in terms of economic and ecological impacts. Crustaceans in particular have been moved interstate for aquaculture purposes and there are concerns that some species may cause damage to indigenous freshwater biota as well as aquaculture facilities, as discussed below.

2.2 Gastropoda

Gastropods can have medical, economic and ecological impacts since many species are intermediate hosts of parasites that affect livestock and humans. The family Lymnaeidae is important in that many species of these snails are intermediate hosts of the common liver fluke, *Fasciola hepatica.* This trematode parasite has been responsible for large losses and a considerable economic impact on the sheep and cattle industry in many countries.

Only two indigenous species of Lymnaeids are recognised in Australia, *Lymnaea tomentosa* and *L. lessoni* and of these, only the former species can act as a host of the liver fluke (Ponder 1975). Introduced hosts, however, can be very efficient in transmitting this fluke because they spread rapidly and are often very abundant in areas subject to human disturbance (S. Schreiber, pers. comm.). *Lymnaea columella,* a particularly well known and successful intermediate host of the liver fluke (Williams 1980), was introduced to Australia some time prior to 1973, evidently in the Sydney region (Ponder 1975).

L. columella is native to eastern North America and has been introduced into Central America, Cuba, west North America, South Africa, Europe and New Zealand (Williams 1980). Experiences with this snail in New Zealand are interesting and relevant. It has spread over most of the North Island and into a few areas of the South Island since the initial introduction in about 1940. The number of liver fluke infections increased following the introduction of the snail, and the different ecological requirements of *L. columella* and the indigenous host of the liver fluke, *L. tomentosa,* have greatly complicated fluke control programs (Ponder 1975).

A New Zealand species of Hydrobiid snail, *Potamopyrgus antipodarum,* was introduced to Australia in about 1870, probably by way of drinking water supplies carried by sea to Tasmania (Ponder 1988). It spread rapidly in Tasmania and from there to the Australian mainland, where it is common in lakes and streams in the south-eastern states as far north as Sydney. This species has been reported from tanks and reservoirs in Sydney, Victoria and Adelaide (S. Schreiber, pers. comm.), and has caused problems by building up large populations in water pipes and distribution systems (Ponder 1988).

The population biology of *P. antipodarum,* has been studied in Lake Purrumbete, Victoria, and its distribution, biology and ecological impact on indigenous snails is presently under investigation as a Ph D project at Monash University, supported by the Cooperative Research Centre for Freshwater Ecology (S. Schreiber, pers. comm.).

In Australia, *Potamopyrgus* is found almost entirely in or close to habitats that have been disturbed by human activities (urban development, agriculture and forestry operations), whereas in New Zealand it occurs in many natural areas as well as in disturbed habitats (Ponder 1988). The introduced gastropod host of the common liver fluke in Australia, *Lymnaea columella,* has likewise spread rapidly and is often very abundant in agricultural areas.

This pattern of association with disturbed environments is common to many other introduced taxa, and is especially evident amongst freshwater fishes introduced to Australia (see Chapter 3). It is one of the important factors to be considered in the assessment of exotic invertebrates in Australia.

Information on translocated gastropods is very limited. The estuarine mud welk, *Velacumantus australis,* has been translocated from eastern Australia to the Swan River estuary in Western Australia, where it is host to the blood fluke, *Austrobilharzia terrigalensis.* This fluke has been found to cause Schistosome dermatitis in some people (S. Schreiber, pers. comm.).

2.3 Crustacea

The predominant crustacean introductions in this country have not been exotic species, but involve three indigenous crayfish of the family Parastacidae. They are the Yabby *Cherax destructor,* the Redclaw *C. quadricarinatus,* and the Marron *C. tenuimanus.*

The Yabby *Cherax destructor* (Clark) has a wide natural distribution in central and southern inland Australia. A commercial fishery operates within its natural range and aquaculture activities are carried out both within the natural range and in Western Australia, where the species has been imported for this purpose. A recreational fishery exists throughout its natural range (Kailola *et al.* 1993).

The Tasmanian Inland Fisheries Commission is opposed to the translocation of *Cherax destructor* into that State because of the crayfish's potential to damage irrigation channel and dam walls by burrowing, to compete with indigenous crayfish, the risk of disease, and the deterioration of water quality in farm dams. In Tasmania, *Cherax destructor* is a declared noxious species and eradications of populations have been undertaken.

Redclaw *Cherax quadricarinatus* (von Martens) has a natural range in northern Australia, from the Daly River in the Northern Territory to the Normanby River on Cape York Peninsula, Queensland. It has been translocated to the Cairns—Innisfail area of northern Queensland and to coastal areas of south-east Queensland for aquaculture purposes. There is no commercial fishery for this species but a regulated recreational fishery exists within its natural range (Kailola *et al.* 1993). Aquaculture production is increasing rapidly and was estimated to approach 150 t in 1991–92 (Kailola *et al.* 1993). As the markets for this species expand, and its value increases, there is likely to be some illegal exploitation of wild stocks.

The Marron *Cherax tenuimanus* (Smith) has a natural range confined to the south-west corner of Western Australia. This species has been translocated to other rivers and farm dams in Western Australia, as well as southern Queensland, northern New South Wales, and South Australia for aquaculture purposes. The translocations to Queensland were generally unsuccessful due to high temperature-related mortality and the better results achievable with Redclaw. Of the 14 t produced by aquaculture in 1989–90, more than 85% was produced in Western Australia, with most of the remainder being produced in South Australia (Kailola *et al.* 1993).

Two fundamental issues arise from consideration of the introductions associated with freshwater crayfish. The first is that a species does not necessarily have to be exotic to pose potential environmental problems, and that any translocations need to be carried out with care and with as much information as possible about their possible impact on local aquatic systems.

The second is that the crowded conditions required for successful aquaculture greatly increase the potential for disease outbreak, and Australia's developing crayfish export industry is founded on this country's disease-free status. Careless translocations and inadequate quarantine precautions could result in the introduction of the crayfish 'plague', the fungus *Aphanomyces astaci* which was responsible for the collapse of the indigenous European crayfish populations, and the industries which depended on them.

Thompson (1990) cites the introduction of the plague vector animal, the North American signal crayfish, *Pacifasticus leniusculus,* as an outstanding example of deleterious translocations, and lists irreparable shifts in species diversity, ecosystem stress, and damaged traditional fisheries as major impacts of the fungus imported via this species. One of the side effects of the crayfish plague was that decimation of the indigenous Swedish crayfish, *Astacus astacus,* allowed macrophytes such as *Chara* spp. and *Elodea canadensis* to proliferate, resulting in the elimination of game fish habitat (Thompson 1990).

2.4 Research and Development Priorities

The following aspects of exotic and translocated invertebrates in Australian freshwater systems are recommended for further investigation by LWRRDC or as joint venture studies:

- A full review of exotic freshwater invertebrates in Australia should be commissioned, possibly with multiple authors to achieve the necessary taxonomic coverage. The review should discuss ecological impacts on indigenous aquatic biota and ecosystems, and the actual and potential economic impacts of aquatic invertebrates (i.e. disease transmission, damage to water supply and aquaculture facilities, water quality problems, etc);
- Research should be commissioned on the distribution, biology and ecological impacts of exotic invertebrates identified by the review as locally significant or likely to become widespread and problematic in Australia. The role of disturbance should be addressed as a factor in the ecology of invertebrate invasions;
- Quarantine issues and the protocols for managing new introductions of freshwater invertebrates, as well as their movement within Australia, may require review and revision;
- Past neglect of this topic suggests that a strategy is required to maintain one or more databases on exotic invertebrates in Australia, and to develop a program for routine surveillance of freshwater systems. Surveillance could be integrated with the State and Territory programs for monitoring river invertebrates as part of the "Monitoring River Health Initiative"; and
- Practical management strategies are needed for some problem species, e.g. the crayfish *C. destructor.*

3.0 Freshwater Fishes

3.1 Introduction

Exotic freshwater fishes form the mainstay of recreational fisheries in south-eastern Australia, as well as providing much of the fish biomass in many streams, especially the Murray-Darling and higher altitude rivers. Exotic species generated in excess of $40 million in commercial production in 1991-92 (estuarine cage-farmed trout; Kailola *et al.* 1993). They are also implicated in direct and indirect impacts on indigenous aquatic fauna and their habitats, and the introduction of diseases and parasites which may affect indigenous fish species.

Australiaís freshwater fish fauna is distinctive in that it consists mostly of species which are not shared with other biogeographic regions. In order to preserve this heritage and to mitigate, if possible, negative interactions, it is important to know the effects of introduced fish species on this relatively specialised biota.

The aim of this chapter is to review the information available on all established exotic freshwater fish species, to assess their environmental and economic impact, and to recommend appropriate research and development priorities.

3.2 Number of Exotic Fish Species

The number of established exotic freshwater fish species in Australia is in the range 19–24 (Arthington 1991; McKay 1989; Fletcher 1986; Allen 1989) depending primarily on the definitions used. This report will assess information on twenty species, including four salmonids, one percid, four cyprinids, six poeciliids, three cichlids, one cobitid, and one gobid. This is a marked increase on the nine species reported by Weatherley and Lake in 1967, which included two salmonids, one percid, five cyprinids, and one poeciliid. Table 3.1 lists the exotic species which have become, or are likely to become, established in Australian freshwaters.

One of the species listed, the Atlantic Salmon *(Salmo salar* : Salmonidae) has not yet become established in freshwater but is presently cultured in large numbers in sea cages in Tasmania (Kailola *et al.* 1993). Escapes from these cages have resulted from the effects of weather and seal attack. Whether the escapees will form sea-run populations and return to the estuaries and their associated freshwaters for spawning remains to be seen. Sea-run Brown Trout (*S. trutta*) have been implicated in the decline of the estuarine fish, Derwent whitebait (*Lovettia sealii*) (F.B. Michaelis, pers. comm.).

Three other species are occasionally included in lists of exotic species, but do not appear to have established self-sustaining populations. The Chinook Salmon (*Oncorhynchus tshawytscha :* Salmonidae) populations are maintained by stocking (Allen 1989, MacKinnon 1987, McKay 1989, Kailola *et al.* 1993). The Jack Dempsey Cichlid (*Cichlasoma octofasciatum* (Regan) has not been recorded since a single individual was found in the late 1970s, and is not considered to have become established (P. Cadwallader, pers. comm.). The Domingo Gambusia (*Gambusia dominicensis*: Poeciliidae), reported in springs and waterholes around Alice Springs (Allen 1989), has been identified as *G. holbrooki* (Lloyd and Tomasov 1985).

3.3 Motives for Introducing Fish

Freshwater fish have been moved around by humans since ancient times (Holcík 1991) and Welcomme (1988) indicates that seven species were introduced to various countries before the 19th century. World-wide, there have been reports of 117 introductions in the 19th century and 859 in the 20th century (to 1985), with the number reaching a peak in the 1960s and declining slightly since (Welcomme 1988).

There appear to have been five principal motives and causes for the spread of exotic fish species. These include: increased food production (aquaculture and wild fisheries); control of nuisance organisms (malaria mosquitoes, excessive plant and algal growth); recreational fishing; for ornamental purposes; and accidental introductions.

Table 3.1: Fish species introduced to Australia which are reported to have established, or are likely to establish, self-sustaining feral populations.

Salmonidae	
Oncorhynchus mykiss (Walbaum)	Rainbow Trout
Salmo salar L.	Atlantic Salmon
Salmo trutta L.	Brown Trout
Salvelinus fontinalis (Mitchell)	Brook Trout
Percidae	
Perca fluviatilis L.	European Perch or Redfin
Cyprinidae	
Carassius auratus L.	Goldfish
Cyprinus carpio L.	European Carp
Rutilus rutilus L.	Roach
Tinca tinca (L.)	Tenth
Poeciliidae	
Gambusia holbrooki (Girard)	Eastern Gambusia or Mosquitofish
Phalloceros caudimaculatus Hensel	One-spot Live Bearer
Poecilia latipinna Le Sueur	Sailfin Molly
Poecilia reticulata Peters	Guppy
Xiphophorus helleri (Günther)	Swordtail
Xiphophorus maculatus (Heckel)	Platy
Cichlidae	
Cichlasoma nigrofasciatum Günther	Convict Cichlid
Oreochromis mossambicus (Peters)	Tilapia or Mozambique Mouth-brooder
Tilapia mariae Boulenger	Black Mangrove or Niger Cichlid
Cobitidae	
Misgurnus anguillicaudatus (Cantor)	Oriental Weatherloach
Gobiidae	
Acanthogobius flavimanus Schlegel	Yellowfin Goby

Accidental introductions are those that have arisen largely from unexpected sources or from a lack of quarantine. Fish contained in the ballast water of ships, introduced inadvertently with another species, fish released by the flooding or overflow of outdoor ponds, and the escape of bait fish are all examples of accidental introductions.

Increased food-fish production has been achieved by intensive culture (aquaculture) to by enhancing wild fisheries. In many countries, socio-economic requirements mean that a high priority is given to increasing fish production in reservoirs and other waterbodies (Fernando 1991). This often leads to the stocking of these sites with exotic species because methods of increasing yield are not available, or are poorly developed, for indigenous species. More than 50% of introductions have been made to provide species for aquaculture or to improve fisheries production (Welcomme 1988).

A number of species with particular dietary preferences have been introduced widely in an effort to **control nuisance organisms.** Examples include the larvivorous fishes of the genera *Gambusia* and *Poecilia,* which have been widely dispersed for mosquito control purposes (Lloyd and Tomasov 1985), and a number of herbivorous carps and tilapias introduced for the purposes of plant and algal control (Welcomme 1988).

The demand for **recreational fishing** has caused many of the introductions recorded throughout the world (Radonski *et al.* 1984). Recreational fishing supports many aquaculture and stocking operations which result in frequent translocations and new introductions (Welcomme 1988).

Of growing importance is the demand for fish suitable for **ornamental purposes.** The ability to keep and display colourful or otherwise interesting fishes has promoted a world-wide traffic in exotic species (Courtenay and Stauffer 1990).

The above five causes have resulted in a number of introductions of exotic species into Australian freshwaters, with some of these exotics becoming established in the wild.

3.4 Summary Reviews of Exotic Fish Species

This report provides details of 20 exotic species which are considered to have established self-sustaining populations in fresh water. For most species, an individual summary review is presented which includes information about taxonomic affiliation, common name, indigenous range, year and purpose of introduction, where the stocks originated, and present distribution. Where available, information is presented about the speciesí environmental and economic impacts, other relevant information, and suggested research and development priorities.

Information contained in the individual summary reviews was derived from a number of sources. Details of a species' indigenous range, the country from which it was imported, the reason for introduction, and the year of introduction were generally obtained from Welcomme (1988). Information about a species' present distribution was generally obtained from Allen (1989). Other sources of these data are cited directly.

The environmental impacts listed for each species include proven interactions, which are extremely difficult to demonstrate, and are, therefore, uncommon. Other adverse environmental interactions listed are based on persuasive circumstantial evidence of impact, with special reference to ecologically sensitive species.

The 'threatened status' classification of indigenous fish species, for example 'vulnerable' or 'endangered', follows the Australian Nature Conservation Agency's "Action Plan for Australian Freshwater Fishes" (Wager and Jackson 1993).

Specific research and development recommendations are given at the end of each species summary (this section). Recommendations for broader research and development consideration, such as species interactions, habitat degradation, and ecosystem issues, are given in Section 3.12, together with a summary of the species recommendations.

3.4.1 *Oncorhynchus mykiss* (Walbaum)

Family:	**Salmonidae**
Common name:	**Rainbow Trout**
Indigenous Range:	Western coast of USA, Canada and Northern Mexico.
Purpose of introduction:	Recreational fishery
Year of introduction:	1894

Present Distribution

Established populations exist in high altitude waters of New South Wales, the Australian Capital Territory, and Victoria, including the headwaters of the Murray-Darling River system, and Tasmania. Stocked populations are maintained in the warmer waters of New South Wales, Victoria, Tasmania, South Australia (Adelaide region), and Western Australia (south of Perth). Isolated sea-run populations are reported in Victorian and Tasmanian streams. Commercial sea cage aquaculture is carried out in Macquarie Harbour on the west coast of Tasmania (Kailola *et al.* 1993).

Environmental Impacts

Along with *Salmo trutta* (Brown Trout), this species is the most widespread of the introduced salmonids and the one with the most extensive literature on known and speculated environmental impacts. These fall into two classes: predation on indigenous fishes; and competitive exclusion of indigenous species, as evidenced by the fragmented distributions of some of those species in areas where trout have been introduced. A number of these indigenous species are classified as endangered or vulnerable (Wager and Jackson 1993).

Adverse impacts have been reported on invertebrates and indigenous fish, especially galaxiids (P.S. Lake, pers. comm.). *O. mykiss* has been shown to prey on Barred Galaxias *Galaxias fuscus,* an endangered species (Wager and Jackson 1993), and the distributions of *O. mykiss* and *Galaxias olidus* around Canberra appear to be mutually exclusive (Lintermans 1991).

O. mykiss competes for food with the 'vulnerable' indigenous fish Macquarie Perch *Macquaria australasica* and possibly predates juveniles (Wager and Jackson 1993). It is suspected of predation on the 'vulnerable' indigenous fishes Yarra Pygmy Perch *Edelia obscura* and Ewen's Pygmy Perch *Nannoperca variegata* (Wager and Jackson 1993).

A paucity of indigenous fish species has been reported in areas where trout (*O. mykiss,*

S. trutta) occur in south-western Western Australia (D. Morgan, pers. comm.).

Although known to interact adversely with some indigenous species, *O. mykiss* distributions appear to have stabilised (P. Gehrke, pers comm.) and the threat of further range expansion in eastern Australia, with consequent environmental impacts, is generally regarded as slight.

Elsewhere, *O. mykiss* is reported to be responsible for declines in indigenous fishes in Peru, Colombia, Chile, Yugoslavia, Himalayan rivers, Lesotho, South Africa, and New Zealand (Welcomme 1988).

Economic Impacts

O. mykiss forms the basis of a multi-million dollar recreational fishing industry in Australia, and the economic benefits arising from this industry ensure that stocking will continue (P. Gehrke, pers comm.). Sea cage aquaculture of this species in Tasmania produced about 400 tonnes in 1990–91 (Kailola *et al.* 1993).

Other Information

A study of the mitochondrial DNA (mtDNA) structure of Tasmanian populations of *O. mykiss* has shown remarkably little diversity. This is probably due to repetitive hatchery and wild stock propagation (Ovenden *et al.* 1993)

R & D Recommendations

- Research is required into the effects of salmonids in general, and *O. mykiss* particular, on endangered indigenous fish species.
- Research is required into the distribution and effects of salmonids in Western Australia.
- It is recommended that lakes which have had no previous introductions of salmonids should not be stocked with *O. mykiss* in the future.

3.4.2 *Salmo salar* L.

Family:	**Salmonidae**
Common name:	**Atlantic Salmon**
Indigenous Range:	North-east coast of USA and Canada and north-west coast of Europe
Introduced from:	USA
Year of introduction:	1864–1870 and 1963–64
Purpose of introduction:	Recreational fishery

Present Distribution

This species is found in the headwaters of the Murray River and streams of the south coast of New South Wales (P. Gehrke, pers. comm.). It is also reported in Tasmanian streams (Allen 1989) and in sea cage aquaculture on the south-east and west coasts of Tasmania (Kailola *et al.* 1993).

Environmental Impacts

The Atlantic Salmon has yet become established in Tasmanian inland waters, but escaped fish from the sea cages have the potential to form sea-run populations and return to the estuaries and their associated freshwaters for spawning, with potentially adverse effects on estuarine and freshwater biota. Elsewhere in Australia, it is uncommon and not well suited to Australian environments. It is considered to have little environmental impact at current population densities in New South Wales (P. Gehrke, pers. comm.).

Economic Impacts

Tasmanian commercial production of *S. salar* and *Oncorhynchus mykiss* (Rainbow Trout), using both freshwater hatcheries and sea-cage growing stages, exceeded 3400 tonnes in 1991-92, with a value of over $40 million.

Other Information

The low genetic (mtDNA) diversity of Tasmanian stocks is probably the result of small brood stock numbers in the 1963–65 introduction (Ovenden *et al.* 1993)

R & D Recommendations

- Monitoring of Tasmanian streams for incursions of sea-run salmonids and, if these occur, research into their environmental effects.
- It is recommended that lakes which have had no previous introductions of salmonids should not be stocked with *S. salar* in the future.

3.4.3 *Salmo trutta* L.

Family:	**Salmonidae**
Common name:	**Brown Trout**
Indigenous Range:	Western Asia and Europe
Purpose of introduction:	Recreational fishery
Year of introduction:	1864
Introduced from:	The Wey and River Itchen, southern England (Tasmanian stocks) (Ovenden *et al.* 1993)

Present Distribution

Established populations exist in high altitude waters of New South Wales, the Australian Capital Territory, and Victoria, including the headwaters of the Murray-Darling, and Tasmania. Stocked populations are maintained in the warmer waters of New South Wales, Victoria, Tasmania, South Australia (Adelaide region), and Western Australia (south of Perth). Isolated sea-run populations are reported in Victorian and Tasmanian streams (Kailola *et al.* 1993).

Environmental Impacts

Salmo trutta has had a major impact on indigenous fish species and is implicated in the decline in numbers of four 'endangered', four 'vulnerable', and one 'poorly known' species (Wager and Jackson 1993). Its principal impacts are predation on the endangered Swan Galaxias *Galaxias fontanus,* the endangered Barred Galaxias *Galaxias fuscus,* and adverse interaction with the endangered Clarence Galaxias *Galaxias johnstoni* (Wager and Jackson 1993). Adverse interactions are also suspected to have produced the mutually exclusive distributions of Brown Trout and *Galaxias olidus* in the ACT (Lintermans 1991).

The Brown Trout is said to be responsible for reduced abundance in the 'vulnerable' Saddled Galaxias *Galaxias tanycephalus* (Wager and Jackson 1993) and to adversely interact with the 'endangered' Pedder Galaxias *Galaxias pedderensis,* causing a dramatic decline in numbers. However, this decline is also linked to invasion by the translocated Climbing Galaxias *Galaxias brevipinnis* (Wager and Jackson 1993).

Apart from galaxiids, *S. trutta* is suspected of predation on juveniles of the 'vulnerable' Australian Grayling and juveniles of the 'poorly known' Macquarie Perch *Macquaria australasica,* the 'vulnerable' Yarra Pygmy Perch *Edelia obscura,* and the 'vulnerable' Ewen's Pygmy Perch *Nannoperca variegata*(Wager and Jackson 1993). In New South Wales, although *S. trutta* interacts with indigenous species, its distribution appears to have stabilised (P. Gehrke, pers. comm.)

Economic Impacts

The Brown Trout forms the basis of a multi-million dollar recreational fishing industry in Australia, and the economic benefits derived from recreational fishing ensure that stocking will continue (P. Gehrke, pers. comm.).

Other Information

Low genetic (mtDNA) diversity of Tasmanian stocks suggests that only the initial introduction (1864) from southern England was successful (Ovenden *et al.* 1993).

R & D Recommendations

- Research is required into the effects of *S. trutta* on endangered indigenous fish species.
- Research is required into the distribution and effects of salmonids in Western Australia.
- It is recommended that lakes which have had no previous introductions of salmonids should not be stocked with *S. trutta* in the future.

3.4.4 *Salvelinus fontinalis* (Mitchell)

Family:	**Salmonidae**
Common name:	**Brook Trout**
Indigenous Range:	North-eastern North America
Purpose of introduction:	Recreational fishery
Year of introduction:	Early 1900s

Present Distribution

Populations of Brook Trout are recorded in mountain streams of New South Wales and Tasmania (Allen 1989). Regular stocking is carried out in Tasmania, New South Wales, and South Australia (Kailola *et al. 1993*).

Environmental Impacts

Salvelinus fontinalis is regarded as uncommon and not well suited to Australian environments. It is considered to have little environmental impact at current population densities in New South Wales (P. Gehrke, pers. comm.).

Economic Impacts

This species forms a significant part of the recreational fishing industry in the states in which it is stocked.

Other Information

Tasmanian stocks of *S. fontinalis* appear to have good genetic (mtDNA) diversity (Ovenden *et al.* 1993).

R & D Recommendations

- It is recommended that lakes which have had no previous introductions of salmonids should not be stocked with *S. fontinalis* in the future.
- The distribution of *S. fontinalis* should be monitored for indications of range expansion.

3.4.5 *Perca fluviatilis* L.

Family:	**Percidae**
Common name:	**European Perch or Redfin**
Indigenous Range:	Europe, excepting Spain, northern Italy and Greece
Introduced from:	UK
Year of introduction:	1862 (Tasmania) 1868 (Victoria) (Kailola *et al.* 1993)
Purpose of introduction:	Recreational fishery

Present Distribution

The European Perch has become established in the south-west corner of Western Australia (Lane and McComb 1988), in South Australia, New South Wales, the Australian Capital Territory (Lintermans *et al.* 1990), Victoria and Tasmania (Welcomme 1988).

Environmental Impacts

Perca fluviatilis carries the epizootic haematopoietic necrosis virus (EHNV), which has been shown to be highly pathogenic for Silver Perch, Mountain Galaxias, Macquarie Perch, and Murray Cod (Langdon 1990). Other indigenous fish are likely to be susceptible (Wager and Jackson 1993). In the ACT, mass mortality of juvenile *P. fluviatilis* has been attributed to EHNV, and major declines in populations of Macquarie Perch in this region are attributed to this disease (Lintermans 1991).

In New South Wales, *P. fluviatilis* is regarded as a significant predator on indigenous fishes, and juveniles may compete with small indigenous fishes for food, but its impact is perceived to be stable and this species has not been linked with large-scale ecological degradation (P. Gehrke, pers. comm.).

A survey of the Murray River in Western Australia has shown the distribution of the once common indigenous fish, *Edelia vittata* (Western Pygmy Perch), to be fragmented, with little overlap between it and the introduced *P. fluviatilis* (Hutchinson 1991). Predation by *P. fluviatilis* on *E. vittata* is considered to be the most likely cause. *P. fluviatilis* is also suspected of predation on the 'vulnerable' Ewen's Pygmy Perch *Nannoperca variegata* and the 'vulnerable' Yarra Pygmy Perch *Edelia obscura* (Wager and Jackson 1993).

Other significant indigenous species on which *P. fluviatilis* is suspected to prey include the 'vulnerable' Dwarf Galaxias *Galaxias pusilla* and juveniles of the 'poorly known' Macquarie Perch

Macquaria australasica (Wager and Jackson 1993). Adverse interactions, in the form of food competition and possible predation, by *P. fluviatilis* on the 'endangered' Trout Cod *Maccullochella macquariensis* are said to have contributed to the cod's decline (Wager and Jackson 1993).

Economic Impacts

P. fluviatilis forms the basis of a small commercial fishery in western Victoria and South Australia (Kailola *et al.* 1993). Large individuals are valued for sport fishing and food.

R & D Recommendations

- Basic ecological research is required on the life history, habitats, diet and distribution of *P fluviatilis.*
- Research is required to determine the environmental impact of *P. fluviatilis* in those locations (Western Australia and the ACT) where it is identified as undergoing range expansion.

3.4.6 *Carassius auratus* (L.)

Family:	**Cyprinidae**
Common name:	**Goldfish**
Indigenous Range:	Eastern Europe, China, central Asia (Welcomme 1988)
Purpose of introduction:	Ornamental
Year of introduction:	1876

Present Distribution

Goldfish have been recorded from the southern half of Australia (Allen 1989), the Fitzroy River in Queensland, and the south-west of Western Australia (Kailola *et al.* 1993). The species is reported to be most abundant in waters of the Murray-Darling basin (Brumley 1991)

Environmental Impacts

Goldfish ulcer disease (*Aeromonas salmonica*), introduced into Australia by infected imported goldfish, has been found in feral goldfish populations (Langdon 1990). This disease is highly pathogenic to salmonids, and for this reason *C. auratus* is a prohibited import into Tasmania (Kailola *et al.* 1993). The incidence of this disease is also considered a problem for salmonid fisheries in other states (P. Gehrke, pers. comm.).

C. auratus is suspected to have an adverse impact on the 'endangered' indigenous Trout Cod *Maccullochella macquariensis* (Wager and Jackson 1993).

Economic Impacts

A bycatch of the commercial carp fishery, but of little value, *C. auratus* is probably being sold for rock lobster bait. *C. auratus* has no sporting value, but is important to the aquarium trade (Kailola *et al.* 1993).

Other Information

C. auratus is very widespread and is, perhaps, the most widely distributed exotic species in the country (Brumley 1991). Despite this, its effects on local biota are generally not known (P.S. Lake, pers. comm.). It is reported to readily hybridise with European Carp *Cyprinus carpio* (Brumley 1991) and, although not as numerous as carp, may have similar effects (P. Gehrke, pers. comm.). Much of its spread is attributed to aquarium releases (Kailola *et al.* 1993) and its use as live bait.

C. aurutus is a prescribed non-indigenous fish in Queensland under the Fisheries Act, which means that it may not be released into Queensland waters but may be held in aquaria. There is concern that its use as live bait may lead to translocations throughout Queensland (P. Jackson, pers. comm.).

R & D Recommendations

- Basic ecological research is required to investigate the environmental requirements of this species and its effects on indigenous biota.
- This species is ubiquitous and generally well known. It could be used as the focal point of educational activities designed to highlight the dangers of releasing aquarium fish, and using exotic or translocated species as live bait.

3.4.7 *Cyprinus carpio* L.

Family:	**Cyprinidae**
Common name:	**European Carp**
Variety	(a) Prospect strain
Purpose of introduction	Ornamental
Year of introduction	1850–60
Variety	(b) Singapore (Yanco) strain (koi)
Purpose of introduction	Ornamental
Year of introduction	1876
Variety	(c) River (Boolara) strain
Purpose of introduction	Aquaculture
Year of introduction	1960–64
Native Range:	Japan, China, central Asia
Introduced from:	UK

Present Distribution

Carp are found from the Warrego River, Queensland, to the mouth of the Murray River in South Australia, including most rivers in the Murray-Darling basin, several coastal streams in New South Wales (P. Gehrke, pers. comm.), Victoria and South Australia, and Lake Frome in South Australia (Kailola *et al.* 1993). Carp are reported to have been eradicated from Tasmania (Kailola *et al.* 1993) but were recently found in Lake Crescent and Lake Sorell in the headwaters of the Clyde River, a tributary of the Derwent system.

Brumley (1991) gives the distributions (and years of introductions, above) of the individual strains as:

(a) Prospect strain: Sydney: restricted

(b) Singapore (Yanco) strain: Murrumbidgee basin: restricted

(c) River (Boolara) strain: Murray-Darling basin: extremely widespread

Environmental Impacts

The principal impact of *C. carpio* has been its massive range expansion in the Murray-Darling system, where it dominates the indigenous fish fauna in numbers and biomass. P. Gehrke (pers.

comm.) cites overwhelming numbers in regions of the Murray, Lachlan and Murrumbidgee, comprising more than 80% of the total fish community, and Brumley (1991) reported that carp and goldfish were more abundant in some Victorian waters than any indigenous species.

While there is little solid evidence of the habitat impacts attributed to *C. carpio* (Fletcher *et al.* 1985; Brumley 1991; Morrison and Hume 1990), it is considered likely that carp contribute to cyanobacterial outbreaks by excreting nutrients, re-suspending sediments and damaging macrophytes (P. Gehrke, pers. comm.).

It is suspected that habitat modification caused by carp has contributed to the decline of the 'vulnerable' Dwarf Galaxias *Galaxias pusilla,* the 'endangered' Trout Cod *Maccullochella macquariensis,* the 'vulnerable' Yarra Pygmy Perch *Edelia obscura,* and the 'vulnerable' Ewen's *Pygmy* Perch *Nannoperca variegata* (Wager and Jackson 1993).

The Carp has been implicated as a secondary factor in the decline of indigenous gastropods in the Murray River, Victoria. While river regulation was considered to cause the greater effect, habitat changes caused by carp may have changed the food available to indigenous aquatic snails (Sheldon and Walker 1993).

C. carpio provides prey for indigenous piscivores including Golden Perch *Macquaria ambigua,* Murray cod *Mucculochella peelii,* and Redfin Perch *Perca fluviatilis,* as well as water rats and birds (Kailola *et al.* 1993).

Economic Impacts

Combined commercial catches of around 1000 t yr^{-1} were recorded from the Murray-Darling system (New South Wales, Victoria, and South Australia) from the mid 1970s to the mid 1980s.(Kailola *et al.* 1993). This fishery has apparently collapsed in New South Wales and Victoria because of declining catches (Brumley 1991; Morrison and Hume 1990). The annual commercial catch from South Australia, however, has not declined, producing about 450 tonnes (Kailola *et al.* 1993), although this catch has relatively low value, returning only A$340 t^{-1} in 1991–92 (Kailola *et al.* 1993).

The costs of managing carp and rehabilitating damaged aquatic ecosystems have not been estimated but are considered to be enormous (P. Gehrke, pers. comm.).

Other Information

The CSIRO Division of Water Resources is conducting experiments on the ecological impacts of carp in ponds (J. Roberts, pers. comm.). In New South Wales, research is in progress on the recruitment, distribution and abundance, and ecological effects of carp, as well as its possible influence on cyanobacterial blooms (P. Gehrke, pers. comm.).

Experimental evidence on the effects of high pH on *C. carpio* indicated that pH values greater than 9.0 significantly reduced growth and survival, while values greater than 10.0 further significantly reduced growth and survival to a sub-lethal level (Korwin-Kossakowski 1992). Such high pH values are often attained in surface waters during blue-green algal blooms (New South Wales Blue-Green Algal Task Force 1992, Bl¸hdorn and Arthington 1994).

C. carpio is a declared noxious species in most states with prohibitions on its use as live bait, the return of captured specimens to the water, breeding for sale, and interstate transfers (Kailola *et al.* 1993).

A Carp Task Force has been established to eradicate carp from Tasmanian waters. In the interim, the Task Force aims to minimise the economic, recreational and ecological impacts of carp in Tasmania.

R & D Recommendations

- Descriptive and experimental studies are required on the impact of carp on populations and communities of indigenous fish, invertebrates and plants.
- There is an urgent need for research into methods of controlling carp populations.
- Primary research funding is required to demonstrate the cost of carp to ecological sustainability, water management, recreational and commercial fisheries, conservation, and water treatment for public health.

3.4.8 *Rutilus rutilus* L.

Family:	**Cyprinidae**
Common name:	**Roach**
Indigenous Range:	Europe excluding Spain, Italy, Greece and Ireland
Introduced from:	UK
Year of introduction:	1860–30
Purpose of introduction:	Recreational fishery

Present Distribution

The Roach is reported from the Murray River and coastal drainages of southern New South Wales and Victoria. It is reported to be very abundant in the rivers of Port Phillip Bay.

Environmental Impacts

The high abundance of *R. rutilus* in the rivers of Port Phillip Bay suggests that there could be considerable effects on indigenous biota (P.S. Lake, pers. comm.). It is uncommon in New South Wales, and is considered to have little impact at its current low population densities (P. Gehrke, pers. comm.).

Economic Impacts

R. rutilus is unimportant as a recreational or commercial fishery.

R & D Recommendations

- Research aimed at providing a basic ecological understanding of the life history, habitat, diet, and distribution of *R.rutilus* in areas of high population density is required.
- A monitoring program is needed to evaluate the distribution and abundance of this species and to give an indication of any significant changes in range and biomass.

3.4.9 *Tinca tinca* (L.)

Family:	**Cyprinidae**
Common name:	**Tench**
Indigenous Range:	Western Asia, Europe except north Scandinavia
Purpose of introduction:	Recreational fishing
Year of introduction:	1876

Present Distribution

The Tench is found in coastal drainages of New South Wales, Victoria, Tasmania, and South Australia. It is locally abundant in the Murray-Darling River system (Brumley 1991).

Environmental Impacts

In Victoria, the Roach is very localised and does not appear to have a great effect on local biota (P.S. Lake, pers. comm.). It is uncommon in New South Wales, with apparently little impact at current population densities (P. Gehrke, pers. comm.).

Economic Impacts

T. tinca is unimportant as a recreational or commercial fishery.

R & D Recommendations

- A monitoring program is needed to evaluate the distribution and abundance of this species and to give an indication of any significant changes in range and biomass.

3.4.10 *Gambusia holbrooki* (Girard)

Family:	**Poeclliidae**
Common name:	**Eastern Gambusia or Mosquitofish**
Indigenous Range:	Southeastern USA (Lloyd and Tomasov 1985)
Introduced from:	Georgia, USA (via Italy)
Year of introduction:	1926
Purpose of introduction:	Mosquito control

Present Distribution

This species is widespread throughout mainland Australia (Allen 1989; Arthington 1991).

Environmental Impacts

Gambusia holbrook has demonstrated agonistic behaviour toward, and predation on, the 'vulnerable' Dwarf Galaxias *Galaxias pusilla,* the 'vulnerable' Yarra Pygmy Perch *Edelia obscura,* and the 'vulnerable' Ewen's Pygmy Perch *Nannoperca variegata* (Wager and Jackson 1993).

It is suspected of causing a decline in the abundance of the 'vulnerable' Honey Blue-eye *Pseudomugil mellis,* the 'endangered' Red-finned Blue-eye *Scaturiginichthys vermeilipinnis,* the 'vulnerable' Oxleyan Pygmy Perch *Nannoperca oxleyana,* and the 'endangered' Purple Spotted Gudgeon *Mogurnda adspersa* (Murray-Darling stock) (Wager and Jackson 1993).

Worldwide, some 35 fish species are reported to have been reduced in abundance or range due to adverse interactions with Gambusia (Lloyd 1990a). These interactions include competition for food and space, interference competition, and predation. In Australia, although much of the evidence is circumstantial, *G. holbrooki* is implicated in the decline of indigenous *Mogurnda, Ambassis, Melanotaenia, Pseudomugil, Craterocephalus*and *Retropinna* species (Lloyd 1990a).

Gambusia have been shown to have significant predatory effects on invertebrate species apart from mosquitoes (Lloyd 1990b; Arthington 1989b). These effects can lead to changes in zooplankton and phytoplankton abundance, often with unpredictable effects on mosquito populations (Bence 1988; Lloyd 1990b). Small, indigenous fish species have been shown to be more suitable for mosquito control than the exotic *Gambusia* (Lloyd 1990b).

Economic Impacts

G. holbrooki has no economic impact other than as a pest (P. Gehrke, L. Lloyd, pers. comm.). It is a non-prescribed non-indigenous fish in Queensland under the Fisheries Act, which means that it may not be released into Queensland waters or held in captivity. The Queensland Department of Primary Industries, Fisheries Branch has produced educational material to encourage the use of indigenous species for mosquito control.

R & D Recommendations

- Research is required to investigate the impacts of *G. holbrooki* on indigenous species and aquatic communities, with an emphasis on areas supporting endangered and vulnerable indigenous species.
- Educational activities aimed at informing the public about the dangers of the release and translocation of aquarium fishes could be focussed on this species.

3.4.11 Other small poeciliids

Phalloceros caudimaculatus **Hensel**

Family:	**Poeciliidae**
Common name:	**One-spot Live Bearer**
Indigenous Range:	Rio de Janeiro to Uruguay and Paraguay
Introduced from:	Unknown
Year of introduction:	Unknown
Purpose of introduction:	Probably mosquito control
Present distribution:	Perth, Western Australia (Allen 1989)

Poecilia latipinna **Le Sueur**

Family:	**Poeciliidae**
Common name:	**Sailfin Molly**
Indigenous Range:	Eastern USA and Mexico
Introduced from:	Singapore
Year of introduction:	1969
Purpose of introduction:	Ornamental and mosquito control
Present distribution:	Coastal drainages of southeastern Queensland (Allen 1989)

Poecilia reticulata **Peters**

Family:	**Poeciliidae**
Common name:	**Guppy**
Indigenous Range:	Venezuela, Barbados, Trinidad, northern Brazil, the Guyanas
Purpose of introduction:	Ornamental
Year of introduction:	Unknown
Present distribution:	Coastal drainages of northern NSW and eastern Queensland (Allen 1989; Arthington 1991)

Xiphophorus helleri **(Günther)**

Family:	**Poeciliidae**
Common name:	**Swordtail**
Indigenous Range:	Southeastern Mexico and Guatemala
Introduced from:	Singapore
Year of introduction:	1965
Purpose of introduction:	Ornamental
Present distribution:	Coastal drainages of northern NSW and eastern Queensland (Allen 1989)

Xiphophorus maculatus **(Heckel)**

Family:	**Poeciliidae**
Common name:	**Platy**
Indigenous Range:	Eastern Mexico and Guatemala (Welcomme 1988)
Purpose of introduction:	Ornamental
Year of introduction:	unknown
Present distribution:	Coastal drainages of northern NSW and eastern Queensland (Allen 1989)

Environmental Impacts

The above five poeciliid species represent a suite of tropical fishes, introduced for mosquito control and as ornamental fishes, and similar in life history to *Gambusia holbrooki.* These species have not been spread as widely as *G. holbrooki,* with most being confined to disturbed urban waterways. The Guppy *Poecilia reticulata* is the exception to this, with established populations in many streams along the Queensland east coast (Arthington 1991).

Associations of two poeciliid species, particularly *G. holbrooki* combined with *X. helleri* or *P. reticulata,* appear to depress populations of indigenous fishes (Arthington *et al.* 1983).

Still maintained as aquarium fishes, it is likely that these poeciliids will continue to be translocated into urban waterways. While these species have not shown the same capacity for unassisted range expansion as other exotics, some populations have persisted for a number of years and the potential for proliferation, especially with human assistance, should not be ignored (Arthington and Lloyd 1989).

Economic Impacts

These species have some value as ornamental fishes. However, outside the aquarium industry, their principal economic impact is that of pest fishes.

R & D Recommendations

- All poeciliid species should be monitored for indications of range expansion, significant increases in populations and evidence of ecological impact.
- Isolated populations should be eradicated where feasible, and new introductions prohibited.

3.4.12 *Oreochromis mossambicus* (Peters)

Family:	**Cichlidae**
Common name:	**Tilapia or Mozambique Mouth-brooder**
Indigenous Range:	Lower Zambesi and associated east-African rivers
Purpose of introduction:	Ornamental
Year of introduction:	Unknown

Present Distribution

This species of Tilapia is found in Brisbane (water supply reservoirs), Townsville (urban drains, Ross River), Cairns (estuaries), and the Gascoyne—Lyons River system, Western Australia (Arthington and Bl¸hdorn 1994a). Its range is expanding, apparently because of translocations. *O. mossambicus* has recently been reported from new water supply reservoirs in the Brisbane area (P. Jackson, pers. comm.) and in other creeks around Townsville and Cairns (R. Wager, J. Harris pers. comm.).

Environmental Impacts

In parts of tropical Asia, *O. mossambicus* contributes significant proportions of the animal protein available to local communities. In 1988 this species produced in excess of 100 000 tonnes from capture fisheries and aquaculture operations (Petr 1992). However, in many Asian countries where this species has been introduced it is now considered a pest fish because of its invasive abilities, lack of acceptance as a food fish, or its propensity to overpopulate small waterbodies with masses of stunted individuals (Blühdorn and Arthington 1992).

In Australia, this species has only been studied in detail in the disturbed habitat of a water supply reservoir (Blühdorn and Arthington 1990a) and no direct evidence of adverse environmental impact was found (A. Arthington). Other studies of distribution and abundance have indicated the potential for competition with indigenous species for food and breeding territories, and incidences of stunting, both in disturbed and relatively pristine habitats (Blühdorn *et al.* 1990, Blühdorn and Arthington 1990b).

O. mossambicus is considered to have the potential to devastate indigenous fish populations if it moves down the Darling River system (P. Gehrke, pers. comm.) and is regarded as a serious threat to the biota of the Murray-Darling River system (B. Lawrence pers comm.).

Economic Impacts

This species presently has no commercial or recreational value in Australia. There is some interest in *O. mossambicus* as a food fish, but its present proscribed status, which prohibits translocation, means that any development of this aspect of the fishery will be localised.

Other Information

O. mossambicus is a prohibited import into Australia. As well, it is declared noxious in Queensland, the Northern Territory, New South Wales and Victoria. It is prohibited in South Australia and commercial utilisation is not permitted in Western Australia (Blühdorn and Arthington 1992).

As the indigenous, highly valued Barramundi *Lates calcarifer* becomes more widespread through the efforts of translocation, there could be increasing pressure to use the exotic *O. mossambicus* as a forage fish. This has serious implications both for the illegal spread of *O. mossambicus* and for the development of Barramundi fisheries in the Murray-Darling basin and the Northern Territory (N. Milward, pers. comm.).

Donnelly (1978) reported accounts of *O. mossambicus* surviving droughts in sandy streams in southern Africa by burying itself in the wet sand layer, often as deep as 3 m. Similar drought and habitat conditions occur in the Gascoyne—Lyons River system of Western Australia, and it is possible that *O. mossambicus* survives the long periods without surface flows in this system in this manner.

R & D Recommendations

- Research aiming to produce practical management strategies for *O. mossambicus* is the highest priority; this may need to involve further basic biological studies in key areas.
- A coordinated education program is required to make the public aware of the risks to the environment from the release of live exotic biota, as well as a program to educate the public on identification of indigenous and exotic species. This should include a message that occurrences of exotic species should be reported to the State or Territory authorities.

3.4.13 *Tilapia mariae* Boulenger

Family:	**Cichlidae**
Common name:	**Black mangrove or Niger cichlid**
Indigenous Range:	Coastal rivers of west Africa
Purpose of introduction:	Ornamental
Year of introduction:	1978

Present Distribution

In Victoria, this species is apparently confined to the heated waters of the Hazelwood Power Station cooling ponds near Morwell (Allen 1989). Established populations have also been recorded in Queensland, in the Cairns area (Barron River, and estuaries) (Blühdorn *et al.* 1990).

Environmental Impacts

In Victoria *T. mariae* is very localised and probably does not affect local biota because of its restriction to thermally disturbed habitats (P.S. Lake, pers. comm., P. Cadwallader, pers. comm.).

In Florida, USA, this species was reported to be extremely aggressive towards other exotic fishes and to be spreading rapidly through the disturbed canal systems of southern Florida (Courtenay and Hensley 1979). Southern Florida has similar climatic and habitat conditions to Queensland, so the establishment of *Tilapia mariae* in the Cairns area could be problematic. Consequently, *T. mariae* is classified as noxious in Queensland under the Fisheries Act. As yet, no studies have been conducted in Australia on its environmental effects.

Economic Impacts

This species has no commercial or recreational value in Australia.

R & D Recommendations

- *T. mariae* requires basic ecological research to determine its distribution, abundance, and effects in tropical Queensland. It should be studied in conjunction with research into *O. mossambicus* in the Cairns area.
- In Victoria, this species, and others found in the thermally disturbed ponds at Morwell, should be monitored to determine if range expansion into the cooler waters of the adjacent stream system has occurred.

3.4.14 *Cichlasoma nigrofasciatum* Günther

Family:	**Cichlidae**
Common name:	**Convict Cichlid**
Indigenous Range:	Western drainages of Central America, eastern drainages of Costa Rica
Introduced from:	Central America
Year of introduction:	1920s
Purpose of introduction:	Ornamental

Present Distribution

In Victoria, this species in confined to the heated waters of the Hazelwood Power Station cooling ponds near Morwell (Allen 1989).

Environmental Impacts

In Victoria this species is very localised and probably does not affect local biota because of its restriction to thermally disturbed habitats (P.S. Lake, pers. comm.). Even in these habitats it is not common, and it is not considered likely to survive in the lower temperature regime of the adjacent waterways (P. Cadwallader pers comm.)

Economic Impacts

This species has some commercial value as an ornamental fish, but feral populations produce mainly negative economic impacts due to the costs of monitoring and management.

R & D Recommendations

- This species, and others found in the thermally disturbed ponds in the Morwell, Victoria area, should be monitored to see if any range expansion into the cooler waters of the adjacent stream system has occurred.

3.4.15 *Misgurnus anguillicaudatus* (Cantor)

Family:	**Cobitidae**
Common name:	**Oriental Weatherloach**
Indigenous Range:	Northeast Asia to central China (Welcomme 1988)
Purpose of introduction:	Ornamental
Year of introduction:	1984

Present Distribution

This species is rapidly expanding its range in the Australian Capital Territory (Lintermans *et al.* 1990). It is abundant in the Yarra, Marybrynong Rivers, and present in the Ovens and Murray Rivers, Victoria, where it is actively expanding its range (P.S. Lake, pers. comm.). *M. anguillicaudatus* is also currently expanding its distribution in southern New South Wales (P. Gehrke, pers. comm.). It has not yet become established in Tasmania (W. Fulton, pers. comm.).

Environmental Impacts

There are presently no Australian data on this species' interactions with indigenous fishes (P. Gehrke, pers. comm.), although there is preliminary evidence that the Weatherloach is adversely affecting *Galaxias olidus* in small lowland streams in the ACT (M. Lintermans, pers. comm.).

Economic Impacts

In Tasmania, there is concern about the potential negative impact on indigenous fauna and the high costs of management (W. Fulton, pers. comm.).

R & D Recommendations

- There is a need for basic ecological understanding of the life history, habitat, diet and distribution of *M. anguillicaudatus* as well as descriptive and experimental studies on the impacts of this exotic species on populations and communities of indigenous fish, invertebrates and plants.
- The distributions of known populations of the Weatherloach should be monitored and likely invasion sites examined to fully determine the extent and rate of spread of this species.

3.4.16 *Acanthogobius flavimanus* Schlegel

Family:	**Gobiidae**
Common name:	**Yellowfin Goby**
Purpose of introduction:	Accidental (ship ballast or contaminated oyster shipment)
Year of introduction:	Around 1971

Present Distribution

This species is mainly established in the marine waters of Sydney Harbour and Botany Bay, but has been found in freshwater reaches of the Hawkesbury River, New South Wales (P. Gehrke, pers. comm.)

Environmental Impacts

A. flavimanus is uncommon and little is known of its local biology or interactions with other species (P. Gehrke, pers. comm.).

Economic impacts

This species has no commercial value in Australia.

R & D Recommendations

- The distributions of known populations of *Acanthogobius flavimanus* should be monitored, especially those found in freshwater.

3.5 Temporal Sequence of Fish Introductions

Aquatic habitats, like all ecosystems, are subjected to invasions over various time-scales, from geological to historical. Australia's position as an island continent has produced a unique freshwater fauna but has also physically limited the species available for invasions. Human activities have, to a certain extent, overcome the physical limitations on invasive species, providing pathways either by accident or intent. To date, only one accidental introduction of an exotic fish species to Australian freshwaters has been recorded—the Yellowfin Goby *Acanthogobius flavimanus.* The remaining exotic fish species established in freshwater were deliberately introduced to Australia, although not always with official sanction.

In Australia, there have been three waves of fish introductions: the late 19th century acclimatisation movement; the poeciliid introductions for attempted mosquito control beginning in the 1920s and apparently continuing today; and the late 20th century wave of introductions for aquaculture and ornamental use.

The acclimatisation societies of the late 19th century were responsible for an initial wave of 10 exotic species, most of which were established successfully. These introductions were intended primarily to provide recreational fisheries based on familiar species, and included all of the salmonids, percids, and cyprinids which are presently established in this country.

Three of these species, *Oncorhynchus tshawytscha, Salmo salar,* and *Cyprinus carpio* ('Boolara strain') were re-introduced in the 1960s for aquaculture purposes. Hybrids of the latter species subsequently achieved a massive range expansion throughout the Murray-Darling River system, the impacts of which are still being felt.

From the 1920s onward, *Gambusia holbrooki* was introduced throughout the country for the purposes of mosquito control. Other poeciliids, including *Phalloceros caudimaculatus, Poecilia reticulata,* and *Poecilia latipinna,* were also introduced for mosquito control, but on a much smaller scale.

The remaining group of species, including the poeciliids, cichlids, and the Weatherloach were apparently originally introduced as ornamental fishes in the 1960s and 1970s. Escapees, or deliberate releases of these fishes, have resulted in the establishment of feral populations, some of which have high potential for range expansion.

3.6 Environmental Impacts of Exotic Species

The potential effects of exotic fish species are competition (resource, spatial, interference); predation (by or upon indigenous biota); hybridisation; the introduction of diseases and parasites; and habitat alteration (Wager and Jackson 1993; Crowl *et al.* 1992; Lloyd 1990a; Taylor *et al.* 1984). All of the above impacts have been recorded or are suggested to have occurred in Australian freshwaters (see individual species' summaries, Section 3.4).

In the worst cases, these impacts are indicated by declining populations of indigenous fishes whose distributions no longer overlap with the exotic species, indicating a complete exclusion of the indigenous species and, in some cases, endangering their survival. Other symptoms of environmental impact may be found in shifts in relative abundance of indigenous biota, rapid expansions in range and abundance of exotic species and disturbances of habitat and water quality (Crowl *et al.* 1992; Brumley 1991; Arthington 1991).

Causal links between a species' introduction and the symptoms of its presence and impact are not always known or demonstrable. One consequence of this is a general lack of conclusive scientific evidence of impacts attributable solely to exotic species.

This state of affairs is the result of three principal, interacting elements. Firstly, there is insufficient information on indigenous biota, which is evidenced by the number of undescribed species and a general absence of monitoring (Wager and Jackson 1993). Secondly, there are the coincident effects of habitat modifications on indigenous biota (usually deleterious) and the exotic species (often advantageous) (Arthington *et al.* 1990). Thirdly, pre-introduction studies are rarely undertaken (Courtenay 1990), so there is little original baseline data on which to base evidence of later impacts.

Even the fact that none of the exotic species have indigenous congeners, thus precluding interbreeding, has not prevented environmental impact as a result of hybridisation. The European Carp *C. carpio* had a sedentary distribution for almost 100 years before a hybrid, believed to be a mixture of the 'Boolara' and 'Yanco' strains (Brumley 1991), dispersed widely within the Murray-Darling River system.

The topic of hybridisation raises an issue which needs to be considered in association with research on exotic fish species. This is the translocation of indigenous species to waterways outside their natural range. Such a practice is effectively the same as introducing an exotic species, with the added danger of hybridisation between the translocated fish and locally occurring, closely related fishes. It is noteworthy that Australia's only purported fish extinction, the Lake Eacham rainbowfish *Melanotaenia eachamensis,* is attributed to the translocation of indigenous fishes (Wager and Jackson 1993). This now appears to be a case of extinction of a local population only.

The topic of indigenous translocations is too large to be considered in greater detail in this report, but it should be considered as part of any strategies developed for managing exotic fish species.

3.7 Economic Impacts of Exotic Species

A number of the exotic species found in Australia generate direct and indirect financial benefits from commercial (wild caught, aquaculture, and ornamental) and recreational fisheries (see individual species' summaries, Section 3.4). Exotic species introduced for recreational fisheries are stocked directly into the natural aquatic systems. Generally, for these species, the environmental and management costs are perceived to be outweighed by the economic benefits they produce.

Wild caught and cultivated exotic species have escaped, or been deliberately released, into their receiving waters. While the financial return from harvesting these stocks can be considerable (e.g. European Carp), so can the negative economic impacts, such as the cost of control programs, loss of amenity, and other opportunity costs.

The ornamental fish industry was reported to be worth close to $200 million in 1988 (Kailola 1990). As with the aquaculture industry, the ornamental exotic fishes which have become established in the wild are the result of escapes or deliberate releases. These escapees have no commercial value and will incur high costs for their effective control.

For other exotic fishes, expected positive economic effects have not eventuated. For example, the Mosquitofish *Gambusia holbrooki* was introduced and widely distributed in this country for the purpose of mosquito control. Lloyd (1990b) concluded that *G. holbrooki* is a relatively poor mosquito predator and that indigenous fish species are more effective and appropriate for mosquito control in this country.

All of the established exotic fish species have a negative economic impact represented by the resources required to monitor, investigate, manage and, in a few isolated cases, exterminate them. However, the principal negative economic impact of exotic species is the cost of rehabilitating the aquatic ecosystems damaged by the presence of exotics. Although potentially massive, these costs are so intertwined with those due to habitat degradation and other anthropogenic impacts as to be impossible to differentiate them exclusively.

3.8 Ecology of Invasions

Craig (1992) suggests that exotics must be: physiologically adapted to the new environment; able to find and compete for food and habitat at each life-history stage; able to avoid predation; and have suitable reproductive potential or flexible life-history traits. In Australia, such species are represented by those introduced successfully in the late 19th century It could be argued that, given appropriate data about the exotic species and the habitat into which it is to be introduced, the process of invasion should be predictable.

However, most successful invasive species are influenced by habitat and anthropogenic factors (fishing pressure, stocking, translocations) which are independent of the biotic tolerances and life-history traits of the invading species. These anthropogenic factors contribute markedly to the instability of fish communities and make it impossible to predict the outcomes of introductions in terms of the final species composition and the time frame required to regain community stability. Achieng (1990) demonstrated that the effects of fish introductions into Lake Victoria, central Africa, 30 years ago are still apparent, and the fish community and populations of many species have not achieved a stable state.

A similar situation could pertain to exotics fishes in the Murray-Darling system, especially the European Carp, which may yet decline or may continue to be a major part of the fish community. The outcome is unpredictable.

3.9 Human Influences

The role of some anthropogenic activities is discussed in Section 3.8 above. Such activities may be of direct influence, such as the introduction and maintenance of fish populations for food, pets, recreation, or aquaculture. Human influences may also be indirect, such as land use effects (disturbance of the riparian zone); water management (disruption of the natural flow regime); water storage (destruction of littoral and riparian communities, and riverine habitat); the creation of lacustrine conditions for which few indigenous species are adapted; and pollution.

Davies (1989) showed that exotic and indigenous species differ in their reactions to both naturally occurring and anthropogenic disturbances. Poor recruitment of *S trutta* was attributed to low flows and the lack of suitable 'nursery' habitat in headwater streams in dry years, while the sympatric indigenous species *Gadopsis marmoratus* showed no adverse effects. In disturbed areas, changes in the flow regime due to irrigation water use and river impoundment (i.e. high summer flows, lowered temperatures) reduced recruitment of *G. marmorutus.*

Meffe (1984) showed a similar pattern of impact of naturally occurring abiotic perturbation in North America. In a location prone to unpredictable flash flooding, the indigenous poeciliid (*Poeciliopsis occidentalis,* the Sonoran Topminnow) was relatively unaffected by flow perturbations, whereas populations of the introduced poeciliid *Gambusia affinis* (with similar life history traits), were devastated. Periodic, flood-induced reductions in *Gambusia* populations permitted the coexistence of the two poeciliids. Similar process appear to permit the coexistence of *Gambusia* and several indigenous species in streams of south-west Western Australia (B. Pusey, pers. comm.).

An even broader range of human influences on aquatic invasions arises from various anthropocentric attitudes towards the aquatic environment in general and fish species in particular. These are the attitudes that define whether a fish is considered a pest or a resource (a single species can be both); whether, and how a species should be exploited or not; the time frame for development or for conservation; the requirements for, and strategies applied to, the management of aquatic systems; and so on.

A number of protocols, such as Endangered Species Legislation, the policy of Ecologically Sustainable Development and the Precautionary Principle, and State based policies on translocations and exotic fish species, have been developed. In the international arena, policies and procedures concerning such issues are contained in the "Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms" (Turner 1988).

3.10 Assessment of Threats and Priority Species

While some impacts on indigenous species have been demonstrated, and many more suggested, a number of other factors should be considered in determining the ecological threat presented by an exotic species.

The group for which most environmental impacts have been demonstrated is the salmonids, in particular Brown Trout *(S. trutta)* and Rainbow Trout (*O. mykiss*). These have three characteristics which distinguish them from the remainder of the self-maintaining exotic fish species in Australia: they have been established in this country for a long time; they require undisturbed or high quality habitat to survive; and they are predacious.

The effects of salmonids have been demonstrated as a fragmentation of the distribution of indigenous galaxiids, and the relegation of co-occurring species, for example, the River Blackfish *Gadopsis marmoratus,* to sub-optimal habitats. These are classic impacts of predatory exotic species (Fernando 1991). To a certain extent, the impacts of salmonids have stabilised and they are unlikely to cause unexpected impacts in the future. As well, their economic and recreational benefits are generally perceived to exceed their environmental costs. However, the salmonids are implicated in the decline of four 'endangered' and four 'vulnerable' indigenous fishes (Wager and Jackson 1993). The principal research and management thrust, therefore, should be the conservation of indigenous species threatened by salmonids.

Another predatory exotic species with a long history in Australia is *Gambusia holbrooki,* which has affected a much wider range of indigenous fish species because it is not limited to cool upland streams. It is implicated in the decline of two 'endangered' and five 'vulnerable' indigenous fishes (Wager and Jackson 1993).

Of the remaining exotic species, those that are causing, or are likely to cause, environmental problems have the common denominator that they are relatively recent introductions and are thus, to a large extent, still in the unstable 'boom-bust' period caused by their introduction. They have probably not achieved their final distribution and their impacts will vary depending on interactions with indigenous biota in new habitats, many of which are likely to be disturbed or altered from a natural state.

Finally, some of the remaining established exotic fish species are considered to have little likelihood of significant range expansion. These are generally ornamental species surviving in urban waterways.

Table 3.2 illustrates the grouping of the various established exotic species by their known interactions with indigenous species and their perceived threat.

3.11 Management Issues and Directions

One of the unfortunate effects of current management of the exotics problem is that the evidence of damage is necessarily after the fact. That is, the damage has been done before preventive action can be taken. Obviously, prevention is, in most cases, the best approach to the management of exotic species. Effective monitoring systems could detect subtle changes in fish communities and act as an early warning system of potential problems, such as range fragmentation or the local eradication of an indigenous species. Suitable early warning methods need to be devised and put in place.

Many of the problems associated with exotic fish species are relatively minor, but they persist and may grow to become major issues. This occurs largely because the responsible management authorities are not provided with sufficient resources to allow effective monitoring and 'house-keeping' activities.

Preventive measures against the spread of invasive species are as simple as public education backed by appropriate legislation and effective enforcement. In general, the legislation is in place, relatively trivial amounts are spent on education, and enforcement is ineffective. As a result, the problems caused by translocation of both exotic and indigenous species continue unabated. Aquarium fish are dumped, bait fish escape, and forage fish are deliberately released. All of these activities require human involvement—very little spread of invasive species can be attributed to unassisted dispersal.

A four-pronged approach is needed. The four elements are research, monitoring, education, and political will. All need to be incorporated into an integrated approach to the multitude of strategies needed for sustainable management of freshwater resources.

3.12 Research and Development Priorities

3.12.1 General Recommendations

The R & D recommendations for individual species were presented with each species summary (Section 3.4). These are summarised below. As well, a number of general recommendations were put forward by the fisheries scientists who responded to our request for information. These have been ordered, to some extent, into priorities, and include:

- Funding for regional or catchment-based inventories of aquatic environments and

Table 3.2: Established exotic freshwater fish species ordered by the type of environmental threat or problem.

Species regarded as economically beneficial despite demonstrated or potential environmental impacts.	
Salmonidae	
Oncorhynchus mykiss (Walbaum)	Rainbow Trout
Salmo salar L.	Atlantic Salmon
Salmo trutta L.	Brown Trout
Salvelinus fontinalis (Mitchell)	Brook Trout
Species regarded as major pests and on which considerable research effort has been or is being expended.	
Cyprinidae	
Cyprinus carpio L.	European Carp
Species regarded as major pests and on which only ad hoc research effort has been or is being expended.	
Poeciliidae	
Gambusia holbrooki (Girard)	Eastern Gambusia or Mosquitofish
Species which are likely to undergo rapid range expansion if not managed effectively.	
Cichlidae	
Oreochromis mossambicus (Peters)	Tilapia or Mozambique Mouth-brooder
Tilapia mariae Boulenger	Black Mangrove or Niger Cichlid (in far north Queensland)
Cobitidae	
Misgurnus anguillicaudatus (Cantor)	Oriental Weatherloach
Percidae	
Perca fluviatilis L.	European Perch or Redfin (in Western Australia and the ACT)
Species which have been established for sufficient time to allow impacts and distributions to become stabilised and for which no current research is under way.	
Percidae	
Perca fluviatilis L.	European Perch or Redfin (other than in Western Australia and the ACT)
Cyprinidae	
Carassius auratus L.	Goldfish
Rutilus rutilus L.	Roach
Tinca tinca (L.)	Tench
Species occurring principally in urban areas, not showing signs of unassisted range expansion, but likely to be augmented by the release of other aquarium fish.	
Poeciliidae	
Phalloceros caudimaculatus Hensel	One-spot Live Bearer
Poecilia latipinna Le Sueur	Sailfin Molly
Poecilia reticulata Peters	Guppy
Xiphophorus helleri (Günther)	Swordtail
Xiphophorus maculatus (Heckel)	Platy
Cichlidae	
Cichlasoma nigrofasciatum Günther	Convict Cichlid
Tilapia mariae Boulenger	Black Mangrove or Niger Cichlid
Newly introduced exotic species about which little is known of potential distribution or likely interactions with indigenous biota.	
Gobiidae	
Acanthogobius flavimanus Schlegel	Yellowfin Goby

biota that are potentially susceptible to exotic species. This includes research into the general ecological requirements of indigenous fish species and the monitoring of indigenous speciesí distributions and abundance. There is a pressing need for long-term records rather than anecdotes.

- Basic ecological research to provide an understanding of the life history, habitat, diets and distribution of important exotic species, and to provide a better understanding of the effects of exotic fishes on local ecosystems. These should include descriptive and experimental studies on the impacts of exotic species at both the population and community level.

  Priority should be given to developing strategies for the practical management of species of major concern, e.g. Tilapias, Gambusia, and Carp. This may involve some basic biological studies but it must be directed at practical management outcomes. It should also include examination of synergistic effects with other causal factors such as habitat degradation and could include a comparison between effects of exotics in flowing waters and impoundments.

- Education is a cost effective method of preventing ill-informed introductions and translocations of aquatic biota and disposal of aquarium fish. Concerted and coordinated education programs should make the public aware of the risks of exotic species to the environment, as well as a program to educate the public on identification of indigenous and exotic species. This should include a message that any exotic fauna found should be reported to the State or Territory authorities.

  Priority should be given to a multi-faceted education campaign aimed at informing decision makers at the various levels of industry and government. Such a campaign could include information dissemination to the ornamental fish industry on: the effects, or potential effects, of exotic fishes; the advantages of utilising indigenous species, along with information about inappropriate translocation of these species; ways of passing this information on to hobbyists; and establishing a disposal/recycling system for unwanted aquarium fishes.

- Public health authorities could be better informed of the choices available for biological control of nuisance organisms such as mosquitoes, and politicians could be apprised of the problems associated with exotic fishes and the wealth of advice available to them for consultative purposes before decisions are made about aquaculture developments, fish stocking programs, and so on.
- Methods of risk assessment and problem evaluation are required, with emphasis on Australiaís tropical environments and faunal assemblages.
- Research is required to demonstrate the cost of exotic species to ecological sustainability, water management, recreational and commercial fisheries, conservation, and water treatment for public health. This information could be used to demonstrate the cost of not funding new research into measures to control exotic species.
- Research is needed to determine the effects of introduced fish in significant conservation areas, such as the southern acid peat flats and the southern forests of south-west Western Australia, the coastal dune wetlands of eastern Australia, and the wet tropics area of northern Australia, because of the number of indigenous species with very restricted distributions in these systems.
- Research should be conducted into the secondary impacts of introductions, such as increased angling pressure on indigenous fishes because of the development of a recreational fishery based on exotic species that are more difficult to catch.
- Many respondents perceived a need for more effective methods of control over movements of exotic and translocated indigenous fish in Australia.
- A survey of translocated indigenous fish is needed to monitor their range and abundance. As well, research is required into the effects of translocated species, particularly those most commonly involved, such as Golden and Silver Perch. There will be continuing political pressure to translocate fish and hard scientific data are required to counteract this.
- There is a perceived need to investigate or develop a policy on utilising established exotic fishes in aquaculture. Income from such operations could be used to fund research into the control of feral populations.

3.12.2 Individual species priorities

The suggested R & D priorities for individual species include:

- Continuing financial support for research into the control of European Carp populations in the Murray-Darling River system.
- Research into the effects of exotic species on threatened indigenous fishes, and methods

for the conservation of remnant populations of endangered indigenous species.

- Research, with management outcomes, on those exotic species identified as undergoing range expansion, including *G. holbrooki, O. mossambicus, T. mariae, M. anguillicaudatus* and *P. fluviatilis.*
- Regular monitoring of exotic fish populations to provide baseline information on distribution and abundance, and also to warn of impending range expansion or other significant changes.

3.13 Research Coordination

Research and development programs initiated by the LWRRDC should be integrated with other national programs to achieve the effective management of exotic fish species and the conservation of Australia's indigenous aquatic biota. Relevant programs include the Australian Nature Conservation Agency's Feral Pests Program and Endangered Species Program, and the Natural Resources Management Strategy for the Murray-Darling Basin.

4.0 Diseases and Parasites

4.1 Introduction

The topic of exotic parasites and diseases brought into Australia with exotic fish is briefly reviewed as part of this report, but a comprehensive treatment has not been attempted. This is a very large and specialised field which merits a thorough review of the issues relevant to environmental protection and industries based on fish and shellfish. It goes well beyond the topic of exotic aquatic biota, extending into the broader realm of localised and interstate translocations of both indigenous and exotic biota within Australia.

Problems associated with pathogenic organisms as a whole may not fall strictly within the R & D portfolio of LWRRDC and any essential R & D initiatives probably should be undertaken either by other organisations/funding schemes, or as a joint venture (e.g. with the Fisheries Research and Development Corporation).

The approach taken here is to outline some key issues concerning diseases and parasites of exotic and translocated fishes, and to comment on high priority issues for Australia at this time. There is limited information on the types and distribution of pathogens affecting exotic Gastropoda and translocated Crustacea, and these taxa are not included in the discussion which follows.

4.2 Diseases and Parasites

The dissemination of pathogenic organisms has accompanied the introduction and translocation of fish, Crustacea and shellfish throughout the world. Diseases introduced with exotic species have frequently been spread to indigenous species within the new country by uncontrolled movements of fish and other host organisms.

Australia has taken a strong stance on the importation of exotic fishes partly because exotic diseases and parasites may be introduced together with the fish and the water used during their transport (McKay 1984).

Certain pathogens are considered to affect only their original host species, genus or family, so the introduction of an infected species within the group may threaten other members present in the new country. Increasingly, however, taxon or species-specific diseases are transmitted to unrelated hosts (Langdon 1990).

The bacterial pathogen, *Aeromonas salmonica,* was introduced to Victoria in the 1970s via infected Japanese goldfish (Trust *et al.* 1980). This episode brought goldfish ulcer disease to cultured and wild Australian goldfish and carp populations ó an issue of some significance for the aquarium industry and aquaculturists. Subsequent studies demonstrated the pathogenicity of *Aeromonas salmonica* to salmonids (Whittington and Cullis 1988) and this discovery led to restrictions on the movements of goldfish within Australia.

The spread of imported pathogens from their exotic hosts to indigenous fish species is of more immediate relevance to environmental protection and may exact a high ecological and economic cost.

Langdon and Humphrey (1987) described a new viral disease of unknown origin, Epizootic Haematopoietic Necrosis Virus (EHNV), affecting Redfin Perch in the wild, which was found to have spread to cultured Rainbow Trout. This disease is known to be highly pathogenic to several indigenous Australian fishes, including Silver Perch, Mountain Galaxias and Macquarie Perch, and to a lesser extent, Murray Cod; it also has a pathogenic effect on *Gambusia* (Langdon 1989).

The translocation of Redfin Perch and salmonids by angling and government bodies without health certification thus poses a threat to valuable indigenous fish stocks in the wild.

Langdon (19901 reported several instances where infectious agents are more pathogenic, or only cause clinical disease, in atypical hosts, and so become a problem when the typical host species come into contact with unusual hosts. Examples are whirling disease in Rainbow Trout, proliferative kidney disease of salmonids and the North American crayfish ëplagueí fungus which is only mildly pathogenic to the host crayfish but has devastated indigenous European astacids.

The same phenomenon has been observed with fish parasites. Moyle (1985) noted that indigenous Californian fishes seemed to be more heavily parasitised by exotic parasites (e.g. the anchor worm, *Lernaea cyprinacea)* than exotic fishes. The anchor worm is now common in several indigenous Australian fishes and also frequently infects *G. holbrooki* in the River Murray (Lloyd *et al.* 1987).

Rowland and Ingram (1991) have recently reviewed the diseases and parasites associated with indigenous freshwater fishes in Australia, giving emphasis to the ectoparasitic and fungal diseases of Murray Cod, Eastern Freshwater Cod, Trout Cod, Golden Perch and Silver Perch. Their report describes the seasonal occurrence, aetiology, diagnosis and treatment of common pathogens, and also briefly reviews the status of bacterial and viral diseases in Australia. These lists have updated earlier compilations of the major pathogens of Australian and overseas fish and shellfish (Langdon 1988; Langdon 1990).

Mr R. McKay, Curator of Fishes at the Queensland Museum, has compiled a list of the parasites associated with indigenous and exotic fish species maintained in culture facilities throughout Australia.

Langdon (1990) and McKay (pers. comm.) consider that the movement of infected indigenous fishes from one drainage system to another, and interstate, is a much more serious issue that the spread of pathogens via exotic fishes. Fish reared under culture conditions are generally much more susceptible to disease than fish in the wild and there have been major outbreaks of disease and mass mortalities of indigenous fish in several hatcheries.

The recent massive mortalities of cultivated Silver Barramundi (*Lates calcarifer*) in Queensland and the Northern Territory due to a picornia-like virus, BPLV (Glazebrook *et al.* 1990) are a case in point. This disease has been unequivocally diagnosed from Barramundi in Australia (Glazebrook *et al.* 1990; Munday *et al.* 1992), as well as from stocks in Thailand and Tahiti. Prior to the introduction of appropriate control measures for this virus, every Australian hatchery using intensive culture of Barramundi larvae suffered massive mortalities attributed to the virus (Munday 1994).

Control measures have been very successful in eliminating the economic loss due to Barramundi mortalities (Anderson *et al.* 1993; Munday 1994), but Munday (1994) has advised that the presence of a few infected fish in a batch could lead to drastic consequences when they are moved across State boundaries.

Recent proposals to establish growout facilities for Silver Barramundi within the Murray-Darling Basin have led to research on the possible transmission of BPLV virus to indigenous Australian fishes. In a project funded by the Natural Resources Management Strategy (Murray-Darling Basin Commission), Dr John Glazebrook from James Cook University, has found evidence that Macquarie Perch, Murray Cod and Silver Perch are susceptible to BPLV

Asymptomatic carriers of BPLV have been detected in Barramundi from South Australia. Thus one of the urgent issues is the development and ready availability of a sensitive and specific test for the detection of the virus in asymptomatic fish. Electron microscope techniques lack the sensitivity to detect latent and low grade infections; the ELISA/PCR technique is considered more effective and sensitive (J. Glazebrook, pers. comm).

Research presently in progress to document the incidence of parasites and diseases associated with both indigenous and exotic freshwater fish species maintained in culture systems, and also in the wild, should be continued and augmented.

4.3 Research and Development Priorities

The following issues could be considered within the context of problems arising from the introduction of exotic fish and movements of exotic and indigenous fishes in Australia.

- Problems with fish diseases and parasites should be referred to one or more experts for a thorough review of the issues and research priorities relevant to the management and monitoring of Australian freshwater systems. Mr McKay and Dr Glazebrook and their colleagues could be contacted in the first instance to discuss and/or scope the topic.
- There is a perceived need for more effective methods of control over movements of exotic and translocated indigenous fish in Australia.
- Avenues for joint funding should be explored where the issues extend beyond LWRRDC's immediate R & D portfolio.

5.0 Acknowledgments

This project was funded by the Land and Water Resources Research and Development Corporation. We thank Dr Nick Schofield and Dr Peter Davies for guidance throughout the study, and Mr Glenn Conroy for assistance with preparation of the final report. Many colleagues contributed to this review through their published work, as cited below. We particularly thank the following people and institutions for their assistance in providing advice, papers and other materials, and for their recommendations on research priorities.

Dr Malcolm Beveridge, University of Stirling, Stirling, Scotland.

Dr Kath Bowmer, CSIRO Division of Water Resources, Griffith, NSW

Dr Andrea Brumley, East Gippsland Community College of TAFE, Victoria

Dr Stuart Bunn, Griffith University, Brisbane

Dr Phil Cadwallader, formerly Dept. of Conservation and Natural Resources, Victoria

Dr Setish Choy, Queensland Dept Primary Industries, Brisbane

Dr Peter Davies, University of Western Australia, Perth

Dr Wayne Fulton, Inland Fisheries Commission, Tasmania

Dr Peter Gehrke, Fisheries Research Institute, Cronulla, NSW

Dr John Glazebrook, James Cook University, Townsville

Dr Marc Hero, CRC for Tropical Rainforest Ecology and Management, Cairns

Dr Pierre Horwitz, Edith Cowan University, Western Australia, Perth

Dr Paul Humphries, Murray-Darling Freshwater Research Centre, Albury

Dr Peter Jackson, Queensland Dept Primary Industries, Brisbane

Dr John Koehn, Arthur Rylah Institute, Victoria

Prof. Sam Lake, Monash University, Clayton, Victoria

Dr Brian Lawrence, Murray-Darling Basin Commission, Canberra

Dr Mark Lintermans, Parks and Conservation Service, Canberra

Dr Lance Lloyd, Rural Water Commission, Victoria

Mr Roley McKay, Queensland Museum, Brisbane

Dr Frances Michaelis, Senate Select Committee, Commonwealth Government, Canberra

Mr Hamar Midgely, Fisheries Consultant, Bli Bli, Queensland

Prof. Norm Millward, James Cook University, Townsville

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Dr Luke Penn, Murdoch University, Western Australia

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Dr Robin Welcomme, FAO, Rome, Italy

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