



Review of Impacts of Displaced/Introduced Fauna Associated with Inland Waters

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Preface

Australia: State of the Environment 1996 (the first ever independent and comprehensive assessment of the state of Australia's environment) was presented to the Commonwealth Environment Minister in 1996. This landmark report, which draws upon the expertise of a broad section of the Australian scientific and technical community, was prepared by seven expert reference groups working under the broad direction of an independent State of the Environment Advisory Council. While preparing the report, the former Department of the Environment, Sport and Territories, on behalf of the reference groups, commissioned a number of specialist technical papers. These have been refereed and are now being published as the State of the Environment Technical Paper Series. Reflecting the theme chapters of the report, the papers relate to human settlements, biodiversity, the atmosphere, land resources, inland waters, estuaries and the sea, and natural and cultural heritage. The topics covered range from air and water quality to sea grasses and historic shipwrecks.

Abstract

This paper provides a review of the current state of knowledge on the impacts of displaced/introduced fauna (fish and invertebrates) based on the OECD pressure-state-response model of state of the environment reporting.

The review also reports on environmental indicators used to assess the state of Australian inland waters in relation to the impacts of displaced/introduced fauna. The two types of indicators discussed and used are direct/primary indicators and indirect/surrogate indicators. Direct indicators are those which show the physical, chemical, biological and ecological effects of introduced/displaced fauna. Indirect indicators provide information about activities or conditions which are likely to result in impacts, for example, rates of introduction of exotic/displaced fauna, and the geographic range and abundance of particular species.

The review covers seven families and 18 species of introduced fish, displaced/introduced invertebrates (particularly Crustacea and gastropod Mollusca), translocation, and diseases of introduced fish and invertebrates.

Effects due to displaced/introduced fauna include:

- physical and chemical impacts on inland waters, such as alteration or degradation of habitat and water quality;
- biological impacts on indigenous/endemic fauna, such as hybridisation or alterations to the genetic structure of populations, and disease transference associated with introduced and displaced fauna; and
- ecological impacts on indigenous/endemic fauna, such as effects on reproduction and survival, abundance, population structure and species distributions, as well as disruption of aquatic communities, and effects on ecosystem processes.

The response of society to problems of introduced and displaced species can be divided into biological conservation and management, catchment management, water conservation and management, as well as water quality and management. The greatest hindrance to management of the problems caused by exotic/translocated biota is the lack of information on the species concerned and their interactions with indigenous species and communities.

1 Introduction

1.1 Scope of the paper

This paper is one of several commissioned by the former Department of the Environment, Sport and Territories, on behalf of the Inland Waters Reference Group (IWRG) for the report, *Australia: State of the Environment 1996*. It provides a review of the current state of knowledge on the impacts of displaced/introduced fauna (fish and invertebrates) associated with inland waters, addressing the issue at a national scale, as background and supporting documentation to the *1996 State of the Environment (SoE)* report.

The review reports on:

1. indicators of the state of inland waters in relation to the impacts of displaced/introduced fauna; and
2. impacts of pests, production species, diseases and displaced indigenous biota such as competition, predation, displaced gene pools, exclusion and physical impacts on the inland water environment in Australia.

Although the brief requested a national status report covering all forms of displaced/introduced aquatic fauna, the IWRG recognised that the inclusion of invertebrates would be difficult within the time available to the consultants. The material presented on invertebrates gives an indication of the main issues

but is far from complete. Much more work is needed on this aspect of state of the environment reporting.

The OECD pressure-state-response model has been used as the framework for this assessment. The paper initially presents a brief account of environmental pressures from human activities that lead to impacts, gives a review of these impacts using direct and indirect indicators, and ends with a summary of societal responses to the impacts of displaced/introduced fauna listed under the headings of 'Catchment management', 'Biological conservation and management', 'Water conservation and management' and 'Water quality and management'. The final section briefly outlines emerging issues.

1.2 Terminology

The title of this paper employs the terminology set down by the IWRG, terminology that is not always of sufficient precision to convey information about 'introduced' fauna. This paper generally adheres to the following terms:

- exotic: a species not naturally found in Australian waters
- indigenous: a species originating and occurring naturally (in Australia), native
- endemic: a species occurring within a natural range or localised area
- translocated: a species moved to new areas within its natural range or outside of its natural range, displaced
- introduced: a species (exotic or translocated) brought in or established
- established: an introduced species which has formed a self-maintaining population.

1.3 Indicators

The desirable characteristics of indicators as defined by the OECD pressure-state-response model are:

- relevance to sub-issue
- relevance to decision-making
- relevance to public interest
- ease of presentation/explanation
- availability of data
- scientific credibility.

Indicators of two types are considered useful to describe the state of inland waters in relation to the impacts of displaced/introduced fauna. The two types of indicators used or discussed in this review are direct/primary indicators and indirect/surrogate indicators. The main inadequacy of both types of indicators lies in there being insufficient or incomplete data available, in most instances, to present a national overview.

1.3.1 Direct/primary indicators

Direct/primary indicators are those which show the effects of displaced and introduced fauna on inland waters and the associated indigenous/endemic fauna/flora, aquatic communities and ecosystem processes. They cover three classes of impact:

- physical and chemical impacts on inland waters, such as alteration or degradation of habitat and water quality
- biological impacts on indigenous/endemic fauna, such as hybridisation or alterations to the genetic structure of populations, and disease transference associated with introduced and displaced fauna
- ecological impacts on indigenous/endemic fauna, such as effects on reproduction and survival, abundance, population structure and species distributions, as well as disruption of aquatic communities, and effects on ecosystem processes.

Physical and chemical (water quality), biological (including genetic) and ecological effects represent the major categories of impact recognised in the literature on this topic, reviewed by Taylor et al. (1984), Pollard (1990), Arthington (1991), Billington and Hebert (1991), Horwitz (1991, 1995a, b), Crowl et al. (1992), Beveridge and Phillips (1993) and Arthington and Blühdorn (1995) amongst others.

The impacts and indicators are relevant to both indigenous and exotic species translocated within and into new drainages for recreational or commercial fishing, species introduced for biological control or any other commercial or recreational objective, species which escape from aquariums, aquaculture facilities, or fish farms engaged in the production of fish for stocking purposes, food production or the aquarium hobby trade, and to any accidentally or maliciously displaced species.

A distinction is made in this paper between introduced species that are self-maintaining in the wild and those maintained purely by stocking, because the scope for management and/or eradication differs vastly

between them. However, introduced species (exotic and translocated) do not have to reproduce in the new environment to cause an impact. The stocking of very large numbers of individuals which survive to feed and grow can be expected to have an effect on local resources, populations and community structure. Repeated escapes of exotic species which are regularly imported as larvae and juveniles for grow-out aquaculture are of particular concern, since large populations can persist without natural reproduction (Baltz 1991). A sustained predatory or competitive effect on indigenous species and communities may follow the escape of long-lived species such as anguillids, which may survive for 30 years or more without reproducing (Baltz 1991).

The Victorian State of the Environment Report for Inland Waters (Victorian Office of the Commissioner for the Environment 1988) recommended three main indicators of the effects of introduced fish on indigenous fishes: (i) changes in distribution of indigenous and exotic fish species (presence/absence), (ii) changes in diversity of fish species at selected sites, and (iii) changes in abundance and population characteristics (age classes/abundance) of indigenous and exotic fishes.

The first of these indicators has been used in this paper, as has the second to some extent. The third indicator is highly desirable but it is rare to find data sets showing changes in abundance and population characteristics of indigenous species that are unequivocally related to the effects of introduced species. Where such data sets do exist they generally fail to eliminate the role of other factors impacting upon fish abundance and population characteristics. A multivariate or experimental approach would be needed to overcome this problem and there has been very little monitoring or research of this type directed towards introduced species in Australia.

The Victorian report also recommended that 5–15 years of data would be required for short-lived fish species and 20 years of data for long-lived species in order to establish long-term trends in population characteristics. This type of monitoring of fish populations has, on the whole, been way beyond the resources of fisheries agencies. Suitable data may be collected in specific areas by research groups, but usually as part of research programs with other objectives.

Information on the direct indicators of impact used in this paper tends to be fragmented and anecdotal, and little of it is based on clear-cut, unequivocal evidence. The paper has had to draw upon information from personal communications as well as the literature to provide a national status report. Evidence of ecological impacts, such as effects on the diversity and structure of aquatic communities and on ecosystem processes, was particularly difficult to find. State of the environment reporting specifically requires the development of direct indicators that are relevant at a national scale, a restriction which has effectively eliminated the reporting of impacts observed at local scales and in small, short-term studies.

1.3.2 Indirect/surrogate indicators

Indirect/surrogate indicators provide information about activities or conditions which are likely to result in impacts of displaced/introduced species on inland waters and their associated fauna. Indicators of this type give information about the state of inland waters and their associated fauna where direct/primary indicators are not available or there is insufficient information.

Indirect/secondary indicators used or discussed in this review are:

- geographic range and abundance of exotic fauna in Australian inland waters
- rates of introductions of exotic fauna into Australia
- geographic range and abundance of translocated fauna in inland waters
- conservation status of indigenous fauna and the state of inland waters
- extent of aquaculture.

Information on some of these indirect indicators is reasonably complete. For example, it has been possible to document the present distribution of most exotic fish species from recently published information and data collected during a concurrent survey of fisheries agencies and biologists conducted on behalf of the Land and Water Resources Research and Development Corporation (Arthington & Blühdorn 1995). This survey also provided data on the relative abundance of some exotic species in Australian inland waters, but at a fairly crude level.

The use of species distributions as an indirect indicator of their impacts has led inevitably to a

certain amount of duplication of material covered under direct indicators.

Rates of introductions of exotic fauna into Australia are a useful indirect indicator of impacts for two reasons. Firstly, there is an on-going risk that more exotic species will escape from containment and become established in inland waters, and secondly, importation of live fish and eggs involves the risk of importation of species-specific pathogens and pathogens which may affect Australian indigenous fauna and other exotic species (Langdon 1988).

The conservation status of indigenous fauna and the general state of inland waters are both partially a consequence of the establishment of exotic and translocated fishes. However, these indicators can rarely be related solely to the impacts of exotic and translocated species as many other human pressures impact upon aquatic systems and their biota (Boon et al. 1992; Barmuta et al. 1992).

1.3.3 Relevance of indicators

All of the indicators used in this review are considered to meet the OECD criteria listed above. Firstly, they have relevance to decision making and the public interest. The issue of exotic and translocated fauna periodically leads to public accusations about the adverse impacts of certain fish species—such as European carp, *Cyprinus carpio*—and to calls for species eradications over large areas.

The direct evidence from Australia and elsewhere that certain exotic species are hardy, opportunistic, readily dispersed and likely to have an impact on indigenous biota and ecosystems has led to the present policies of government agencies regarding further importations of species, restrictions on the movements of species and efforts to eradicate species (e.g. *Gambusia*, carp, tilapias, certain Crustacea).

Stocking with trout remains in the public interest despite its reported adverse effects on indigenous biota and aquatic ecosystems.

The translocation of indigenous fishes into Lake Eacham in north Queensland and their role in the reported extinction of the Lake Eacham rainbowfish, *Melanotaenia eachamensis* Allen and Cross, in the wild (Barlow et al. 1987; Wager & Jackson 1993) stimulated an intense public debate, a management response and further research.

Reporting of disease outbreaks in aquaculture systems producing species for human consumption are decidedly of public interest, and have impacted on commercial management procedures and decision making by fisheries agencies.

The scientific credibility of the direct indicators is well established in the literature cited throughout this paper, and most of the indicators lend themselves to simple explanations and unequivocal presentation in tables and figures. However, the data upon which the indicators are based are often less reliable than could be desired. This is particularly so of indicators concerning impacts on aquatic communities and ecosystem processes, which are ultimately the most sensitive and relevant indicators of adverse effects.

The scientific credibility of the indirect indicators is perhaps more debatable, taking as they do a risk-assessment approach (e.g. the risk that additional species and diseases will become established if importations of exotic species continue at the present rates). The list of exotic species currently allowed into Australia is a direct outcome of efforts to prohibit fish species with a high risk of establishment and/or adverse impacts in Australian waters. The actual levels of risk of escapes and accidental introductions of exotic species cannot be estimated or presented quantitatively with existing knowledge of management and husbandry practices. There is also a risk of human error and of deliberate introductions.

1.4 Information gaps

Information on direct and indirect indicators was sought from State/Territory fisheries agencies (see Appendix 1) and the literature. The information provided by agencies varied in quantity and quality, largely due to the short time frame for this review. Some of the data provided were not compiled in a way that could be used immediately and the additional time and funding required to extract and interpret essential facts could not be made available. Supporting information was sought from published sources but again time was a limiting factor and some of the published data was inconsistent from one source to another.

It was obviously difficult for most fisheries agencies and impossible for others (Tasmania) to respond to this task so rapidly and grateful acknowledgment is due to all persons who contributed information upon request. More advance notice and possibly a special budgetary allocation to assist in reporting processes

will be required for future state of the environment reporting.

2 Environmental pressures resulting from human activities

2.1 Introduced/displaced species in context

The range of human activities with potential to damage and degrade river systems has been categorised by Boon et al. (1992) as including: (i) supra-catchment effects such as acid deposition and inter-basin transfers; (ii) catchment land-use change (afforestation and deforestation, urbanisation, agricultural development, land drainage and flood protection); (iii) corridor engineering (removal of riparian vegetation, flow regulation via dams and weirs, channelisation, dredging and mining); and (iv) in-stream impacts (chemical and thermal pollution, water abstraction, navigation, exploitation of indigenous species and introduction of exotic species). Barmuta et al. (1992) described human stresses on Australian streams in terms of harvesting of renewable resources, discharge of pollutants, physical modification and restructuring, and the introduction of exotic species.

In many instances some or all of these human pressures on aquatic ecosystems coincide and interact and it becomes difficult to distinguish the impacts of a single type of pressure, such as exotic and translocated Australian fauna. Often the changes made to aquatic systems provide conditions that are suitable or ideal for exotic species, facilitating their range expansion and exacerbating their impacts (Courtenay 1990; Arthington et al. 1990).

Australia's indigenous freshwater fauna, like its terrestrial plants and animals, is distinctive in that it consists mostly of unique species, very few of which are shared with other biogeographic regions (Williams & Campbell 1987). Australia's position as an island continent has also physically limited the species available for invasion from other countries. Human activities have to a certain extent overcome the physical limitations on dispersal of exotic species, providing pathways for invasion either by accident or intent. All but one of the exotic fish species established in Australian freshwaters (the Yellowfin goby, *Acanthogobius flavimanus*) were deliberately

introduced to this country, although not always with official sanction.

The movement of indigenous species within a country (displacement or translocation) represents a further pressure on the environment with potentially very damaging consequences. Impacts due to species displacement within continents such as Australia are poorly known, but they can be expected to parallel those observed when exotic species become established in countries outside their natural range.

The following parts of this section give a brief account of human pressures on the environment relating to:

- introductions of exotic fish species for recreational fishing and ornamental purposes, for aquaculture and biological control;
- translocations of fauna within Australia to enhance recreational fishing, and for aquaculture purposes; and
- introduction and translocation of aquatic invertebrates.

All three categories of human activities have resulted in environmental impacts due to the establishment of introduced species in areas beyond their natural range. These impacts are reviewed in detail in Section 3.

2.2 Introduction of exotic fish species into Australia

2.2.1 Phases of introduction

McKay (1984) described three phases of exotic fish introductions into Australia. The first period involved the acclimatisation societies of 1862–1896 and colonial governments; these agencies sought to make the wildlife more familiar to European colonisers and were responsible for an initial wave of 10 exotic species, most of which were successfully established. The second phase was the liberation of the mosquitofish, *Gambusia*, initially in the 1920s and again during World War II, and apparently continuing in some areas today, to control mosquito populations.

The most recent introductions have occurred in the late 20th century for aquaculture and aquarium purposes (McKay 1984). The latter group of species, including the poeciliids, cichlids and the oriental weatherloach, were apparently introduced as ornamental fishes in the 1960s and 1970s. Escapees or deliberate releases of these fishes have resulted in the establishment of self-maintaining populations, some of which have enormous potential for range expansion.

The number of exotic fish species reported from Australian inland waters is at least 24 (Fletcher 1986; McKay 1989; Allen 1989; Arthington 1991; Arthington & Blühdorn 1995). Most of the information in this paper concerns 18 self-maintaining species (three salmonids, one percid, four cyprinids, six poeciliids, three cichlids, and one cobitid). This is double the number of species reported

by Weatherley and Lake in 1967 (two salmonids, one percid, five cyprinids and one poeciliid).

Table 1 provides a list of the exotic fish species introduced into Australian freshwaters that are known to have established self-maintaining populations, with dates of initial and major introductions and the reasons for these introductions.

Table 1: Fish species introduced to Australia which are reported to have established self-sustaining feral populations, with dates of initial/major introduction and reasons for introduction

Family/Species	Common name	Dates	Reason
Salmonidae			
<i>Oncorhynchus mykiss</i> (Walbaum)	Rainbow trout	1894	Acclimatisation
<i>Salmo trutta</i> L.	Brown trout	1864	Acclimatisation
<i>Salvelinus fortinalis</i> (Mitchell)	Brook trout	1883	Acclimatisation
Percidae			
<i>Perca fluviatilis</i> L.	European perch or redfin	1862	Acclimatisation
Cyprinidae			
<i>Carassius auratus</i> L.	Goldfish	1876	Ornamental
<i>Cyprinus carpio</i> L.	Carp	1850–80, 1960–64	Ornamental/Aquaculture
<i>Rutilus rutilus</i> L.	Roach	1860–80	Acclimatisation
<i>Tinca tinca</i> (L.)	Tench	1876	Acclimatisation
Poeciliidae			
<i>Gambusia holbrooki</i> (Girard)	Eastern Gambusia or mosquitofish	1926	Acclimatisation/biological control
<i>Phalloceros caudimaculatus</i> Hensel	One-spot live bearer	Unknown	Aquarium-ornamental
<i>Poecilia latipinna</i> Le Sueur	Sailfin molly	1969	Aquarium-ornamental
<i>Poecilia reticulata</i> Peters	Guppy	Unknown	Aquarium-ornamental
<i>Xiphophorus helleri</i> (Günther)	Swordtail	1965	Aquarium-ornamental
<i>Xiphophorus maculatus</i> (Heckel)	Platy	Unknown	Aquarium-ornamental
Cichlidae			
<i>Cichlasoma nigrofasciatum</i> Günther	Convict cichlid	1920s	Aquarium-ornamental
<i>Oreochromis mossambicus</i> (Peters)	Tilapia or Mozambique mouth brooder	1978 ?	Aquarium-ornamental
<i>Tilapia mariae</i> Boulenger	Black mangrove or Niger cichlid	1978	Aquarium-ornamental
Cobitidae			
<i>Misgurnus anguillicaudatus</i> (Cantor)	Oriental weatherloach	1984	Aquarium-ornamental
Gobidae			
<i>Acanthogobius flavimanus</i> Schlegel	Yellowfin goby	~ 1971	Accidental (ballast-water/shipment)

Table 2: Current distribution of exotic species which are reported to have established self-sustaining feral populations in Australia by State/Territory

Species	State/Territory							
	NSW	Vic	Tas	SA	WA	ACT	Qld	NT
Salmonidae								
Rainbow trout	*	*	*	*	*	*		
Brown trout	*	*	*	*	*	*	*	
Brook trout			*					
Percidae								
Perch/redfin	*	*	*	*	*	*		
Cyprinidae								
Goldfish	*	*		*	*	*	*	
European carp	*	*	*	*	*		*	
Roach	*	*						
Tench	*	*	*	*				
Poeciliidae								
Mosquitofish	*	*		*	*	*	*	*
One-spot live bearer					*			
Sailfin molly							*	
Guppy							*	
Swordtail							*	
Platy							*	
Cichlidae								
Mozambique mouth brooder					*		*	
Niger cichlid		*					*	
Convict cichlid		*						
Cobitidae								
Oriental weatherloach	*	*		?	?	*	*	
Gobiidae								
Yellowfin goby	*							

Note: ? = unconfirmed reports

Six other species are often included in lists of exotic species from inland waters, but they are known not to have established self-maintaining populations or their present status is unknown. A distinction between species reproducing in the wild and those maintained by stocking is important from a management perspective because the latter can be eliminated by ceasing to stock. These species are discussed in

Section 3.5 under ‘Indirect indicators’; they are the Atlantic salmon (*Salmo salar*), the Chinook (Quinnat) salmon (*Oncorhynchus tshawytscha*), a cyprinid, the rosy barb (*Puntius conchonius*), the Domingo gambusia (*Gambusia dominicensis*), *G. affinis* and the Jack Dempsey cichlid (*Cichlasoma octofasciatum*).

Table 2 gives the current distribution of exotic species which have become established in the wild in each State/Territory. Figure 1 gives State/Territory boundaries and for comparison, Figure 2 gives the boundaries of the Australian drainage divisions (Merrick & Schmida 1984). The disparity between political and natural boundaries is of some importance to reporting the state of the environment in Australian inland waters as well as to management programs (see Section 4).

2.2.2 Recreational fishing

The demand for recreational fishing has led to many of the fish introductions recorded throughout the world (Radonski et al. 1984). Recreational fishing also supports many aquaculture, fish farming and stocking operations which result in frequent translocations and introductions (Welcomme 1988).

Exotic species used to feed cultivated stocks have been known to escape and may also contribute to the overall impact of recreational fishing on the environment.

Early introductions of exotic fish into Australia (see Table 1) were primarily to provide a recreational

pursuit for European settlers who expressed disappointment at the lack of fighting qualities in Australian indigenous fish (McNee & Greenham 1991).

Today, freshwater angling is a major recreational industry in Australia (Kailola et al. 1993). The total expenditure on recreational fishing in Western Australia is estimated to lie between \$200 million and \$415 million annually (Linder & McLeod 1991). Pepperell (1982, cited in McNee & Greenham 1991) estimated that New South Wales spends approximately \$277 million annually on recreational fishing, of which inland angling accounts for an expenditure of \$60 million annually.

Inland fisheries are managed by State and Territory governments. Few of the States and Territories have adequate management information on the numbers of recreational anglers, or the fish species they are catching (McNee & Greenham 1991). In a more recent assessment, Kailola et al. (1993) stated that recreational fishing in Australia involves a large but unquantified amount of fish. Data on the quantities of each species caught are patchy.



Figure 1: Map of Australia showing State and Territory boundaries

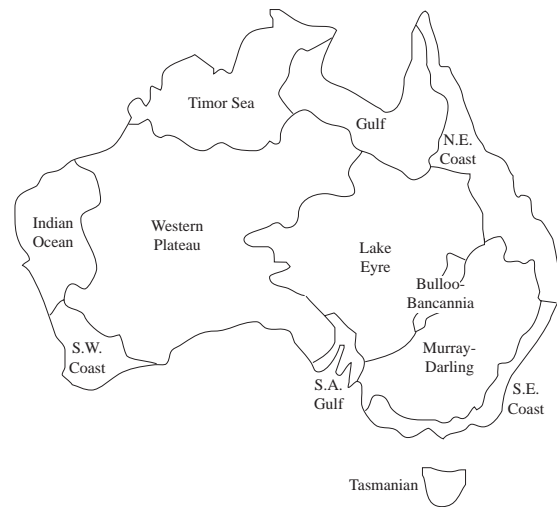


Figure 2: Map of Australia showing drainage divisions

Source: Merrick & Schmida 1984

Brown trout, *Salmo trutta*, and rainbow trout, *Oncorhynchus mykiss*, have been stocked in reservoirs and rivers throughout south-eastern Australia for angling purposes (Cadwallader 1983) and to a lesser extent in some other States. These species form the basis of a multi-million dollar recreational fishing industry in Australia, and the economic benefits and enjoyment arising from this industry ensure that stocking will continue.

2.2.3 Aquarium or ornamental fishes

The demand for fish suitable for ornamental purposes is an issue of growing importance and contention. The ability to keep and display colourful or otherwise interesting fishes has promoted a world-wide traffic in exotic species (Courtenay & Stauffer 1984). Since the 1960s, recreational interests have generated an aquarium fish hobby and trade which is responsible for the importation of thousands of exotic fish into Australia each year (Kailola 1990). Most of the ornamental fish sold in Australia are imported (Kailola et al. 1993). During a peak period between 1972 and 1978, as many as 15 million fish were imported per annum (Kailola 1990). Due to a reduction in the mortality rate and changes in quarantine requirements in 1986–1987, the number of live fishes imported was just under eight million (Kailola 1990).

Offsetting the decline in imports has been an increase in the number of non-indigenous fish bred in Australia (Kailola 1990). Breeding of ornamental fish in aquaculture systems is rapidly expanding with demand for fish exceeding supply (Humphrey 1989; Kailola et al. 1993). There is also a large scale ‘backyard’ breeding market of non-approved aquarium fish—either of smuggled imports or previously approved taxa; these fishes are widely traded in Australia (Kailola 1990).

All poeciliids, the cichlids and the oriental weatherloach, now established in Australian inland waters, 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 and some species have already undergone range expansion, whilst others have enormous potential for spread in natural and modified aquatic systems.

2.2.4 Other fish introductions

Exotic fish species have been introduced into Australia for aquaculture purposes and biological control (Table 1). Three of the most recent introductions of exotic fish into Australia have occurred for aquaculture purposes (the Chinook salmon, the Atlantic salmon, and the ‘Boolara strain’ of *Cyprinus carpio*). The Atlantic salmon was re-introduced in 1983–84 for aquaculture, mostly in the form of sea cage aquaculture on the south-east and west coasts of Tasmania (Kailola et al. 1993). The river (Boolara) strain of the European carp was introduced (apparently illegally) for aquaculture purposes during the period 1960–64 (Brumley 1991).

A number of species with particular dietary preferences have been introduced in an effort to control nuisance organisms, especially the larvivorous fishes of several poeciliid genera widely dispersed for mosquito control purposes (McKay 1984; Arthington & Lloyd 1989). *Gambusia holbrooki* was first brought into Australia as an aquarium species, but from the 1920s onwards was introduced throughout the country for mosquito control (Lloyd & Tomasov 1985). Other poeciliids, including *Phalloceros caudimaculatus*, *Poecilia reticulata* and *Poecilia latipinna*, were also released for mosquito control, but on a much smaller scale.

2.2.5 Introductions of invertebrates

Aquatic 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 mammalian 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).

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.

The brine shrimp, *Artemia salina*, has been introduced worldwide to provide a food resource for cultivated and aquarium fishes and as part of solar pond management techniques. As a result of these introductions, and of translocations in areas where *Artemia* occurs naturally, few regions of the world with non-marine saline waterbodies now lack *Artemia* (Geddes & Williams 1987). A large number of reproductively isolated taxa are involved within the genus and 36 different strains have been recognised in the Iberian Peninsula alone (Amat Domenesch 1980).

Effects on indigenous species and strains of *Artemia*, and on indigenous species within other families of brine shrimps, such as *Parartemia*, and effects on other aquatic fauna adapted to saline waters are the main areas of concern in Australia and elsewhere (Geddes & Williams 1987).

2.3 Translocation of fauna in Australian inland waters

Translocation, the movement of a species or a distinct genetic stock within its natural range or to an area outside its natural range, is effectively equivalent to the introduction of an exotic species. Every translocated or displaced species is an exotic in its new habitat, and it has been suggested that such species are potentially more devastating in Australia than many exotics as they are already acclimatised to some extent (Kailola 1990). This movement of live fishes and crustaceans is regarded as a major factor in the spread of diseases and parasites (Langdon 1988; Horwitz 1991).

Pressure from recreational fishing groups has been the major factor in the stocking of 'sport' fishes in impoundments, wetlands and rivers, most notably in eastern Australia (see, for example, Harris & Battaglione 1990). Details of the fish species translocated within Australia to enhance recreational

fisheries are given in Section 3.5.3, 'Translocations of indigenous fauna in Australian inland waters'.

In Australia, three indigenous decapod Crustacea of the family Parastacidae have been translocated for aquaculture purposes, the yabby *Cherax destructor* Clark, the redclaw, *C. quadricarinatus* (von Martens), and the marron, *C. tenuimanus* (Smith) (Kailola et al. 1993).

A small amount of stocking is conducted or proposed in Australia for conservation purposes, for example as part of the species recovery plans for endangered fishes and Crustacea (Horwitz 1991, 1994).

2.4 The freshwater aquaculture industry

With the declining returns of world fisheries, aquaculture is regarded as a way to provide increasing quantities of aquatic products in the future. Worldwide aquaculture production is increasing rapidly as modern techniques are applied to an expanding range of species (Pullin 1993). Irrespective of the type of aquaculture system or management strategies employed, escapes of cultivated species into the wild are virtually impossible to prevent.

Escaped aquaculture species may interact with indigenous species by breeding with local populations of the same species or through hybridisation with closely related species (Munday et al. 1992a; Beveridge & Phillips 1993). The escape of transgenic species from aquaculture facilities is regarded as a further dimension of the threat to indigenous biota arising from exchange of genetic material (Kapusinski & Hallerman 1991).

Aquaculture structures such as cages and pens may act as fish aggregation devices (Beveridge & Phillips 1993) and the enriched conditions caused by excess food often produce a succession in biota attracted to aquaculture operations. Such conditions can lead to enhanced populations of indigenous or escaped fishes in the areas surrounding aquaculture operations as much as 12 times higher than distant, unaffected sites (Iwama 1991; Weston 1991). Predators are also attracted to culture facilities by the shelter they provide, and by the increased abundance of food represented by the culture species themselves and by local species concentrated around cages and pens. In their efforts to access caged stock, aggressive or large predators can cause structural damage to enclosures

and so greatly increase the possibility of escapes (Iwama 1991; Munday et al. 1992a).

Disease outbreaks in cultivated stock may also be increased by predators attracted to aquaculture facilities. While bird attacks may often be unsuccessful, a not inconsiderable number of caged fish are wounded by such attacks. Under the normally crowded culture conditions, such damage increases the susceptibility of the fish to bacterial or fungal infection (Beveridge 1984; Iwama 1991). Predators may also act as intermediate hosts of parasites, or assist in the transfer of pathogens.

Aquaculture is a relatively small industry in Australia (Treadwell et al. 1992). In 1989–90, the gross value of aquacultural production was estimated at \$190 million, or 17% of total fisheries production (including aquaculture: ABARE 1991); however, most of this production involves marine species. The species cultured vary between States and Territories, largely due to differences in climatic conditions (Section 3). The industry is growing rapidly.

3 Indicators of the state of Australia's inland waters in relation to the impacts of introduced fauna

3.1 Descriptions and indicators (direct or primary) of impacts of exotic fishes introduced into Australian inland waters

3.1.1 Salmonidae

Salmonid fishes were first introduced into Australia late in the nineteenth century (Table 1). These introductions were amongst the first for the family and the species involved are now among the most widespread fishes in cool fresh waters (Crowl et al. 1992). Trout are reported to be responsible for declines in indigenous fishes in Peru, Colombia, Chile, Yugoslavia, Himalayan rivers, Lesotho, South Africa and New Zealand (Welcomme 1988).

The impact of trout on Australian indigenous fishes is well documented relative to other introduced species

and probably reflects, more than other factors, the importance of trout. Nevertheless, Crowl et al. (1992) in a review of the impact of trout on Australasian indigenous biota concluded that 'the limited data that have been gathered in Australasia make it difficult to produce many unambiguous generalisations about the impact of trout on indigenous fishes'.

Evidence of the impacts of trout in terms of non-overlapping distributions of trout and indigenous species, and changes in relative abundance of indigenous species, cited by Crowl et al. (1992), is given in Tables 3 and 4. While there are no studies which have determined the precise mechanisms underlying the impacts of trout, competition for food and space, and predation, are the processes invoked (Tilzey 1980; Fletcher 1986; Crowl et al. 1992). Table 5 presents information on the mechanisms underlying the effects of trout on various Australian indigenous species.

A number of the indigenous fish species affected by trout are classified as 'endangered' or 'vulnerable' (Wager & Jackson 1993). Rainbow trout, *Oncorhynchus mykiss*, competes for food with the 'vulnerable' Macquarie perch, *Macquaria australasica* (e.g. Cadwallader 1978, 1979) and possibly preys on juveniles (Wager & Jackson 1993). Rainbow and brown trout are suspected of predation on the 'vulnerable' indigenous Yarra pygmy perch *Edelia obscura* and Ewen's pygmy perch *Nannoperca variegata* (Wager & Jackson 1993). Few native fish species are reported in areas of Western Australia where rainbow trout occur.

The brown trout is implicated in the decline in numbers of four 'endangered', four 'vulnerable', and one 'poorly known' species (Wager & 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 & Jackson 1993). The brown trout is also thought to be responsible for reduced abundance in the 'vulnerable' saddled Galaxias, *Galaxias tanycephalus* (Wager & Jackson 1993).

Table 3: Evidence of non-overlapping distributions of introduced trout and Australian indigenous species

Family/Species	Common name	Waterbody	Reference
Galaxiidae		Kiewa River (Vic.) Murray Darling drainage	Frankenberg (1966) Cadwallader (1978)
<i>Galaxias brevipinnis</i> Günther	Climbing Galaxias	Lake Tarli Karng (Vic.) Lake Eucumbene catchment (NSW) Waters of the Otway Range (Vic.)	Frankenberg (1966) Tilzey (1976) Jackson & Williams (1980)
<i>Galaxias olidus</i> Günther	Mountain Galaxias	Lake Eucumbene catchment (NSW) Seven Creeks catchment (Vic.) Watchbox Creek (Vic.) Yarra River (Vic.) Waters of the Otway Range (Vic.)	Tilzey (1976) Cadwallader (1970) Fletcher (1979) Jackson & Williams (1980) Jackson & Williams (1980)
<i>Galaxias fontanus</i> Fulton	Swan Galaxias	Swan River (Tas.)	Fulton (1978)

Source: Crowl et al. 1992

Table 4: Evidence of changes in relative abundance of Australian indigenous species following the introduction of trout

Family/Species	Common name	Effect	Waterbody	Reference
Galaxiidae				
<i>Galaxias brevipinnis</i> Günther	Climbing Galaxias	Disappearance	Lake Tarli Karng (Vic.)	Frankenberg (1966)
<i>Galaxias maculatus</i> (Jenyns)	Common jollytail	Decline	Lake Purrumbete (Vic.)	Cadwallader & Eden (1982)
<i>Galaxias olidus</i> Günther	Mountain Galaxias	Decline	Lake Eucumbene catchment (NSW)	Tilzey (1976)
		Decline	Watchbox Creek (Vic.)	Fletcher (1979)
<i>Paragalaxias dissimilis</i> (Regan)	Shannon Paragalaxias	Disappearance	Some Tasmanian waters	Frankenberg (1966)

Source: Crowl et al. 1992

Table 5: Mechanisms underlying the effects of introduced trout on Australian indigenous fish species

Family/Species	Common name	Mechanism	Reference
Percichthyidae <i>Macquaria australasica</i> Cuvier <i>Maccullochella macquariensis</i> (Cuvier)	Macquarie perch	Dietary overlap	Butcher (1945) Cadwallader & Rogan (1977) Cadwallader (1978, 1979)
	Trout cod	Predation Dietary overlap Predation	Butcher (1945) Cadwallader (1978, 1979) Butcher (1945)
Galaxiidae <i>Galaxias</i> spp. <i>Galaxias pedderensis</i> Frankenberg <i>Galaxias olidus</i> Günther <i>Galaxias maculatus</i> (Jenyns)	Pedder Galaxias	Predation	Evans (1942) Tilzey (1980)
	Mountain Galaxias	Dietary overlap Predation	Tilzey (1976) Fletcher (1979) Cadwallader (1978, 1979) Fletcher (1979)
	Common jollytail	Predation	Cadwallader & Eden (1982)
Gadopsidae <i>Gadopsis marmoratus</i> (Richardson)	River blackfish	Dietary overlap Predation	Jackson (1978) Fletcher (1979) Cadwallader (1979) Butcher (1945) Fletcher (1979) Cadwallader (1978, 1979)

Source: Crowl et al. 1992; Tilzey 1980

The role of brown trout in the decline of the ‘endangered’ Pedder Galaxias, *Galaxias pedderensis*, is more controversial. This decline has also been linked to interactions with the climbing Galaxias, *Galaxias brevipinnis*, a very widespread species in Tasmania (Fulton 1990) but not recorded from Lake Pedder prior to the flooding of the lake for an hydroelectricity scheme (Sanger & Fulton 1989). When the predacious climbing Galaxias became abundant in Lake Pedder, *G. pedderensis* declined (Sanger & Fulton 1989).

Apart from galaxiids, the brown trout is suspected of predation on juveniles of the ‘vulnerable’ Australian

grayling and juveniles of the ‘poorly known’ Macquarie perch, *Macquaria australasica* (Wager & Jackson 1993). Sea-run brown trout have been implicated in the decline of the estuarine fish, Derwent whitebait (*Lovettia sealii*).

Brown trout have been reported to alter the species composition and abundance of stream invertebrates (Fletcher 1979). Particular attention has been given to this theme in Tasmania but, in general, trout are believed to have had minimal impact on micro- and macro-invertebrates in high altitude streams (Sloane & French 1991).

The introduction and spread of trout have been linked to the absence of the primitive mountain shrimp, *Anaspides tasmaniae* and *A. spinulae*, in streams within the Western Lakes world heritage area, Tasmania (Horwitz 1990; O'Brien 1990). However, Sloane and French (1991) presented evidence that the distribution of *Anaspides* in runnels, ponds, soaks and small streams is essentially delineated by the distribution of galaxiid fishes, principally *G. brevipinnis*. Direct predation by the galaxiid on juveniles of *Anaspides* has been implicated. In plateau lakes, *Anaspides*, galaxiid fishes and trout coexist, and there is limited evidence that trout prey on the mountain shrimp (Sloane & French 1991). Fulton has suggested that trout reduce the abundance of galaxiids, thereby reducing predation pressure on *Anaspides* (W. Fulton, pers. comm. to Sloane & French 1991).

Populations of the brook trout, *Salvelinus fontinalis*, have been 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). Sloane (1991) suggested that the more specialised spawning requirements of the brook trout and domestication have probably limited its success in competition with other salmonids in Tasmanian waters. *S. fontinalis* is considered to have little environmental impact at current population densities in New South Wales (P. Gehrke, pers. comm.).

The Atlantic salmon (*Salmo salar*) has not yet become established in freshwater but is presently cultured in large numbers in sea cages in Tasmania (Kailola et al. 1993) and is also stocked in New South Wales. Escapes from these cages have resulted from the effects of weather and attacks by seals. It remains to be seen whether these escapees will form sea-run populations and return to the estuaries and their associated freshwaters for spawning.

The Chinook salmon, *Oncorhynchus tshawytscha*, has been reported to feed on indigenous galaxiids and pygmy perch (Cadwallader & Eden 1982).

3.1.2 Percidae

The European perch or redfin, *Perca fluviatilis*, was introduced into Tasmania in 1862 and into Victoria in

1868 as a sport and table fish (Table 1). Redfin were also released into rivers in the south-west of Western Australia in 1892 and again in the early 1900s (Coy 1979). Relatively large populations have been found in shallow reaches and tributaries of the Collie River and Murray River in south-western Australia (Hutchinson 1991; Pen & Potter 1992).

Redfin feed initially on small planktonic crustaceans, shifting to benthic invertebrates with increasing size, but all size classes of perch may injest juvenile fish (Craig 1978; Goldspink & Goodwin 1979; Pen & Potter 1992; Pen et al. 1993). Predation and competition for food resources and habitat are the mechanisms by which perch are reported to affect indigenous fishes in Australia (Table 6).

A survey of the Murray River, Western Australia, has shown the distribution of the once common western pygmy perch (*Edelia vittata*) to be fragmented, with little overlap between it and redfin (Hutchinson 1991). Predation by the redfin on *E. vittata* is considered to be the most likely cause (Hutchinson 1991). In contrast, Pen and Potter (1992) concluded that indigenous fish species have coexisted with the redfin in the Collie River since the early 1900s, in spite of 'appreciable predation and a relatively high abundance of *P. fluviatilis*'. They suggested that coexistence was facilitated in this instance by the abundance of invertebrate prey (a consequence of nutrient enrichment) and limited interspecific dietary overlap between redfin and three indigenous species. Furthermore, redfin in this river system usually do not enter tributary creeks where *E. vittata*, *Bostockia porosa* and *Galaxias occidentalis* breed, effectively preventing the perch from preying on their eggs and young larvae (Pen & Potter 1992).

The redfin is suspected of predation on the 'vulnerable' Ewen's pygmy perch, *Nannoperca variegata*, and the 'vulnerable' Yarra pygmy perch, *Edelia obscura*, the 'vulnerable' dwarf Galaxias, *Galaxias pusilla*, and juveniles of the 'poorly known' Macquarie perch, *Macquaria australasica* (Wager & Jackson 1993). Adverse interactions, in the form of food competition and possibly predation, by the redfin on the 'endangered' trout cod, *Maccullochella macquariensis*, are said to have contributed to the cod's decline (Wager & Jackson 1993).

Table 6: Probable interactions of redfin with Australian indigenous fishes

Family/Species	Common name	Interaction	Reference
Percichthyidae			
<i>Maccullochella peelii peelii</i> (Mitchell)	Murray cod	Competition for food and space	Lintermans et. al. (1990)
<i>Macquaria ambigua</i> (Richardson)	Golden perch	Competition for food and space	Lintermans et al. (1990)
<i>Maccullochella macquariensis</i> (Cuvier)	Trout cod	Competition for food and predation	Wager & Jackson (1993)
<i>Macquaria australasica</i> Cuvier	Macquarie perch	Predation	Wager & Jackson (1993)
Kuhliidae			
<i>Edelia obscura</i> Klunzinger	Yarra pygmy perch	Predation	Wager & Jackson (1993)
Nannopercidae			
<i>Nannoperca variegata</i> Kuitert and Allen	Ewen's pygmy perch	Predation	Wager & Jackson (1993)
<i>Edelia vittata</i> Castelnau	Western pygmy perch	Predation	Hutchinson (1991)
Galaxiidae			
<i>Galaxiella pusilla</i> (Mack)	Dwarf Galaxias	Predation	Wager & Jackson(1993)

In New South Wales, the redfin is regarded as a significant predator on indigenous fishes, and juveniles probably compete with small planktivorous fishes for food, but the perch's impact is perceived to be stable and the species has not been linked with large-scale ecological degradation (P. Gehrke, pers. comm.).

3.1.3 Cyprinidae

The family Cyprinidae is one of the largest fish families with a diversity of species in Europe, Africa, Asia and North America. There are no indigenous cyprinid fish of South America or Australia (McDowall & Shearer 1980) but four species have become established in Australian inland waters (Table 1).

Goldfish, *Carrassius auratus*

Information on the impacts of goldfish on Australian indigenous species is limited. Goldfish, carp and hybrids (Hume et al. 1983; Shearer & Mulley 1978) have been reported to have a diverse omnivorous diet (Hume et al. 1983; Merrick & Schmida 1984). Wager and Jackson (1993) suggest that a possible interaction

with goldfish has contributed to the decline of indigenous trout cod, *Maccullochella macquariensis*.

Goldfish populations with nuisance status will probably persist in all major waterways of Australia (Brumley 1991). Goldfish have no utility for food or sport and their widespread introduction is regarded as 'unfortunate' (Merrick & Schmida 1984).

European carp, *Cyprinus carpio*

Introductions of the European or common carp into Australia began last century and have involved three distinct stocks, the 'Prospect', 'Yanco' and 'Boolara' strains. Carp were present in Australia for a considerable time prior to their rapid increase in abundance and expansion of range from 1964 (Shearer & Mulley 1978). The rapid expansion of carp resulted from an illegal release near the River Murray of a cultured Victorian stock identified as the 'Boolara' strain (Shearer & Mulley 1978).

The European carp was declared a noxious fish in Victoria in 1962 in response to concerns about the environmental impacts which were being documented overseas (Brumley 1991; Roberts 1993). A special carp program was undertaken between

1979 and 1982 to investigate the environmental impacts of this species in Victoria (CNR 1991). No associations between carp densities and high turbidity or the decline of vegetation communities were found, although circumstantial evidence indicated that carp may have been responsible for the disappearance of the macrophyte *Potamogeton* at specific sites. Fletcher et al. (1985) concluded that fluctuating water levels were the most important factor governing variable turbidity and vegetation communities in many waterways.

Experimental research in New South Wales has found that carp adversely affect some aquatic plant species, particularly delicate submerged species, with the relative impact being determined by carp stocking density and food availability (Oswald 1993). Roberts (1993) concluded that carp feeding behaviour has the potential to reduce aquatic plant biodiversity at three life-cycle stages. Aquatic plants are absent from nearly all inland rivers and floodplain wetlands in south-western New South Wales and it is a

widespread public belief that the carp is to blame. Roberts (1993) concluded that the 1960s expansion of carp coincided ‘broadly and loosely speaking’ with the decline of aquatic plants at specific wetland sites.

Although there is limited direct evidence of habitat degradation due to carp (Fletcher et al. 1985; Morrison & Hume 1990; Brumley 1991), it is suspected that habitat modification caused by carp has contributed to the decline of the ‘endangered’ trout cod, *Maccullochella macquariensis*, the ‘vulnerable’ dwarf Galaxias, *Galaxias pusilla*, the ‘vulnerable’ Yarra pygmy perch, *Edelia obscura*, and the ‘vulnerable’ Ewen’s pygmy perch, *Nannoperca variegata* (Wager & Jackson 1993).

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

Table 7: Australian indigenous fishes with diets which are similar to or overlap with the diet of European carp

Family/Species	Common name	Reference
Clupeidae <i>Nematalosa erebi</i> (Günther)	Bony bream	Cadwallader (1978)
Plotosidae <i>Tandanus tandanus</i> Mitchell	Catfish	Cadwallader (1978)
Terapontidae <i>Bidyanus bidyanus</i> (Mitchell)	Silver perch	Cadwallader (1979)
Retropinidae <i>Retropinna semoni</i> (Weber)	Australian smelt	Fletcher (unpublished)
Eleotridinae <i>Hypseleotris klunzingeri</i> (Ogilby)	Western carp gudgeon	Fletcher (unpublished)
Galaxiidae <i>Galaxias rostratus</i> Klunzinger	Flathead Galaxias	Fletcher (unpublished)

Source: Fletcher 1986

Overlap in spawning site requirements between carp and indigenous fish species is another potential impact of carp. While no competition for sites has been reported, competition amongst fry for limited food resources may occur (Fletcher 1986). Table 7 lists Australian fish species with diets similar to or overlapping with the carp's diet.

Some authorities suggest that carp probably contribute to cyanobacterial outbreaks by excreting nutrients, re-suspending sediments and damaging macrophytes (P. Gehrke, pers. comm.).

Tench, *Tinca tinca*, and roach, *Rutilus rutilus*

These fishes were introduced late last century (see Table 1) and are little known and seldom fished for in Australia (McDowall & Shearer 1980). There is relatively little information on the impacts of tench and roach on Australian indigenous fishes and aquatic systems.

Tench are carnivorous fish which feed on aquatic insects and crustacea, and their feeding habits are thought to cause muddying of waters (Merrick & Schmida 1984). In Victoria, this species 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.).

Roach are omnivorous and in Australia are mostly benthic feeders (Merrick & Schmida 1984). As with tench, these fish are not well known, probably because of their restricted range (McDowall & Shearer 1980), although they may be locally abundant (Fletcher 1986). The high abundance of roach in the rivers of Port Phillip Bay suggests that considerable effects on indigenous biota are probable (P.S. Lake, pers. comm.).

3.1.4 Poeciliidae

Eastern Gambusia or mosquitofish, *Gambusia holbrooki*

Worldwide, some 35 fish species are reported to have been reduced in abundance or range due to adverse interactions with species of *Gambusia* (Lloyd 1990a). These interactions include resource competition for food and habitat, interference competition (involving aggressive behaviours and fin-nipping) and predation on the eggs and young juveniles of indigenous fish species (Meffe et al. 1983; Meffe 1985; Lloyd 1990a).

The opportunistic foraging behaviour (Arthington 1989) and wide environmental tolerances of the mosquitofish have enhanced its capacity to survive and become established in a wide variety of inland waters, and *G. holbrooki* is now widespread in suitable inland waters throughout Australia (Arthington & Lloyd 1989; Allen 1989).

G. holbrooki 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 & Jackson 1993). The mosquitofish is implicated in the low abundances of the 'vulnerable' honey blue-eye, *Pseudomugil mellis*, the 'endangered' red-finned blue-eye, *Scaturiginichthys vermeili-pinnis*, the 'vulnerable' Oxleyan pygmy perch, *Nannoperca oxleyana*, and the 'endangered' purple spotted gudgeon, *Mogurnda adspersa* (Murray-Darling stock) (Wager & Jackson 1993). Whilst there is no direct evidence of impacts on the honey blue-eye and Oxleyan pygmy perch (Arthington & Marshall 1993; Arthington 1996), moderate levels of dietary overlap suggest that competition for limited food resources could be significant in streams and lakes of very low productivity (Arthington & Marshall 1993, Arthington 1996).

Although much of the evidence is circumstantial, predation and competition for food have implicated the mosquitofish in the decline of other indigenous species in eastern Australia (species of *Ambassis*, *Melanotaenia*, *Pseudomugil*, *Craterocephalus* and *Retropinna*) (Arthington et al. 1983; Lloyd 1990a).

The mosquitofish is widespread and abundant in the Canning and North Dandalup catchments, Western Australia, dominating the fish fauna in lowland areas (Pusey et al. 1989). In these rivers, natural winter spates regularly reduce the population density of the mosquitofish to low levels, facilitating the coexistence of this exotic species and small indigenous species with similar habitat and dietary requirements (*Edelia vittata*, *Bostockia porosa* and *Galaxias occidentalis*). However, regulation of the Canning River by the Canning reservoir, which rarely overflows, has resulted in wide, deep and slow-flowing lower reaches, especially in summer, creating habitat conditions especially suited to the mosquitofish. The maintenance of winter spates in the

Canning River appears to be necessary to restore/maintain natural habitat characteristics in its lower reaches and thence to reduce the suitability of the system for proliferation of the mosquitofish (B. Pusey, pers. comm.). Similar considerations probably apply to *Phalloceros caudimaculatus*.

G. holbrooki also coexists in relatively high densities with *E. vittata*, *B. porosa* and *G. occidentalis* in the Collie River, south-western Australia. Pen et al. (1993) showed that the three indigenous species breed earlier than *Gambusia*, achieving relatively large body sizes by the time this exotic species has produced its live young. The threat of predation would be much reduced in these circumstances. However, in sub-tropical streams, Milton and Arthington (1983) found that *G. holbrooki* began to breed earlier in spring than several small indigenous species, and concluded that this could expose eggs and small juveniles to significant predation from young *Gambusia*.

The mosquitofish has been shown to have significant predatory effects on invertebrate species apart from mosquitoes (Hurlbert & Mulla 1981; Lloyd 1990b). These effects can lead to changes in zooplankton and phytoplankton abundance, often with unpredictable impacts on populations of larval mosquitoes (Lloyd 1990b). Such effects may cascade through an aquatic ecosystem but trophic cascades due to exotic species are only now beginning to be explored in Australian waters.

Other Poeciliidae

Five other poeciliid species have become established in Australian inland waters (Table 1), the one-spot live bearer, *Phalloceros caudimaculatus*, the sailfin molly, *Poecilia latipinna*, the guppy, *Poecilia reticulata*, the swordtail, *Xiphophorus helleri*, and the platy, *Xiphophorus maculatus*.

These are sub-tropical and tropical fishes with similar life history to *G. holbrooki*. They have not been spread as widely as the mosquitofish, with most being confined to disturbed urban waterways. The guppy is the exception to this, with populations established in many coastal creeks near urban centres between Brisbane and Townsville, Queensland (McKay 1978; Arthington 1991). Associations of two poeciliid species, particularly the mosquitofish and the swordtail or guppy, appear to depress populations of

indigenous fishes, possibly via resource competition (Arthington et al. 1983). The guppy and mosquitofish have very similar foraging strategies and diet composition in Brisbane streams (Arthington et al. 1983; Arthington 1989).

As aquarium fishes, it is likely that poeciliids will continue to be placed into urban waterways and they are also known to be moved from one creek to another by children. While these Poeciliidae have not shown the same capacity for unassisted range expansion as other exotics, many populations have persisted for a number of years and the potential for proliferation (especially with human assistance) and environmental impacts should not be ignored.

3.1.5 Cichlidae

Tilapia or Mozambique mouth-brooder, *Oreochromis mossambicus*

In parts of tropical Asia, *O. mossambicus* contributes significant proportions of the animal protein available to communities. 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 social acceptance, or its propensity to overpopulate eutrophic waterbodies with stunted individuals (Blühdorn & Arthington 1992).

In Australia, the Mozambique mouth-brooder has only been studied in detail in the disturbed habitat of a water supply reservoir (Blühdorn & Arthington 1990a, b) and no direct evidence of adverse environmental impact has been found (Arthington & Blühdorn 1994a, b). Other studies of distribution and abundance have reported the incidence of stunting in both disturbed and relatively pristine habitats (Blühdorn & Arthington 1990a, b; Arthington & Blühdorn 1994a). The potential for competition with indigenous species for breeding territories has been noted but remains unstudied (Arthington & Blühdorn 1994a). Further surveys and studies are in progress in north Queensland (N. Milward, pers. comm.).

The Mozambique mouth-brooder is considered to have the potential to devastate remaining indigenous fish populations if it moves down the Darling River system (P. Gehrke, pers. comm.) and is regarded as a serious threat currently facing the Murray–Darling River system (B. Lawrence, pers. comm.).

**Black mangrove or Niger cichlid,
*Tilapia mariae***

In Victoria, the Niger cichlid is confined to the heated waters of the Hazelwood Power Station cooling ponds near Morwell (Allen 1989). It is very localised and probably does not affect local biota because of its restriction to thermally disturbed habitats (P. Cadwallader, pers. comm.). Established populations have also been recorded in the Barron River and several estuaries in the Cairns area, north Queensland (Blühdorn et al. 1990).

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 & Hensley 1979). Given the climatic similarity of Southern Florida and Queensland, further spread of the Niger cichlid in disturbed habitats might be expected. Consequently, this species is classified as noxious in Queensland under the *Fisheries Act* 1974. As yet, no studies have been conducted in Australia on its environmental effects, although surveys are in progress in north Queensland (N. Milward, pers. comm.).

Convict cichlid, *Cichlasoma nigrofasciatum*

The convict cichlid is confined to the heated waters of the Hazelwood Power Station cooling ponds near Morwell, Victoria (Allen 1989). It 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.).

3.1.6 Cobitidae

Cobitids are popular aquarium fish that comprised approximately 1% of all aquarium fish imported to Australia during 1978–80 (McKay 1978). *Misgurnus anguillicaudatus*, the oriental weatherloach, is a valued aquarium fish with an indigenous Eurasian distribution (Allen 1984). It was first reported to be established in the wild in Australia in 1984 by Allen (1984), who noted that due to its relatively high fecundity, hardiness and mobility there is a high risk of self-sustaining populations occurring.

Evidence that the weatherloach breeds in the wild originated from specimens collected from streams in the Australian Capital Territory (Allen 1984).

Weatherloach was probably introduced into these waterways following the release of unwanted aquarium fish (Lintermans et al. 1990).

The impact of weatherloach on indigenous species is not known although Lintermans et al. (1990) suggested that competitive interactions with indigenous species are possible. In Halls Creek, Australian Capital Territory, the indigenous mountain Galaxias, *Galaxias olidus*, is only found from 150 metres upstream of the range of the weatherloach; the factors responsible for this distribution pattern have not been determined (Lintermans et al. 1990).

In Tasmania, there is concern about the potential negative impact of *M. anguillicaudatus* on indigenous fauna, and the high costs of management (W. Fulton, pers. comm.). The weatherloach was banned from importation into Australia in 1986 because of its feral habits (Burchmore et al. 1990).

3.1.7 Gobiidae

The yellowfin goby, *Acanthogobius flavimanus*, was evidently introduced accidentally in ship ballast or contaminated oyster shipments. It 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.). The yellowfin goby is uncommon and little is known of its local biology or interactions with other species (P. Gehrke, pers. comm.).

**3.2 Descriptions and indicators
(direct or primary) of impacts
of exotic invertebrates
introduced into Australian
inland waters**

The biological and ecological impacts of exotic aquatic invertebrates have received little attention and are very poorly understood in Australia (Arthington & Blühdorn 1995).

McKay (1977) reported that at least six species of aquatic snails were introduced into Western Australian waters through the aquarium trade. The snail *Lymnaea columella*, a vector of mammalian liver fluke, was probably introduced into Australia on aquarium plants. Other species of aquatic snails entered Australia in the same manner (McKay 1977).

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 (McKay 1978). In New Zealand, 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 (Ponder 1975).

The New Zealand hydrobiid snail, *Potamopyrgus antipodarum*, introduced to Australia in about 1870, has 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).

Geddes and Williams (1987) discussed the potential for the exotic brine shrimp, *Artemia salina*, to interact with indigenous species and strains of *Artemia* in non-marine saline waterbodies. In Australia, there is particular concern because salt lakes support a large number of endemic species of *Parartemia*, and this is the only continent where a distinctly different halobiont anostracan has evolved. *Parartemia* comprises several morphologically distinct species with localised distributions.

Artemia has been found in several small and isolated sites (a salt lake south of Perth, a samphire swamp at Port Adelaide and from a saline pool in Coopers Creek, central Australia (Geddes & Williams 1987), and is considered to have the potential to establish in natural salt lakes. It is known that two forms of *Artemia* occur in Australia, increasing the probability that strains with different environmental preferences could become established successfully in different areas of the continent.

Effects on other aquatic fauna adapted to saline waters are also of concern in Australia and elsewhere. Useful aquatic organisms inhabit saline lakes; for example *Dunaliella* is a source of glycerol and beta-carotene, and *Spirulina* is a source of protein (Geddes & Williams 1987). The protection of salt lakes and their distinctive biota, including indigenous *Artemia* populations, has become a significant conservation issue worldwide.

3.3 Direct impacts of the translocation of fauna in Australian inland waters

3.3.1 Freshwater fishes

Translocations of indigenous fish species have been undertaken to enhance recreational fisheries, for stocking of private dams and for aquaculture purposes, and to a small extent to meet conservation objectives (Wager 1994). Environmental impacts are potentially the same as those occurring when exotic species become established in the wild and the same indicators of impact are applicable.

There is relatively little information on the direct ecological impacts of translocated indigenous fishes within Australia although most fisheries agencies express concern about the issue and either have a policy on translocation or are developing policies and practices. Monitoring of ecological impacts is virtually non-existent or at best ad hoc, but specific research projects have produced evidence of impacts.

The disappearance of the Lake Eacham rainbowfish (*Melanotaenia eachamensis* Allen and Cross) from Lake Eacham on the Atherton Tableland, following the introduction of indigenous fishes, has been cited as an example of the impact of translocations (Barlow et al. 1987). The indigenous fishes introduced were the mouth almighty, *Glossamia aprion* (Richardson), the archer fish, *Toxotes chatareus* (Hamilton), the bony bream, *Nematalosa erebi* (Günther) and the banded grunter, *Amniataba percoides* (Günther). Barlow et al. (1987) presented circumstantial evidence that the presumed extinction of the Lake Eacham rainbowfish may have been due largely to predation by the carnivorous mouth almighty and possibly also the archer fish. Two other indigenous fish species and a crayfish also declined in the lake after the translocations.

In 1993, Wager (1993) and Wager and Jackson (1993) classified the Lake Eacham rainbowfish as extinct in the wild, the only indigenous fish species placed in this category. However, Moritz et al. (1995) demonstrated the presence of wild populations in a few tributaries of the upper Johnstone River and the upper Barron River, north Queensland, using the technique of DNA sequencing. Recently, Pusey et al. (1997) showed that *M. eachamensis* is widespread in the upper and lower reaches of the North and South Johnstone rivers and is also present in Nitchaga Creek

and the Tully River upstream of Koombaloo Dam.

The potential environmental impacts resulting from fish that escape from aquaculture facilities have been outlined in Section 2. Hybridisation may be a serious threat posed by translocated species stocked in the wild and by escaped aquaculture species, since interbreeding of closely related species often produces viable offspring. Welcomme (1988) reported that the stresses associated with introduction may lead to a breakdown in normal behaviour and the formation of hybrids between species and even genera which do not normally hybridise when they coexist in the wild.

Weston (1991) and Beveridge and Phillips (1993) noted that there have been very few studies of the ensuing genetic interactions between escaped aquaculture or farmed fish species and wild stocks. Assessment of the potential risk of adverse genetic effects has been attempted for salmonids, especially the Atlantic salmon, but the effects on this well-studied species are not fully understood (Hindar et al. 1991, Munday et al. 1992a). Meffe (1986) suggested that combinations of genes that are coadapted within a population may be broken up by hybridisation to form gene associations that reduce overall fitness.

Keenan and Salini (1990) observed that the determination and protection of the genetic differentiation of fish stocks is a relatively new consideration in Australia. They expressed concern that the genetically distinct stocks of species from disparate drainage systems, such as silver barramundi (*Lates calcarifer* Bloch.), cod and Anguillidae, may interbreed as a result of stocking programs, as well as escapes from aquaculture (Keenan & Salini 1990). Salini and Shaklee (1988) identified seven strains of genetically distinct stocks of barramundi from northern Australia; one of these was from Western Australia. In an important species such as barramundi, the mixing of distinct strains due to aquaculture, recreational fisheries enhancement or restocking could reduce naturally occurring genetic diversity essential for any future selection program (Lawrence 1993).

Infertile exotic or translocated species may be used to prevent hybridisation or the establishment of feral populations. The induction of triploidy has been used to produce infertile aquatic species, with direct

benefits to the farmer due to the increased growth rates after the usual age at maturity of diploid individuals (Lawrence 1993).

3.3.2 Freshwater Crustacea

Exotic and translocated decapod crustaceans have caused water quality deterioration, habitat alterations and the displacement of indigenous freshwater species in the USA, Europe and Japan (Welcomme 1988). For example, the Louisiana red crayfish *Procambarus clarkii* (Girard), indigenous to the United States, is regarded as a pest in many areas where it has been introduced because of its burrowing behaviour. The underground galleries it creates may cause extensive damage to earthen irrigation structures and the banks of aquaculture ponds (Welcomme 1988).

Three indigenous Australian decapod crustaceans of the family Parastacidae have been translocated for aquaculture purposes: the yabby, *Cherax destructor*; the redclaw, *C. quadricarinatus*; and the marron *C. tenuimanus* (Kailola et al. 1993).

Horwitz (1990, 1991) reviewed the problems that may arise when indigenous Australian decapod crustaceans are translocated within and between States but at that time could provide no evidence of the impacts reported in other countries. Nevertheless, the Tasmanian Inland Fisheries Commission has opposed the translocation of the yabby, *C. destructor*, into that State because of its potential to damage irrigation channels and dam walls by burrowing and to cause the deterioration of water quality in farm dams. Other concerns are the risk of competition with indigenous crayfish and of disease transmission (Kailola et al. 1993). In Tasmania, the yabby is a declared noxious species and eradications of populations have been undertaken.

The yabby has been introduced into inland waters in Western Australia and the George Gill Range in the Northern Territory (Horwitz 1995a). In Western Australia, *C. destructor* is regarded as a good example of a crustacean species introduced originally to confined locations (farm dams) which has subsequently become established and widely spread. First introduced in 1932, the yabby is now found throughout the south-west of Western Australia (Lawrence 1993), even in the aquatic habitat of a cave community north of Perth (Jasinska et al. 1993).

Horwitz (1995b) reported that the introduction and establishment of crayfish populations may be

threatening the indigenous fauna of cave communities in Western Australia, and that the distinctive fauna of mound springs in central Australia could be vulnerable to translocated crayfish species.

In the Northern Territory, yabby burrows have spread extensively up the banks of billabongs, destabilising the banks and causing the collapse of riparian trees (J. Davis, pers. comm. to Horwitz 1995a). On Kangaroo Island off the coast of South Australia, indigenous species of shrimps are rarely found where translocated yabbies have become well established (P. Suter, pers. comm. 1995).

The marron, *C. tenuimanus*, has a natural range confined to the extreme south-west of Western Australia (Morrissy 1978) where it occurs in permanent waters (Horwitz 1994). This species has been translocated for aquaculture purposes to other rivers and farm dams in Western Australia, as well as southern Queensland, northern New South Wales and South Australia (Kailola et al. 1993), and to other continents (Horwitz 1994).

Lawrence (1993) suggested that the translocation of the marron within its native range in Western Australia would be unlikely to have any ecological impact or risk of disease transmission, but noted the implications of interbreeding between genetically distinct forms. Austin (1986) distinguished two subspecies of marron. One is endemic to the Margaret River system, whereas the second form appears to be the one that has been translocated widely within the State (Horwitz 1994).

In 1990, Horwitz warned that if within-State translocations continued unabated then the two forms would interbreed and significant morphological and genetic variation would be 'lost or made unavailable' by hybridisation (Horwitz 1990). Within five years, Horwitz (1994) reported 'circumstantial evidence' that interbreeding between the two forms is already occurring in the Margaret River. Lawrence (1993) recommended the preservation of this genetic material for use in the future development of marron aquaculture in Western Australia.

Minor translocations of Crustacea have been undertaken for research and conservation purposes (Horwitz 1991).

3.3.3 Gastropoda

Information on translocated indigenous 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.).

3.4 Diseases and pathogens associated with introduced and displaced aquatic fauna

3.4.1 Pathogens of freshwater fishes

Fish are known to host a wide variety of pathogenic or potentially pathogenic transmissible agents including viruses, bacteria, fungi, algae, protozoans, helminths and crustaceans as well as a range of commensal and epiphytic organisms (Humphrey 1995).

Australia is free of many of the diseases found in finfish and waters in other countries (Kailola et al. 1993) and the disease status of Australian fish is regarded as one of the best in the world (Langdon 1988). This freedom from diseases and parasites confers major advantages for domestic production and exports of finfish and is regarded as a national asset worthy of protection (Nunn 1995).

The greatest risks of disease are posed by the introduction and translocation of living aquatic animals (Langdon 1990). Importation of live fish and eggs involves the risk of importation of pathogens specific to the species imported and pathogens which may also affect other exotic species as well as indigenous fauna (Langdon 1988). The establishment of populations of exotic species also provides a host pool for replication of group or species-specific pathogens that could be introduced through occasionally discarded aquarium fish (Langdon 1988).

Pathogens of aquatic animals are generally group-specific (capable of infecting a specific host family, genus or species) or polyxenous, that is, they may infect many different hosts (Langdon 1990). Truly group-specific pathogens exist (Humphrey 1995) but examples of species-specific infectious agents which are more pathogenic, or only cause clinical disease, in atypical hosts have been reported (Langdon 1990). These may 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 plague fungus, *Aphanomyces astaci*, which is only mildly pathogenic to the host crayfish but has had a devastating impact on indigenous European astacids. Asiatic and Australasian species of freshwater crayfish also appear to have little or no resistance to infection with this fungus (Unestam 1975).

De Kinkelin and Hedrick (1991) consider that ornamental finfish are particularly likely to be sources of exotic pathogens because of their diverse origin, often from wild sources with no disease history, their mixing with other species, and the stresses experienced during transportation.

There is great potential to introduce exotic diseases of fish with the large numbers of ornamental fish imported into Australia (McKay 1984; Langdon 1988; Humphrey 1989). Exclusion of ornamental fish on the basis of disease risks has not occurred in Australia, which is unfortunate as pathogens are known to have been imported in this way and there are

numerous overseas reports of the importation of diseases via ornamental fish (McKay 1984; Fletcher 1986; Langdon 1988).

The ability of fish to harbour latent viral, bacterial and parasitic infections is of concern (Humphrey 1989). Procedures are available to identify asymptomatic carriers which would bring fish importation in line with importation of other animals (Humphrey 1989).

Table 8 shows some diseases and pathogens which are associated with species of exotic fish established in Australia. Fishes included in this table also suffer from other diseases and host various pathogens in Australia, but these diseases are not exclusively associated with exotic fishes. Langdon (1988) provided a comprehensive list of diseases which occur in Australian and exotic fishes and gave details of disease outbreaks in Australia. Diseases which are known to occur overseas, or have been detected in quarantine or found in exotic fish kept by Australian aquarists are given in Table 9. Two particular examples of pathogens introduced to Australia via exotic fishes, and spread by them, are discussed below.

Table 8: Some diseases and introduced pathogens associated with exotic fishes in Australia

Pathogen	Distribution	Host spp.	Native fish affected	Exotic fish affected
Epizootic haematopoietic necrosis virus	NSW, Vic. NSW (Australia only)	Redfin Rainbow trout	Murray cod Mountain <i>Galaxias</i>	Atlantic salmon Mosquitofish Redfin Rainbow trout
<i>Triangula percae</i>	Vic. (Australia only)	Redfin	None	Redfin
<i>Sphaerospora</i> spp.* <i>Mitraspora</i> spp.	Vic., WA, Tas., NSW (overseas)	Cyprinids	(?)	? Salmonids (? proliferative kidney disease) ? Tench ? Roach
<i>Aeromonas salmonidica</i> (Australian strain)	Vic., NSW	Goldfish Roach	(?)	Salmonids Carp Goldfish
Infectious haematopoietic necrosis virus ⁺	Vic. (overseas)	Chinook salmon	(?)	Salmonids
<i>Ichthyophthirius multifiliis</i> *	All states (overseas)	most spp.	Most freshwater fish susceptible	
<i>Costia necatrix</i> *	Tas., Vic., NSW (overseas)	mainly Salmonids, Goldfish	(?)	Salmonids and others

Source: Langdon 1988

* introduced
+ eradicated

Table 9: Major diseases known to occur in exotic fishes allowed into Australia for aquarium purposes

Fish	Pathogen/Disease	Origin
<i>Apistogramma ramirezi</i> Dwarf cichlid	Dwarf cichlid iridovirus	South America
<i>Betta splendens</i> Fighting fish	Thelohania	South East Asia
<i>Brachydanio rerio</i> Zebra danio	Infectious pancreatic necrosis virus	United Kingdom
<i>Labeo bicolor</i> Redtail "shark"	Epizootic ulcerative syndrome	South East Asia
<i>Paracheirodon innesi</i> Neon tetra	<i>Plistophora hyphessobryconis</i>	Asia
<i>Poecilia sphaerops</i> Black molly, and other poeciliids	<i>Camallanus cotti</i> *	Asia
<i>Pterophyllum</i> spp. Angel fishes	<i>Cryptosporidium</i> sp. *,** Herpes virus	Asia Amazon
<i>Puntius conchonius</i> Rosy barb	<i>Edwardsiella ictaluri</i> ** Rosy barb birna? virus**	Asia
<i>Toxotes jaculator</i> Archer fish	Epizootic ulcerative syndrome	Indo-Pacific
<i>Trichogaster trichopterus</i> Blue gourami	Epizootic ulcerative syndrome	Asia
<i>Trichogaster vittatus</i> Croaking gourami	Epizootic ulcerative syndrome	Asia
<i>Symphysodon discus</i> Discus fish	Infectious pancreatic necrosis virus	United Kingdom

Source: Fletcher 1986

* Known to occur in Australian aquarium fishes.

** Detected in quarantine.

In Australia, redfin perch host and suffer from pathogens and diseases, and may have facilitated their introduction and/or spread in Australian inland waters (Langdon 1988, 1989). The perch carries the epizootic haematopoietic necrosis (EHN) virus, which has been shown to be highly pathogenic to silver perch, *Bidyanus bidyanus*, mountain Galaxias, Macquarie perch and Murray cod (Langdon & Humphrey 1987; Langdon 1990). Other indigenous fish are likely to be susceptible (Wager & Jackson 1993). In the Australian Capital Territory, mass mortality of juvenile perch has been attributed to EHN virus, and it is considered likely that this disease has been responsible for major declines in populations of Macquarie perch in this region (Lintermans 1991). A chronic form of EHN virus with a lower mortality also occurs in farmed rainbow trout (Langdon & Humphrey 1987).

Aeromonas salmonicida, the bacterium responsible for goldfish ulcer disease, was introduced into Victoria in 1974 when infected *C. auratus* were imported from Japan (Langdon 1990). This disease became widespread in wild, farmed and aquarium goldfish in Australia (Langdon 1988, 1990) and also became established in some indigenous species, such as silver perch, *Bidyanus bidyanus* (Humphrey & Ashburner 1993). Goldfish ulcer disease is highly pathogenic to salmonids and the importation of goldfish into Tasmania has been prohibited to protect valuable salmon fisheries (Kailola et al. 1993). The incidence of goldfish ulcer disease is also considered a problem for salmonid fisheries in other States (P. Gehrke, pers. comm.). More recently, the same disease agent has been identified in wild populations of Koi carp and roach (Humphrey & Ashburner 1993). In 1993, strains of this disease have been

isolated from marine flounder from Tasmania (Humphrey 1995). Goldfish carry other potentially lethal diseases which have not, as yet, been introduced into Australia (Fletcher 1986; Humphrey 1989).

Langdon (1990) and McKay (pers. comm.) consider that the movement of infected indigenous fishes from one drainage system to another, and interstate, is potentially a much more serious issue than the spread of pathogens via exotic fishes.

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), illustrate this concern. BPLV has been unequivocally diagnosed from barramundi in Australia (Glazebrook et al. 1990; Munday et al. 1992b), 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 (J. Glazebrook, pers. comm. 1995).

Rowland and Ingram (1991) have 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, Queensland Museum) has for some years compiled a list of the parasites associated with indigenous and exotic fish species maintained in culture facilities throughout Australia. This list is not up to date and is not available at this time (R. McKay, pers. comm., 1995).

In 1992, the Australian Quarantine and Inspection Service (AQIS) commissioned the Bureau of Resource Sciences (BRS) to conduct a major review of aquatic animal health and quarantine as a basis of reviewing its quarantine policies and procedures for aquatic animals and their products (Nunn 1995). Reports arising from the review were released in October 1995 (Humphrey 1995; Nunn 1995). The BRS review gives detailed lists of diseases, pathogens and parasites of fish (as well as shellfish and Crustacea), updating those of earlier workers cited above. Humphrey (1995) states that more than 1700 transmissible agents have been reported from Australian aquatic animals.

3.4.2 Pathogens of freshwater invertebrates

Freshwater Crustacea harbour a variety of symbiotic and parasitic organisms, including viruses, bacteria, fungi, protozoans and invertebrates. However, like finfish, Australian crustaceans, molluscs and other aquatic invertebrates are relatively free of the major infectious diseases found elsewhere (Nunn 1995).

Brine shrimp, *Artemia*, have the potential to carry a range of viral, bacterial, fungal, protozoan and metazoan agents (e.g. Cestoda) of pathogenic or potentially pathogenic significance for finfish, shellfish and other species. These agents have been found in association with the eggs, nauplii, juveniles and mature individuals of *Artemia* (Humphrey 1995). Sorgeloos et al. (1977) described bacteria, plant and animal species on the external surfaces of cyst shells and the occurrence of serious infections in cultured fish and crustacea after addition of shrimp nauplii, cysts and shells.

The crowded conditions required for successful aquaculture greatly increase the potential for disease

outbreaks, 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' caused by the fungus *Aphanomyces astaci*, which was responsible for the collapse of indigenous European crayfish populations and the industries which depended on them. This fungus is reported to be capable of infecting the red claw, *Cherax quadricarinatus* (Lee & Wickins 1992).

Thompson (1990) illustrated the spread of the crayfish plague throughout Europe and discussed the pathology of the fungus and the ecological consequences of the loss of endemic crayfish species as a result of the plague. He cites the introduction of the plague vector animal, the North American signal crayfish, *Pacifastacus leniusculus* Dana, 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, *A. astacus*, allowed macrophytes such as *Chara* spp. and *Elodea canadensis* Rich., to proliferate, resulting in the elimination of game fish habitat (Thompson 1990).

Other important fungi known to infect Australian species include forms likely to affect eggs or larvae of hatchery reared freshwater crayfish, such as *Saprolegnia* sp., *Fusarium* sp. and other oomycetes (Horwitz 1991).

Microsporidian Protozoa *Thelohania* sp. and *Vavraia parastacida* cause microsporidiosis in species of *Cherax* (Langdon 1991).

3.5 Descriptions and indicators (indirect or secondary) of impacts of introduced fauna on Australia's inland waters

3.5.1 Distribution and abundance of exotic fish species

Salmonidae

The distributions of brown trout, rainbow trout and Atlantic salmon in Australia are shown in Figure 3. Salmonid fishes were initially introduced into south-eastern Australia, which has waters with suitable temperature regimes. Later introductions into

other Australian waters were less successful; for instance, trout have only a limited distribution in South Australia and Western Australia. Attempts to establish trout in north Queensland failed.

The Atlantic salmon (*Salmo salar* L.), first introduced to Australia as fertilised eggs, is presently cultured in large numbers in sea cages in Tasmania (Kailola et al. 1993) and is stocked in New South Wales but there are no known self-maintaining populations there or in Tasmania. The Chinook (Quinnat) salmon (*Oncorhynchus tshawytscha* Walbaum), first introduced in 1877, is maintained in Australian waters by stocking (Allen 1989; MacKinnon 1987; McKay 1989; Kailola et al. 1993).

Self-maintaining populations of rainbow trout exist in the higher altitude waters of New South Wales, the Australian Capital Territory and Victoria, including the headwaters of the Murray–Darling River system, and Tasmania (Kailola et al. 1993). Stocked populations are maintained in the warmer waters of New South Wales, Victoria, Tasmania, South Australia (Adelaide region), and Western Australia (south of Perth).

Populations in Western Australia are largely maintained by stocking as there is an absence of suitable natural spawning sites. Morrissy (1973) found that Western Australian strains of rainbow trout had a higher temperature tolerance compared with trout from south-eastern Australia.

There are isolated populations of sea run rainbow trout in Tasmania and Victoria (Kailola et al. 1993). Although known to interact adversely with some indigenous species, rainbow trout 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.

Brown trout are established in high altitude waters of New South Wales, the Australian Capital Territory, and Victoria, including the headwaters of the Murray–Darling, and Tasmania. There is at least one established population in Queensland. Stocked populations are maintained in the warmer waters of NSW, 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). In New South Wales, brown trout interact with indigenous species, but their distribution appears to have stabilised (P. Gehrke, pers. comm.), suggesting that further adverse impact is unlikely.

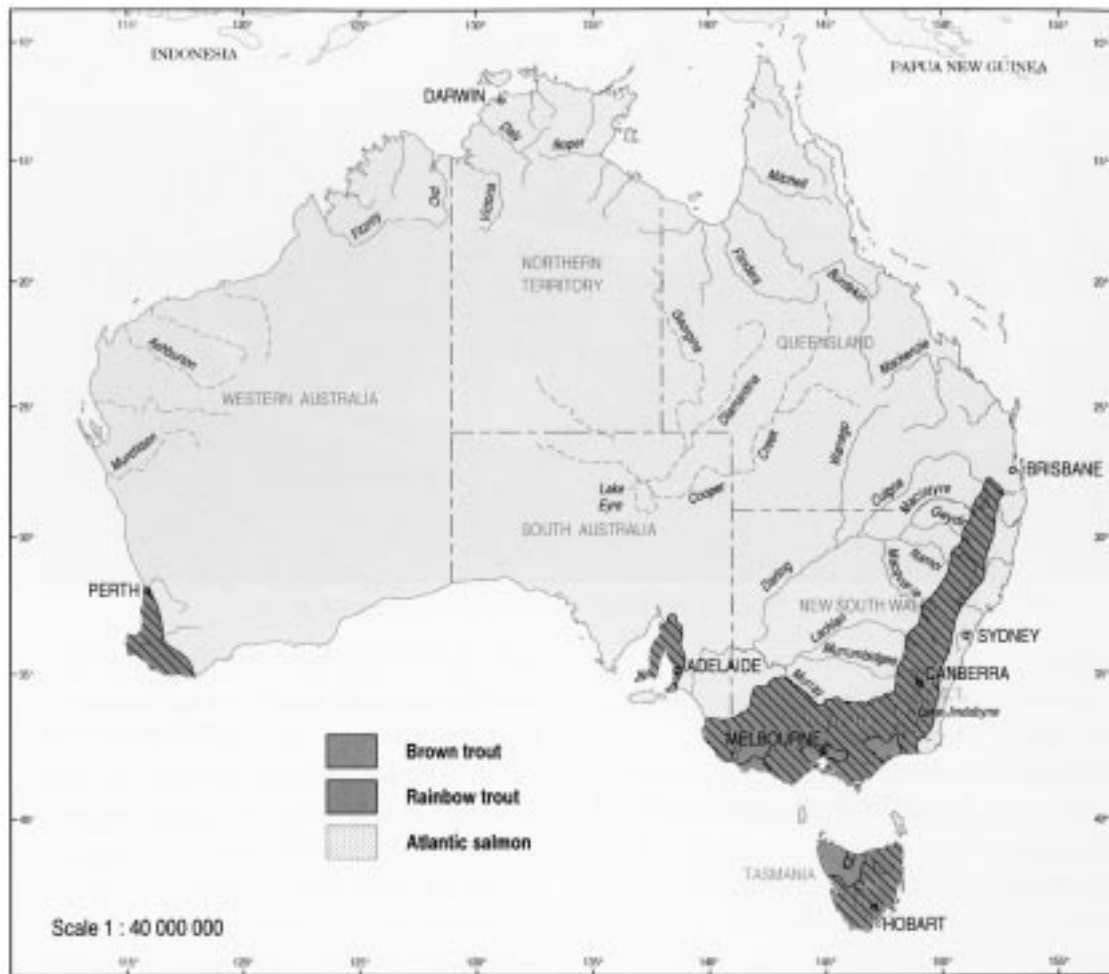


Figure 3: Geographic distribution of brown trout, rainbow trout and Atlantic salmon in Australian waters

Source: Kailola *et al.* 1993

Brook trout populations are recorded in mountain streams of New South Wales and Tasmania (Allen 1989), but the only self-maintaining population is in Clarence Lagoon, Tasmania. Other populations are maintained by stocking (Sloane 1991; Kailola *et al.* 1993). Chinook salmon populations are maintained in two lakes in Victoria by stocking (Allen 1989; MacKinnon 1987; McKay 1989; Kailola *et al.* 1993).

Percidae

The redfin, *Perca fluviatilis*, is widespread but patchily distributed throughout New South Wales, Victoria, South Australia, Tasmania and the south-west corner of Western Australia (McDowall 1980; Merrick & Schmida 1984; Hutchinson 1991). Lintermans *et al.* (1990) give details of their

introduction into the Australian Capital Territory. Although very abundant in the Collie River, Western Australia, the redfin has not had detrimental effects on indigenous fishes (Penn & Potter 1992). It has been conceded that Redfin could represent a threat to rare indigenous fishes in waters of low natural productivity (Penn & Potter 1992).

Cyprinidae

The goldfish, *Carassius auratus*, is said to be one of the most widespread of the exotic fish species introduced into Australia and appears in most permanent freshwater systems the southern half of Australia (Allen 1989; Brumley 1991), extending from the Fitzroy River in Queensland to the south-west of Western Australia (Kailola *et al.* 1993).

Figure 4 shows the distribution of goldfish in Australia. Goldfish are reported to be in greatest abundance in the Murray–Darling basin (Brumley 1991), and both goldfish and European carp have been found to be more abundant than any indigenous species in some Victorian waters (Brumley et al. 1987, cited in Brumley 1991).

The European carp, *Cyprinus carpio*, is reported 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 NSW (P. Gehrke, pers. comm.), Victoria and South Australia, and Lake Frome in South Australia (Kailola et al. 1993). Figure 5 shows the distribution of carp in Australia prior to the discovery of carp in two Tasmanian lakes in 1995.

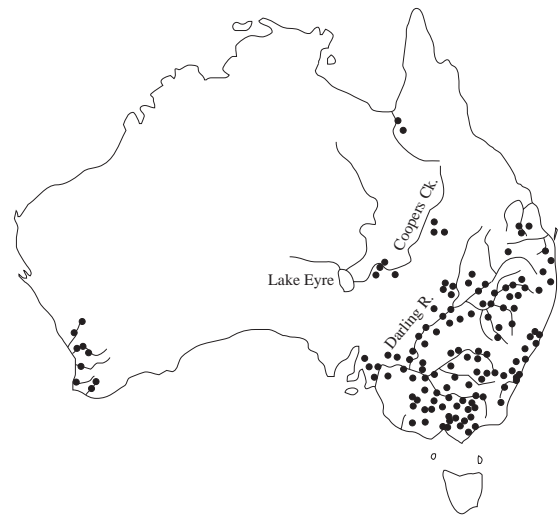


Figure 4: Distribution of goldfish in Australian waters

Source: Brumley 1991

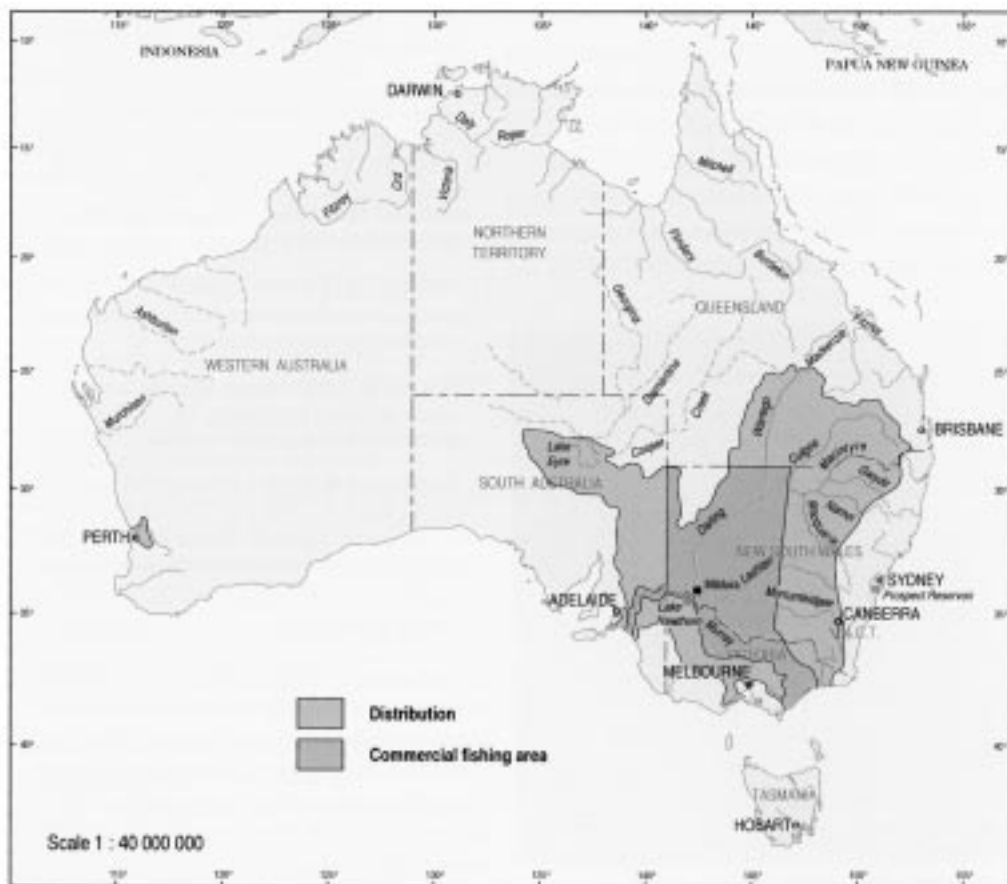


Figure 5: Geographic distribution and commercial fishing areas for European carp in Australian waters

Source: Kailola et al. 1993

Intensive efforts are being made to eradicate these Tasmanian populations (A. Sanger, pers. comm. 1996).

Brumley (1991) gives the distributions of the individual strains as: (a) Prospect strain: Sydney: restricted; (b) Singapore (Yanco) strain: Murrumbidgee Basin: restricted; and (c) River (Boolara) strain: Murray–Darling Basin: extremely widespread.

In most waters the abundance of carp has declined from peak levels although carp are still expanding their range and are likely to remain one of the most common species over that range (Morison & Hume 1990). There is potential, given the appropriate hydrological conditions (i.e. good floods), for carp to increase to peak levels again (Morison & Hume 1990). Carp have spread and become more numerous in the Albert River, south-eastern Queensland, over the past five years (B. Pusey, M. Kennard, pers. comm. 1996).

The principal indirect impact of carp has been its massive range expansion in the Murray–Darling system. Accompanying the range expansion has been the domination of fish numbers and biomass by carp. P. Gehrke (pers. comm.) cites overwhelming numbers in regions of the Murray, Lachlan and Murrumbidgee, comprising more than 80% of the total fish community. The costs of managing carp and rehabilitating damaged aquatic ecosystems are considered to be enormous (P. Gehrke, pers. comm.). The range and abundance of carp in the Murray–Darling Basin is considered a major threat to the indigenous fish fauna.

The tench, *Tinca tinca*, is reported to be widespread and locally abundant in the Murray–Darling River system although tench are restricted to the western side of the Great Dividing Range (McKay 1984; Brumley 1991). Tench are also found in the coastal drainages of New South Wales, Victoria, Tasmania, and South Australia (Merrick & Schmida 1984).

The roach, *Rutilus rutilus*, is restricted to the South-east Coast Division of Australia and is common in the Murray River and coastal drainages of southern NSW and Victoria (Merrick & Schmida 1984). The roach is reported to be very abundant in the rivers of Port Phillip Bay and likely to have an impact on natural aquatic systems.

The rosy barb, *Puntius conchonius*, was reported from several localities around Brisbane in the late 1970s (McKay 1978) but apparently has not formed a reproducing population (Arthington et al. 1983; McKay 1989).

Poeciliidae

The eastern *Gambusia* or mosquitofish, *Gambusia holbrooki*, is widespread throughout Australia (Allen 1989; Arthington & Lloyd 1989). Figure 6 gives the distribution of the mosquitofish in Australia and dates of major introductions. This species is still being spread about for mosquito control in some areas. However, several indigenous fish species have been shown to be more suitable for mosquito control than the mosquitofish (Lloyd 1990b) which is considered to have no economic value other than as a pest (P. Gehrke, pers. comm.).

The Domingo *Gambusia*, *Gambusia dominicensis* Regan), reported in springs and waterholes around Alice Springs (Allen 1989), has been identified as *Gambusia holbrooki*, and *G. affinis* is not known from Australian waters (Lloyd & Tomasov 1985).

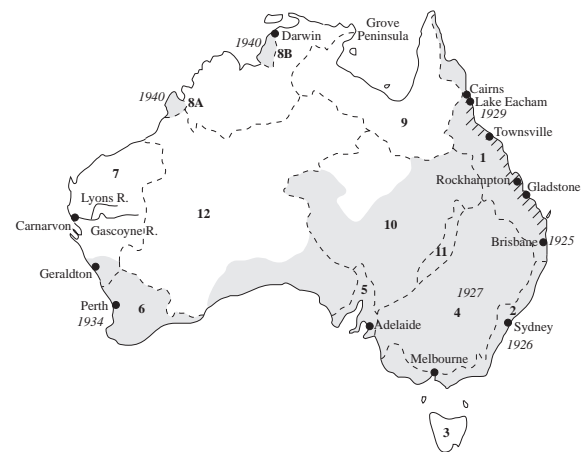


Figure 6: Distribution of mosquitofish and other Poeciliidae in Australian waters

Australia showing major drainage divisions (1–2, see below), the localities and dates of major introductions of *Gambusia affinis* in Australia (e.g. Cairns 1929) the present distribution of *G. affinis* in each division (speckled area), the location of Lake Eacham on the Atherton Tableland, south of Cairns, the distribution of *Poecilia reticulata* in coastal Queensland (cross-hatched area), localities supporting *Oreochromis mossambicus* (Brisbane, Townsville and Cairns, Queensland; Gascoyne River and Lyons River east of Carnarvon, Western Australia). Numbers 1–12 refer to the drainage divisions recognised by the Australian Water Resources Council. Shade areas indicate the presence of mosquitofish within at least parts of the drainage division (Arthington & Lloyd, in press).

1. North-east Coast Division;
2. South-east Coast Division;
3. Tasmanian Division;
4. Murray–Darling Division;
5. South Australian Gulf Division;
6. South-west Coastal Division;
7. Indian Ocean Division;
8. Timor Sea Division A—Cape Levesque Coast, B—Finnis River;
9. Gulf of Carpentaria Division;
10. Lake Eyre Division;
11. Bulloo–Bancannia Division;
12. Western Plateau Division.

Source: Arthington 1991

The one-spot live bearer is presently confined to Perth, Western Australia (Allen 1989). The sailfin molly occurs in coastal drainages of south-eastern Queensland. The guppy is more widespread, occurring in many coastal drainages of northern NSW and eastern Queensland (Allen 1989; Arthington 1991), as do the swordtail and platy.

The above five poeciliid species have not been spread as widely as the mosquitofish and have not shown the same capacity for unassisted range expansion as other exotics, with most being confined to disturbed urban waterways. However, as aquarium fishes, it is likely that they will continue to be translocated into natural waterways. Known populations have persisted for a number of years and the potential for proliferation, especially in response to habitat changes brought about by humans, remains a threat.

Cichlidae

The Mozambique mouth-brooder, *Oreochromis mossambicus*, has been reported from Brisbane (water supply reservoirs), Townsville (urban drains, the Ross River, several small creeks), Cairns (estuaries) and the Gascoyne-Lyons River system, Western Australia (Arthington & Blühdorn 1994). Figure 7 shows the known distribution of the Mozambique mouth-brooder in Australia.



Figure 7: Distribution of Mozambique mouth-brooder in Australian waters (Brisbane, Townsville, Cairns, Gascoyne-Lyons River, WA)

Source: Arthington 1991

This distribution continues to expand apparently because of translocations and probably also due to natural spread on flood waters. The Mozambique mouth-brooder has recently been reported from new water supply reservoirs in the Brisbane area (P. Jackson, pers. comm.) and other creeks in the Townsville area (R. Wager, pers. comm.). It does not occur in the wet tropics area of north Queensland (Pusey & Kennard 1993).

The Mozambique mouth-brooder is considered to have the potential to devastate remaining indigenous populations if it moves down the Darling River system (P. Gehrke, pers. comm.) and is regarded as probably the most serious threat currently facing the Murray–Darling River system (B. Lawrence, pers. comm.).

The Mozambique mouth-brooder 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 & Arthington 1992).

As the indigenous, highly valued silver barramundi becomes more widespread through the efforts of translocation, there may be increasing pressure to use this cichlid as a forage fish. This has serious implications both for the illegal spread of the Mozambique mouth-brooder 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 the Mozambique mouth-brooder surviving droughts in sandy streams in southern Africa by burying itself in the wet sand layer, often as deep as three metres. Similar drought and habitat conditions occur in the Gascoyne-Lyons River system of Western Australia, and it is a possibility that the Mozambique mouth-brooder utilises this strategy to survive the long periods between surface flows in this semi-arid river system.

The black mangrove or Niger cichlid, *Tilapia mariae*, is confined to the heated waters of the Hazelwood Power Station cooling ponds near Morwell, Victoria (Allen 1989). Established populations have also been recorded in Queensland, in the Cairns area (Barron River, estuaries) (Arthington & Blühdorn 1994). In Florida, USA, this species was reported to be spreading rapidly through the disturbed canal systems of southern Florida (Courtenay & Hensley 1979). Southern Florida has similar climatic and habitat conditions to Queensland, so the discovery of the Niger cichlid in the Cairns area could be problematic.

Consequently, this species is classified as noxious in Queensland under the *Fisheries Act 1994*.

The convict cichlid, *Cichlasoma nigrofasciatum*, is also confined to the heated waters of cooling ponds at the Hazelwood Power Station (Allen 1989). It is very localised, and it is not considered likely to survive in the lower temperature regime of the adjacent waterways (P. Cadwallader, pers. comm.). The Jack Dempsey cichlid, *Cichlasoma octofasciatum*, has not been recorded since a single individual was found in the late 1970s in the Hazelwood Power Station cooling ponds and is not considered to have become established (P. Cadwallader, pers. comm.).

Cobitidae

Lintermans et al. (1990) noted the rapid expansion of the range of the oriental weatherloach, *Misgurnus anguillicaudatus* in Victoria and the Australian Capital Territory. 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.). The weatherloach is also currently expanding its distribution in southern New South Wales (P. Gehrke, pers. comm.). Figure 8 shows the range expansion of weatherloach following extensive surveys of the Ginninderra Creek, ACT.

Burchmore et al. (1990) reported the widespread occurrence of successfully reproducing weatherloach in the Wingecarribee River (NSW) and suggest a possible downstream expansion to the Hawkesbury Nepean River system. In an attempted eradication of the species in the Wingecarribee River, weatherloach comprised 16% of total catch recorded, and 50% of the total catch were exotic species, comprising three of the eight species found (Burchmore et al. 1990).

Gobiidae

The yellowfin goby, *Acanthogobius flavimanus*, 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.). There is limited evidence of spread beyond the original sites of introduction.

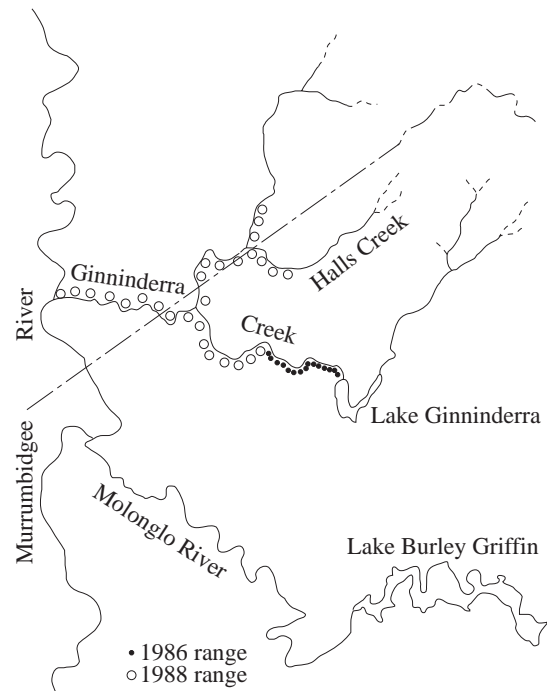


Figure 8: The spread of oriental weatherloach in the Ginninderra Creek catchment (ACT) between 1986 and 1988

Source: Lintermans et al. 1990

3.5.2 Continued introductions of exotic fish into Australian inland waters

Recreational fishing

The practice of stocking salmonid fishes in public waters for recreational purposes is ongoing in Victoria and New South Wales. State government agencies are responsible for the stocking of public waters. In South Australia limited trout stocking is undertaken by a recreational fishing group. Salmonids are regularly released in Tasmanian waters (Kailola et al. 1993). Queensland and the Northern Territory do not stock exotic fish in public waters.

In New South Wales, approximately two million salmonids are produced annually for stocking public waters. These are mainly rainbow and brown trout which are stocked into approximately 290 waterways (streams, rivers and impoundments) in the State (P. Crew, pers. comm.).

Trends in trout stocking in Victoria over the past thirty years have been well documented providing an illustration of the considerable changes in stocking practices. The major trends are shown in Figures 9 and 10 and discussed in Cadwallader et al. (1992).

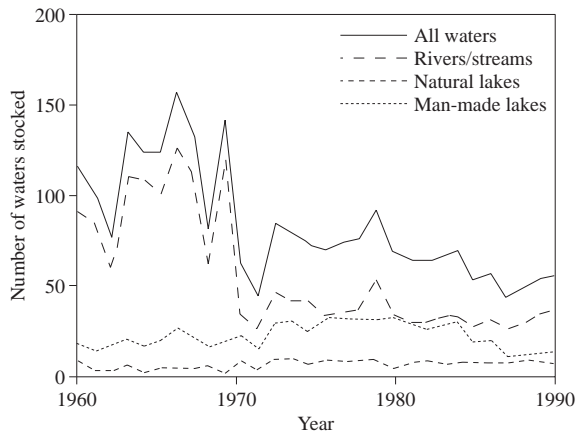


Figure 9a: Brown trout stocked in Victorian waters each year, 1960–1990: number of waters stocked

Source: Cadwallader et al. 1992

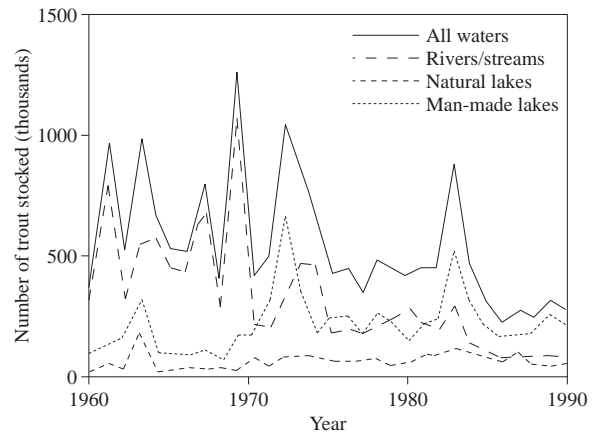


Figure 9b: Brown trout stocked in Victorian waters each year, 1960–1990: number of trout stocked

Source: Cadwallader et al. 1992

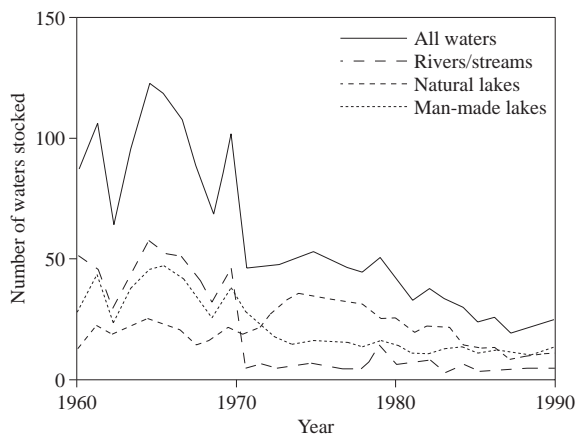


Figure 10a: Rainbow trout stocked in Victorian waters each year, 1960–1990: number of waters stocked

Source: Cadwallader et al. 1992

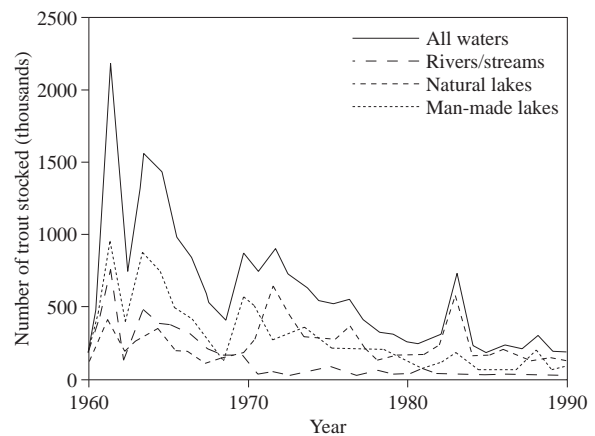


Figure 10b: Rainbow trout stocked in Victorian waters each year, 1960–1990: number of trout stocked

Source: Cadwallader et al. 1992

Briefly, trout stocking has changed considerably from extremely *ad hoc* stocking programs, production and distribution in the 1960s. During the 1970s management of trout stocking and assessment were rationalised, including the concentration of effort on waterbodies which would yield returns and an awareness of the necessity to exclude trout from some

waters in the interests of protection of indigenous fish stocks. In the 1980s annual consultations between interested parties, as well as survey and assessment, provided input to the management of trout fisheries (Cadwallader et al. 1992). Figures 11 and 12 show the changes in distribution of trout stocked waters in Victoria.

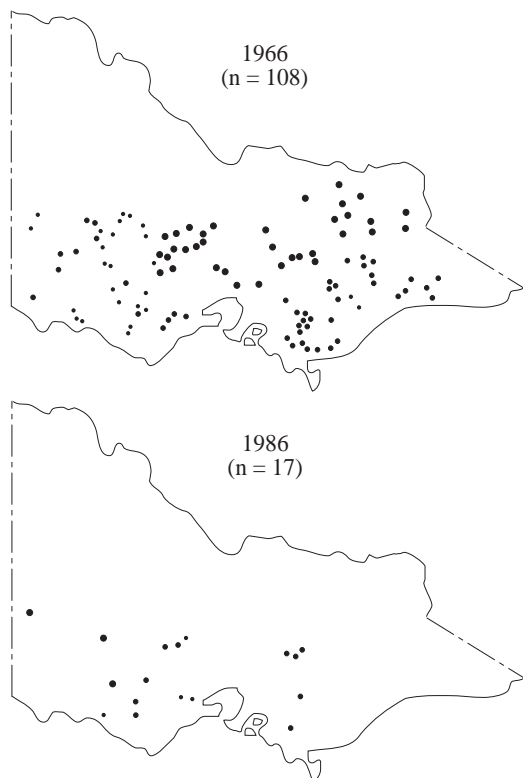


Figure 11: Distribution of waters in Victoria stocked with rainbow trout in 1966 and 1986.

Source: Cadwallader et al. 1992
 Note: n = number of waters stocked

Brown trout and rainbow trout were originally stocked in Western Australia in 1896 and 1902 for recreational fishing and have been actively stocked since then (Lawrence 1993). Trout stocking over the past 10 years has involved 12 dams and impoundments (11 000 yearlings stocked in 1994), and 17 streams and rivers (28 000 yearlings stocked in 1994) (data supplied by Fisheries Department, Western Australia). Stocking of trout in Western Australian waters is subject to ongoing debate.

Escapes of live bait species such as the goldfish and carp (e.g. in Tasmania) also contribute to the continued introduction of exotic species.

Aquarium or ornamental fishes

Introductions of many fish (Table 1) into Australia's inland waters can be largely attributed to the aquarium industry, particularly those established in more recent times (McKay 1984; Kailola 1990). McKay (1984) gives examples of probable escapes of aquarium fish during floods, and unwanted aquarium fish are also deliberately released.

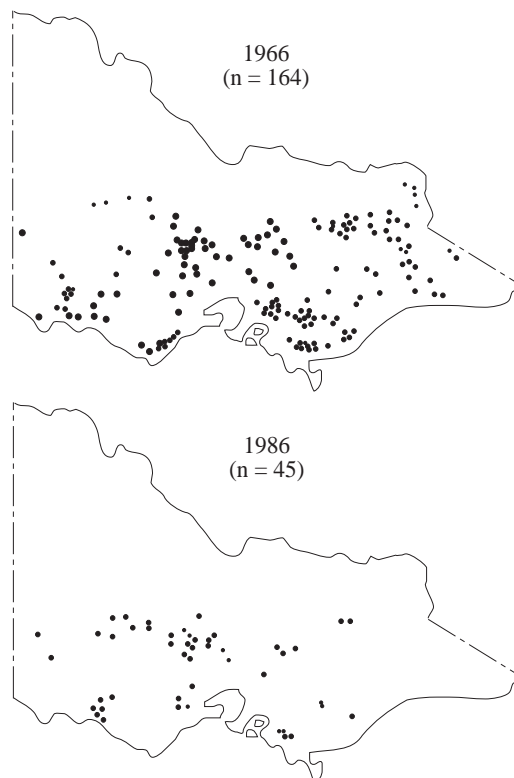


Figure 12: Distribution of waters in Victoria stocked with brown trout in 1966 and 1986.

Source: Cadwallader et al. 1992
 Note: n = number of waters stocked

The values of ornamental fishes imported into Australia for 1990–94, and Australian production for 1989–1991 are given in Table 10.

The disease risks associated with the importation of live fishes are of major concern (Langdon 1988); lists of diseases are provided in Tables 8 and 9.

3.5.3 Translocations of indigenous fauna in Australian inland waters

Freshwater fish

The practice of translocating indigenous fishes within Australia to enhance recreational fisheries poses a constant threat to aquatic systems, although the public's perceptions of this vary and there is little real understanding of the environmental implications. The citation of evidence from overseas is often scorned by those whose interests lie in ready access to sport fishes of choice; these same interests do not appreciate that translocated species may have similar impacts to exotic species.

Table 10: Imports of ornamental fish into Australia for 1991–1994 and Australian production of aquarium fish in 1989–1991

	1989 – 1990		1990 – 1991		1991 – 1992		1992 – 1993		1993 – 1994 ^p	
	tonnes	\$'000	tonnes	\$'000	tonnes	\$'000	tonnes	\$'000	tonnes	\$'000
Imports of ornamental fish *	NA	NA	NA	NA	NA	2488	NA	2555	NA	2720
Aquacultural production of aquarium fish **	NA	828	NA	882	NA	NA	NA	NA	NA	NA

p = preliminary; NA = not available

* Source: Abare 1994

** Source: Treadwell et al. 1992

New South Wales, Victoria and Queensland stock indigenous fish in public waters for recreational and conservation purposes. Fish are also stocked privately in farm dams in these States and in Western Australia. In the past ten years there have been considerable advances in technology and practice which have allowed for successful hatchery production of indigenous fish species. States which do stock indigenous fish have developed or are developing policy which addresses the issues of translocation, most usually giving emphasis to the genetic compatibility of stocks. Where stocks are incompatible, a closed water system is usually required to prevent escapes. Concern over the lack of information about ecological impacts of translocations was highlighted by the States engaged in stocking indigenous species.

Table 11 lists the fish species translocated in Australia and the areas involved. Australian distributions of Murray cod and golden perch are shown in Figures 13 and 14. Statistics on the rates of stocking of species into drainage systems beyond their natural range, and the rivers/impoundments involved, have been difficult to compile.

In Victoria, golden perch, Macquarie perch, Murray cod and trout cod are stocked into public waters. Stocking rates are variable as the indigenous fish

stocking policy stipulates considerations for stocking based on conservation principles and recreational facility. Between 1988 and 1993 the following mean numbers of fish were stocked per annum: golden perch 141 849, Macquarie perch 29 418, Murray cod 112 978 and trout cod 9094. The policy for stocking indigenous fish in Victoria is to stock those fish only in waters that are within the known natural range of the species, except where special management or research needs exist (CNR 1988).

New South Wales stocks approximately one million indigenous fish per annum. The species stocked are golden perch, silver perch, Murray cod, and trout cod; Australian bass and Eastern freshwater cod have been stocked periodically. Examples of stocking rates include 220 000 Australian bass stocked between 1985 and 1991, and 11 209 Eastern freshwater cod stocked in 1988–1989. Indigenous fish are only approved for stocking within their natural range except golden and silver perch, which although indigenous only to the western drainages of New South Wales, are also currently stocked in the Hunter River system. Private stocking of these species into farm dams in the eastern drainages is permitted where they are off-stream storages and above the once-in-one hundred year flood level (NSW Fisheries, pers. comm.).

Table 11: Translocations of Australian native freshwater fishes

Family/Species	Common name	State
Ceratodidae <i>Neoceratodus forsteri</i> Krefft	Queensland lungfish	Qld
Clupeidae <i>Nematalosa erebi</i> (Günther)	Bony bream	Qld
Osteoglossidae <i>Scleropages leichardti</i> Günther <i>Scleropages jardini</i> Saville-Kent	Saratoga Gulf saratoga	Qld Qld
Galaxiidae <i>Galaxias pedderensis</i> Frankenberg Galaxiids	Pedder Galaxias Various species	Tas. Tas.
Plotosidae <i>Neosilurus hyrtlilii</i> Steindachner <i>Tandanus tandanus</i> Mitchell	Hyrtl's tandan Freshwater catfish	Qld Qld, NSW, Vic.
Belonidae <i>Strongylura krefftii</i> Günther	Longtom	Qld
Melanotaeniidae <i>Melanotaenia splendida australis</i> Castelnau	Western rainbowfish	Qld
Centropomidae <i>Lates calcarifer</i> Bloch	Barramundi	Qld
Percichthyidae <i>Maccullochella peelii peelii</i> (Mitchell) <i>Maccullochella macquariensis</i> (Cuvier) <i>Maccullochella peelii mariensis</i> Rowland <i>Macquaria novemaculeata</i> (Steindachner) <i>Macquaria ambigua</i> (Richardson)	Murray cod Trout cod Mary River cod Australian bass Golden perch	Qld, NSW, ACT, Vic. NSW, Vic. Qld Qld, Vic. Qld, NSW, ACT, Vic., NT WA, SA? NSW, Vic.
<i>Macquarie australasica</i> Cuvier	Macquarie perch	
Terapontidae <i>Bidyanus bidyanus</i> (Mitchell) <i>Leiopotherapon unicolor</i> (Günther) <i>Hephaestus fuliginosus</i> (Macleay) <i>Amniataba percooides</i> (Günther)	Silver perch Spangled perch Sooty grunter Banded grunter	Qld, NSW, NT Qld Qld Qld
Apogonidae <i>Glossamia aprion</i> (Richardson)	Mouth almighty	Qld
Toxotidae <i>Toxotes chatareus</i> (Hamilton)	Archerfish	Qld
Gadopsidae <i>Gadopsis marmoratus</i> (Richardson)	River blackfish	Tas.
Eleotridinae <i>Hypseleotris galii</i> (Ogilby) <i>Hypseleotris kluzingeri</i> (Ogilby) <i>Oxyeleotris lineolatus</i> (Steindacher)	Firetail gudgeon Western carp gudgeon Sleepy cod	Qld Vic. Qld

Source: updated from McKay 1989

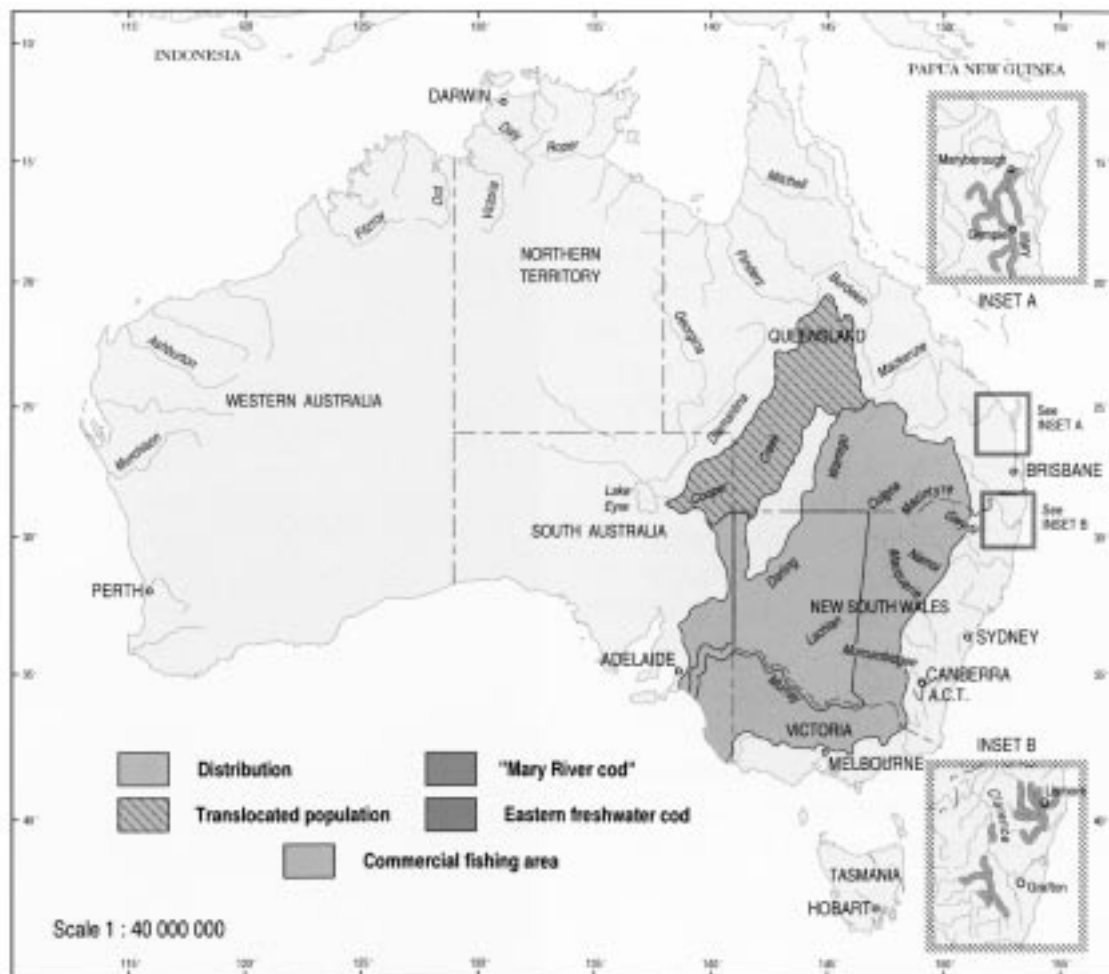


Figure 13: Geographic distribution and commercial fishing area for Murray cod. Distribution of the Mary River cod (inset A) and the eastern freshwater cod (inset B) are also shown.

Source: Kailola *et al.* 1993

Queensland has operated an extensive stocking program, the Recreational Fisheries Enhancement Program, to enhance indigenous fish populations in impoundments throughout the State. However, most stocking has been confined to coastal systems and the vast interior of the State remains unaffected by deliberate fish translocations. Wager (1994) reported that 68 impoundments and two weirs in seven river basins are included in this program. Seven species are stocked and there is pressure from anglers to increase the numbers of species.

The following numbers of fish were stocked between 1985–1994: silver perch (2 814 112), golden perch (1 661 591), Murray cod (90 820), Australian bass (355 921), sleepy cod (2400), Saratoga (2313) and sooty grunter (200). Details of where these fish were stocked are available. While Queensland does not presently stock indigenous fish into other waterways, local fish management groups do release fish directly into waterways and there is increasing pressure for riverine stocking. There is also considerable potential for fish stocked into impoundments to move into waterways.

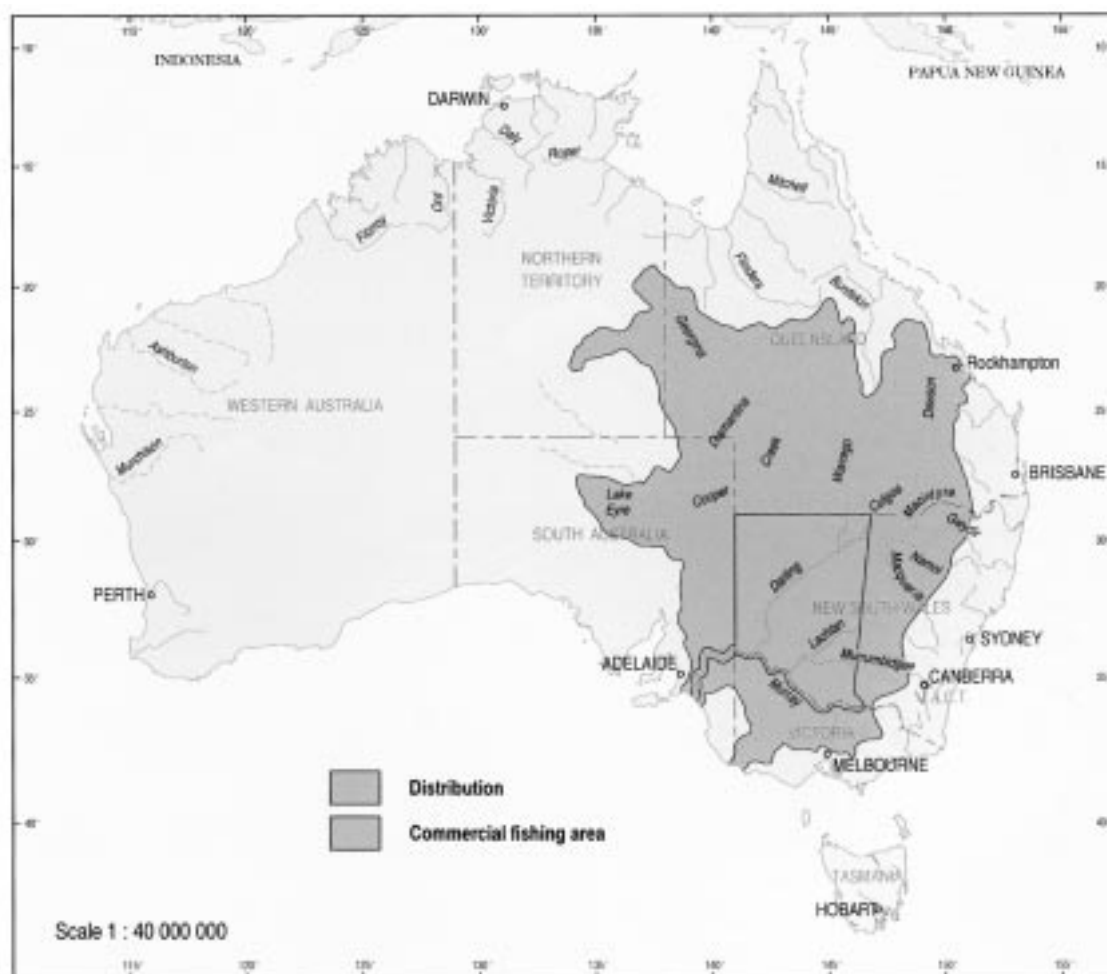


Figure 14: Geographic distribution and commercial fishing area for golden perch

Source: Kailola *et al.* 1993

Lawrence (1993) listed interstate imports of aquatic organisms into Western Australian waters in 1991–1992. Species imported were golden perch, silver perch, Murray cod, eels, redclaw and silver barramundi.

South Australia does not undertake to stock public waters with fish. In the Northern Territory indigenous fish stocking is confined to the release of barramundi into the Manton Dam. No information on fish stocking was supplied for Tasmania.

Freshwater Crustacea

As noted earlier, translocations of Crustacea for aquaculture purposes in Australia have involved three indigenous crayfish of the family Parastacidae, the yabby, the redclaw and the marron (Horwitz 1991).

The yabby has a wide natural distribution in central and southern inland Australia (Figure 15). Recreational and commercial fisheries operate within its natural range and aquaculture activities are carried

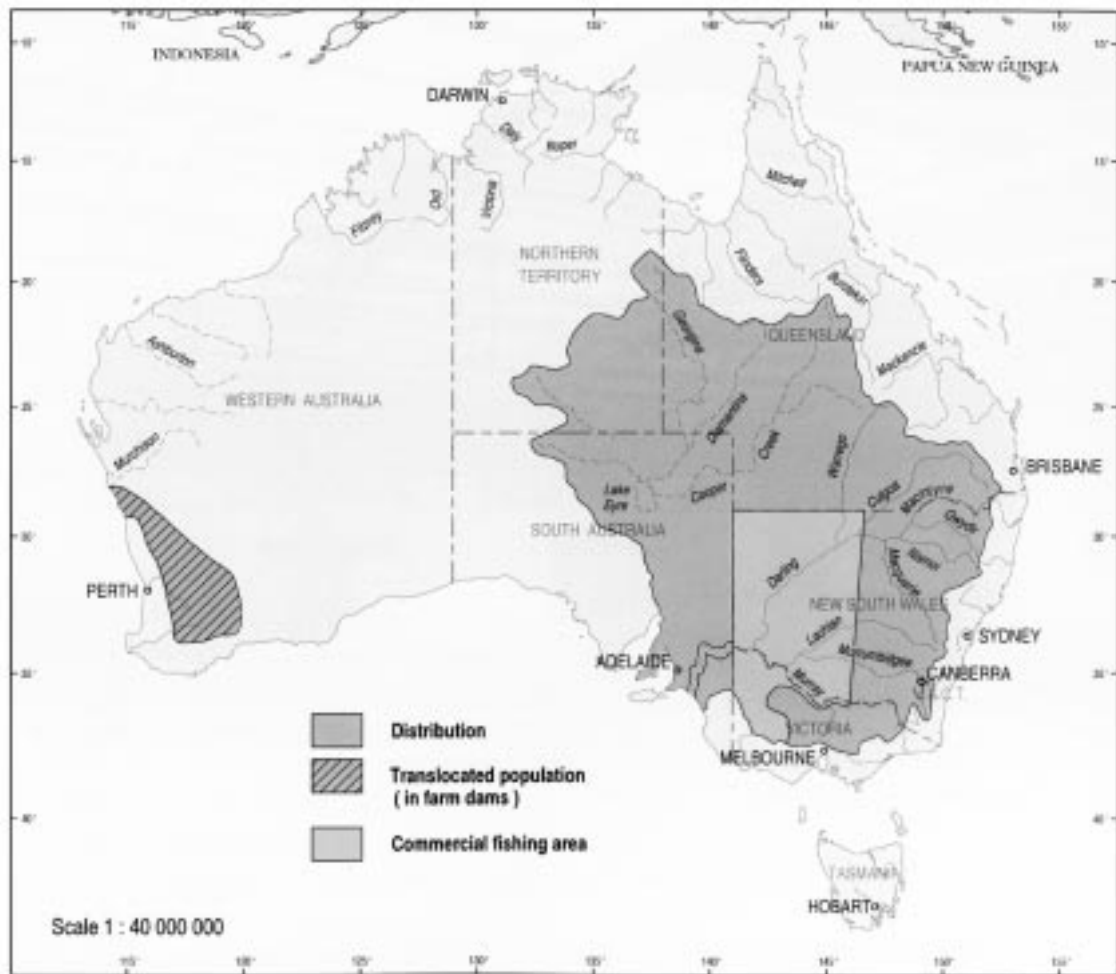


Figure 15: Geographic distribution and commercial fishing of yabbies in Australian inland waters, including translocated populations

Source: Kailola *et al.* 1993

out both within the natural range and in translocated populations in Western Australia (Kailola *et al.* 1993).

In Tasmania, *Cherax destructor* is a declared noxious species and eradications of populations have been undertaken.

The redclaw or tropical blue crayfish has a natural range which includes New Guinea, and extending in northern Australia from the Daly River in the Northern Territory to the Normanby River on Cape York Peninsula in Queensland (Figure 16). It has been translocated to the Cairns–Innisfail area of northern Queensland and to coastal areas of south-east Queensland and New South Wales for aquaculture

purposes. Redclaw were introduced to Lake Tinaroo on the Atherton Tablelands to create a recreational fishery. Escapes from an aquaculture facility have led to establishment of redclaw in Lake Dalrymple (Burdekin catchment) and to the establishment of a recreational fishery.

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 tonnes 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.

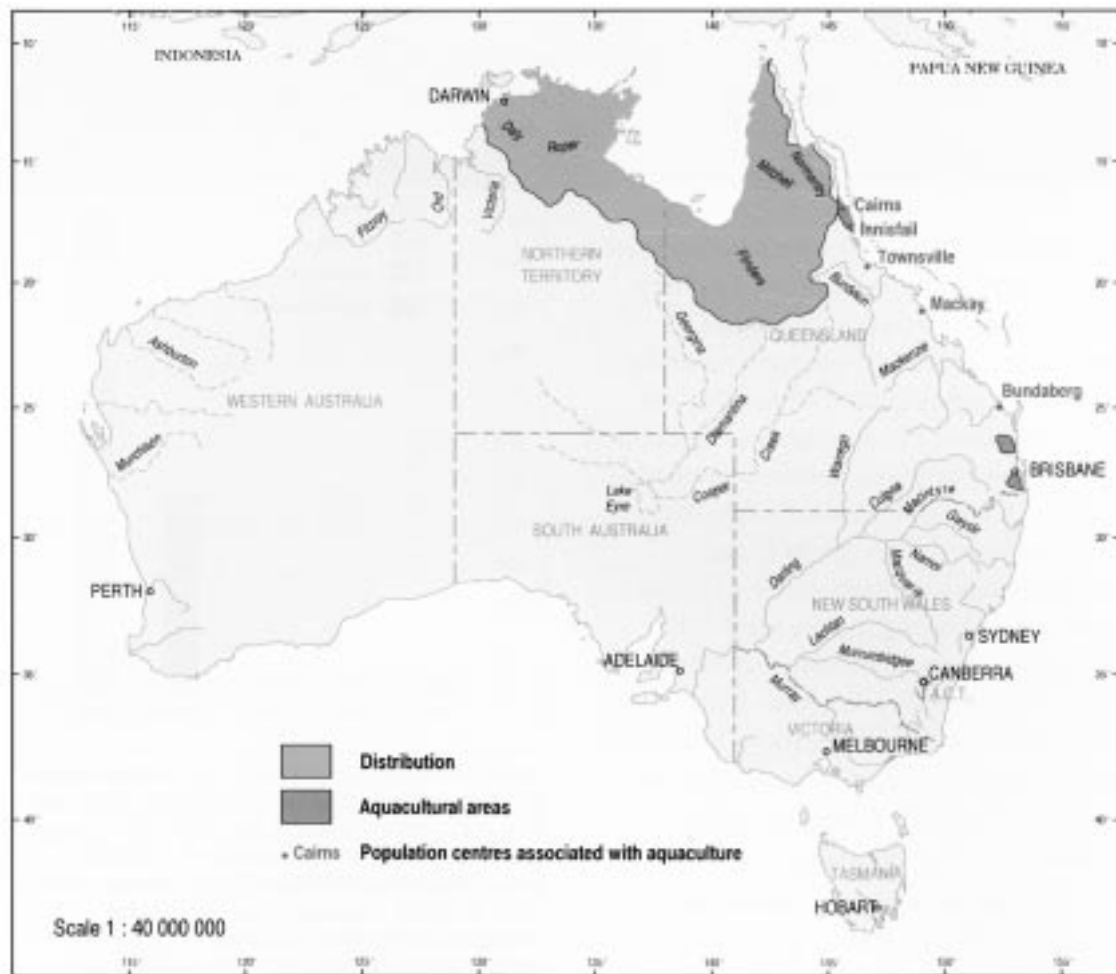


Figure 16: Natural distribution of redclaw in Australian inland waters and centres of aquaculture production in Queensland

Source: Kailola *et al.* 1993

The marron has a natural range confined to the south-west corner of Western Australia. This species has been translocated for aquaculture purposes to other rivers and farm dams in Western Australia, as well as southern Queensland, northern New South Wales and South Australia (Figure 17). Translocations of marron to Queensland were generally unsuccessful due to high temperature-related mortality and the better results achievable with redclaw. Marron were recently found in a National Park on Kangaroo Island off the south coast

of Australia, as a result of illegal importations (Horwitz 1991).

The marron is a noxious species in Victoria because of the likelihood of establishing feral populations, competition with endemic species and the risks of disease. Of the 14 tones of marron 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).



Figure 17: Geographic distribution of marron in Australian inland waters, including extensions to the range through translocation to rivers and farm dams

Source: Kailola *et al.* (1993)

Freshwater crayfish harbour symbiotic and parasitic organisms and there are now documented cases of the translocation of symbionts such as temnocephalans (Horwitz, pers. comm. 1996). The conservation of crayfish thus also involves these organisms, some of which are host-specific and have restricted distributional ranges (Horwitz 1991, 1994).

3.5.4 Freshwater aquaculture

Aquaculture and fish farming in Australia involve a variety of purpose-built outdoor and indoor ponds

and facilities. In addition to ponds some freshwater aquaculture production occurs in wetlands, billabongs and on natural waterways. Effluent from many flow-through fish farms can be discharged to natural waters. Conditions for aquaculture farming are variable between States. Guideline/policies for freshwater aquaculture contain disease outbreak contingency plans and requirements for the prevention of escapes of aquaculture stock. The stringency of guidelines and environment protection provisions vary considerably in principle and practice between the States.

The fish species currently produced in freshwater aquaculture systems for growout (edible-sized fish) are listed in Table 12. The list of species produced each year is highly variable in each State, but production is generally increasing in numbers and value. Production information supplied for this review was too fragmentary to give an adequate overview of its size in Australia. Alternative sources of information, such as ABARE (1994) and Treadwell *et al.* (1992), do not provide precise figures for the range of species farmed in freshwater aquaculture systems in Australia. Other information available which purports to contain reliable statistical information on Australian freshwater aquaculture appeared to be inconsistent with data provided by State fisheries departments.

Freshwater hatcheries operate in most States producing larvae and fingerlings for growout and stocking of public and private waters. The species which are produced from hatcheries vary annually in each State. Production information from hatcheries was as variable as that provided for aquaculture growout.

The production of ornamental (aquarium) fish is part of the freshwater aquaculture industry. The size of this industry is not well known in any State. The production of the goldfish in Victoria is estimated to be three million individuals per year (R. Fallu, pers. comm.). In New South Wales, hatchery production of goldfish for 1992–1993 was 547 330 and for 1993–1994 was 421 534 individuals. The production of other aquarium fish in New South Wales was 266 911 in 1992–1993 and 296 901 in 1993–1994 (P. Crew, pers. comm.).

Table 12: Freshwater species farmed in Australian States and Territories in 1994

Species Name	Common Name	State/Territory						
		NSW	SA	NT	QLD ⁺	VIC	WA	TAS
<i>Cherax destructor</i> Clark	Yabby	*	*				*	
<i>Cherax quadricarinatus</i> (von Martens)	Redclaw	*		*	*			
<i>Cherax tenuimanus</i> (Smith)	Marron	*	*				*	
<i>Cherax albidus</i> Clark	Yabby	*					*	
<i>Cherax rotundus setosus</i> Riek	Yabby	*						
<i>Cherax cuspidatus</i> Riek	Yabby	*						
<i>Cherax</i> spp.	Yabbies					*		
<i>Euastacus spinifer</i> (Heller)	Spiny crayfish	*						
<i>Euastacus armatus</i> (von Martens)	Murray crayfish	*						
<i>Euastacus valentulus</i> Riek	Giant spiny crayfish	*						
<i>Macquaria ambigua</i> (Richardson)	Golden perch	*			*	*		
<i>Maccullochella peelii peelii</i> (Mitchell)	Murray cod	*				*		
<i>Bidyanus bidyanus</i> (Mitchell)	Silver perch	*	*		*	*		
<i>Macquaria australasica</i> Cuvier	Macquarie perch	*				*		
<i>Lates calcarifer</i> Bloch	Barramundi	*	*	*	*			
<i>Myxus petardi</i> Castelnau	Freshwater mullet	*						
<i>Maccullochella macquariensis</i> (Cuvier)	Trout cod					*		
<i>Anguilla</i> spp. (<i>reinhardtii</i> , <i>australis</i>)	Eels	*				*		
<i>Carassius auratus</i> L.	Goldfish	*	*			*		
<i>Cyprinus carpio</i> L.	Carp	*						
<i>Salmo salar</i> L.	Atlantic salmon	*						*
<i>Oncorhynchus mykiss</i> (Walbaum)	Rainbow trout	*					*	*
<i>Salvelinus fontinalis</i> (Mitchell)	Brook trout	*						
Trout spp.	Trout spp.		*			*		*
Aquarium/ornamental fishes		*	*		*		*	

Source: State and Territory fisheries departments 1995–6

+ Source: Mr R Lobegeiger, Bribie Island Aquacultural Research Centre

In Queensland, silver and golden perch, silver barramundi, Mary River cod, eel-tailed catfish, spangled perch, *Anguilla* spp., and the yabby and redclaw are grown in hatcheries or are listed as farmed species. Queensland hatchery production was estimated using sales of fish which are categorised as exotic or indigenous. Production for Queensland was: 1991–1992: exotic species 371 000, indigenous species 24 400; 1992–1993: exotic species 24 400, indigenous species 21 500; 1993–1994: exotic species 83 204, indigenous species 107 405 (R. Lobegeiger, pers. comm.).

Freshwater aquaculture in Western Australia involves marron, yabby, barramundi, trout and aquarium species. Production statistics for marron show an increase from 2.5 to 18 tonnes between 1989 and 1993 (= 92 farmers). Yabby production increased from 30 to 289 tonnes in the same period, with 50 farmers involved in 1993. Trout production increased from 12 to 48 tonnes between 1989 and 1993, involving seven farms in 1992 and 1993 (Fisheries Department of Western Australia). Aquarium fish production figures are not available but eight farmers were involved in

1992 and 1993. The production of barramundi in 1993 was 0.5 tonnes.

There are many other Australian species considered suitable for aquaculture, and the industry is expected to grow, with increasing probability of adverse environmental impacts (ABARE 1991, 1994).

3.5.5 Status of Australia's indigenous fish fauna

The conservation status of indigenous fauna and the general state of inland waters are both partially a reflection of the establishment of exotic and translocated fishes and invertebrates, or aquarium escapees, and their diseases and parasites. These indicators can rarely be related solely to the impacts of introduced/displaced species as many other human pressures impact upon aquatic systems and their biota, usually in concert, and some exacerbate the effects of introduced species, for example flow

regulation (Arthington et al. 1990; Boon et al. 1992; Barmuta et al. 1992).

Tables 13, 14 and 15 present a summary of the Australian fishes in various conservation categories that are believed to be adversely affected by exotic fishes, drawn from Wager and Jackson (1993). The conservation categories listed are: endangered species (Table 13), vulnerable species (Table 14) and rare, poorly known and common indigenous species (Table 15).

Ten of the 24 Recovery Outlines present in the *Action Plan for Australian Freshwater Fishes* (Wager & Jackson 1993) nominate exotic fishes as the major threatening process. Five Recovery Outlines list brown trout and five list the mosquitofish. The threat of displaced indigenous species is also discussed in the *Action Plan* but it appears to warrant more attention than it has so far received in Australia, preferably in the form of a coordinated national effort backed by strong policies and legislation (see Section 4).

Table 13: Endangered indigenous Australian fish species adversely affected by exotic fishes

Family/species	Common name	R. trout	B. trout	Redfin	Carp	Goldfish	Mos.fish
Galaxiidae							
<i>Galaxias fontanus</i> Fulton	Swan Galaxias		*				
<i>Galaxias fuscus</i> Mack	Barred Galaxias	*	*				
<i>Galaxias johnstoni</i> Scott	Clarence Galaxia		*				
<i>Galaxias pedderensis</i> Frankenberg	Pedder Galaxias		*				
Pseudomugilidae							
<i>Scaturiginichthys vermeilipinnis</i> Ivanstoff	Red-fined blue eye						*
Percichthyidae							
<i>Maccullochella macquariensis</i> (Cuvier)	Trout cod			*	*	*	
Gobiidae							
<i>Chlamydogobius</i> sp.A	Elizabeth Springs goby						?

Source: Wager & Jackson 1993

Table 14: Vulnerable indigenous Australian fish species adversely affected by introduced exotic fishes

Family/species	Common name	R.trout	B.trout	Redfin	Carp	Mos.fish
Prototroctidae <i>Prototroctes maraena</i> Günther	Australian grayling		*			
Galaxiidae <i>Galaxiella pusilla</i> (Mack)	Dwarf Galaxias			*	*	*
<i>Galaxias tanycephalus</i> Fulton	Saddled Galaxias		*			
Pseudomugilidae <i>Pseudomugil mellis</i> Allen and Ivantsoff	Honey blue-eye					*
Atherinidae <i>Craterocephalus fluviatilis</i> McCulloch	Murray hardyhead					?
Nannopercidae <i>Edelia obscura</i> Klunzinger	Yarra pygmy perch	*	*	*	*	*
<i>Nannoperca oxleyanna</i> Whitley	Oxleyan pygmy perch					*
<i>Nannoperca variegata</i> Kuitert and Allen	Ewen's pygmy perch	*	*	*	*	*

Source: Wager & Jackson 1993

Table 15: Rare, poorly known and common indigenous Australian fish species adversely affected by exotic fish species

Family/species	Common name	R.trout	B.trout	Redfin	Mos.fish	OW Loach
Rare species						
Electrididae <i>Mogurnda adspersa</i> Castelnau	Purple spotted gudgeon Murray–Darling strain				*	
Poorly known species						
Chandidae <i>Ambassis agassizii</i> Steindachner	Olive perchlet				?	?
Percichthyidae <i>Macquaria australasica</i> Cuvier	Macquarie perch		*	*		
Common species						
Galaxiidae <i>Galaxias olidus</i> Günther	Mountain Galaxias	*				
Nannopercidae <i>Edelia vittata</i> Castelnau	Western pygmy perch			*		

Source: Arthington & Lloyd 1989, Lloyd 1990b, Wager & Jackson 1993.

4 Societal responses to problems of introduced and displaced species

4.1 Legislation and enforcement

The following sections give a brief summary of Commonwealth, State and Territory legislation concerning displaced/introduced fauna, and initiatives relevant to the management of inland water resources, especially fisheries. This material is presented under the headings 'Biological conservation and management', 'Catchment management', 'Water conservation and management' and 'Water quality and management' in accordance with the study brief.

The final section of this review presents a short statement on emerging issues related to exotic/displaced aquatic fauna.

4.2 Biological conservation and management

4.2.1 Commonwealth legislation

Commonwealth, State and Territory legislation and management programs governing inland waters, fisheries and introduced/displaced species have been reviewed recently by Wager and Jackson (1993). This material is too lengthy to reproduce fully in this paper. Key points, areas of contention, recent changes in legislation and issues requiring a stronger societal response are briefly discussed.

The relevant Federal Acts are the *Wildlife Protection (Regulation of Exports and Imports) Act 1982* and the *Endangered Species Protection Act 1992*.

The Wildlife Protection (Regulation of Exports and Imports) Act 1982 aims to ensure that Australia complies with the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), and to advance the protection and conservation of the indigenous biota of Australia and other countries. Schedule 6 lists exotic fish species that are prohibited imports because they are considered likely to establish and cause damage in Australian waters. The list is somewhat contentious and not all States agree with the prohibited species.

The Endangered Species Protection Act 1992 has five key features. The first is a listing process which

identifies nationally endangered and vulnerable species, endangered ecological communities and threatening processes of national importance. Ten of the 24 Recovery Outlines present in the *Action Plan for Australian Freshwater Fishes* (Wager & Jackson 1993) nominate exotic fishes as the major threatening process (Section 3.5.5).

The Endangered Species Protection Act 1992 emphasises the development of Recovery Plans for endangered species, and to this end funds research and development projects and promotes community involvement. Except where Commonwealth land is involved, the activation of Recovery Plans is the responsibility of State governments. Political will and resources are required to ensure that Recovery Plans are effectively enacted and monitored. Multiple legislative and management responsibilities for catchments and inland waters do not always lend themselves to an integrated approach to water resources and endangered species management (see Section 4.3—Catchment management, below).

The Environmental Protection (Impact of Proposals) Act 1974 has been modified to clarify the circumstances in which environmental assessments must address issues of endangered species and communities.

The Australian Quarantine and Inspection Service (AQIS) delivers inspection and quarantine services for the Commonwealth Government to ensure maximum protection against the entry and spread of undesirable pests and diseases of animals and plants. In 1992, AQIS commissioned the Bureau of Resource Sciences (BRS) to conduct a major review of aquatic animal health and quarantine as a basis of reviewing its quarantine policies and procedures for aquatic animals and their products (Nunn 1995). The BRS review has provided detailed lists of diseases, pathogens and parasites of fish, as shellfish and Crustacea, and provided guidelines and recommendations related to a wide range of imported aquatic animals and products as well as indigenous diseases of fish (Humphrey 1995; Nunn 1995).

Australia is committed to the concept of ecologically sustainable development based on the principles of the World Commission on Environment and Development and the National Conservation Strategy. These initiatives have the objective of preserving genetic diversity, maintaining essential ecological processes and life support systems, ensuring the sustainable utilisation of species and

ecosystems, and maintaining and enhancing environmental qualities. Problems of introduced species must be considered if these principles are to be upheld in Australia.

4.2.2 State and Territory legislation

The summary provided by Wager and Jackson (1993) refers. Recent changes to legislation and policy are discussed below. Wager (1994) reviewed recent policy developments governing the translocation of Australian indigenous biota (for any purpose), commenting as follows:

The draft National Strategy for the Conservation of Australia's Biological Diversity and the National Strategy for the Protection of Threatened Species and Communities both make specific reference to the detrimental effects of species translocations. The Australian and New Zealand Environment and Conservation Council (ANZECC) has developed a draft Policy for Translocations of Vertebrate Animals in Australia with specific reference to translocations of threatened species for conservation purposes. The Advisory Committee on Live Fishes (ACOLF) has recently called for the development of a Federal Policy on translocations of aquatic animals. The Standing Committee on Fisheries has recently recommended that each State develop decision-making protocols for translocation.

Wager (1994) goes on to state that in late 1993 no Australian State had a fish translocation policy with specific reference to decision-making protocols, and that there were then no State policies with specific guidelines for assessing translocations, and that these may be permitted without consideration of the detrimental effects.

This review sought information from each State and Territory on policies and practice regarding translocations. The responses received are summarised below and update the review of Wager (1994). Policies concerning the translocation of Crustacea in Australia are discussed by Horwitz (1991, 1994, 1995b).

Queensland

The Fisheries Act 1994 provides legislation for the management of fishes and invertebrates in marine and fresh waters. The Queensland Department of Primary Industries has been developed a policy for the translocation of freshwater fishes in Queensland

freshwater systems, including translocation into rivers, impoundments, farm dams and aquaculture facilities. The policy sets out key principles under which the Department will operate. These are consistent with principles of ecologically sustainable development. It also sets out a decision-making procedure including the requirement to follow specific decision-making protocols. Stakeholder consultations took place during 1995.

Several issues are of concern in Queensland: the continual lack of public understanding of the uniqueness and variety of Queensland's freshwater fish fauna and the adverse effects of translocations, exotic species and diseases; the limited database on fish diseases in Queensland waters; the lack of monitoring of effects of existing translocated species; and the continuing evidence of aquarium species being released into Queensland waters particularly around urban population centres.

Queensland has also developed an interim contingency plan for dealing with diverse outbreaks of diseases and parasites transmitted via aquaculture stock to wild fishes; a more detailed plan is under development. Freshwater aquaculture cannot be undertaken in Queensland without an appropriate permit; any condition deemed appropriate by the Department of Primary Industries, through the Fisheries Division or the Queensland Fish Management Authority, may be included in the permit. Various conditions are included to ensure that aquaculture premises are secure and that fish/juveniles/eggs/larvae cannot escape into natural waters. Examples include that aquaculture of prescribed non-indigenous fish (e.g. goldfish) can only be carried out in above-ground pools, the provision of sand filters to prevent escape of eggs and larvae, screening of all discharge points, and ponds to be built above flood levels.

New South Wales

The Fisheries Management Act 1994 (No. 38), Division 7, covers the importation or release of live fish, with the purpose of preventing any adverse effect on existing fish and fish habitats by introduced species of fish, and preventing spread of diseases in fish. It is illegal to import live fish not taken in New South Wales waters, or to release live fish into any waters, except under the authority of a permit issued by the Minister or, in the latter case, an aquaculture permit. Live fish cannot be taken from New South Wales

waters except under the authority of a permit issued by the Minister.

In New South Wales, fish and crustacean cultivation requires a Fish Farm Permit which must comply with the provisions of the *Fisheries and Oyster Farms Act 1935*; 107 standard and special conditions are covered by Fish Farm Permits (July 1994 edition), many relating specifically to freshwater species. Aquarium species (i.e. indigenous Australian fish species and all fish listed in Schedule 6 of the *Wildlife Protection (Regulation of Exports and Imports) Act 1982*) may be farmed but only under special conditions to prevent escapes to natural waterways.

Live fish may be sold for stocking farm dams but species from west of the Great Divide may not be sold for stocking farm dams east of the Divide; the exceptions are silver and golden perch. When these species are stocked east of the Divide, the ponds, dams and tanks must be isolated from natural waterways, above the once-in-one hundred year flood and free from danger of fish escapes into natural waterways. Other special conditions must be met to prevent probability of escapes to natural waterways. Similar and additional special conditions apply to the cultivation of marron and redclaw or any species of crayfish not indigenous to the area.

The Department of Fisheries does not hold a database on the numbers and species involved in the transport of live fish, but acknowledges that silver barramundi have been transported from Queensland and Atlantic salmon from Tasmania. These fish are sold live in Chinatown, Sydney, and there is a through traffic of species from Queensland through New South Wales to Victoria and Tasmania.

Victoria

The protection of fish species in Victoria is covered by the *Fisheries Act 1968* and the *Flora and Fauna Guarantee Act 1988*. There is no legislation aimed at controlling live fish brought into Victoria; once fish enter the State, importers are required to notify the Department of Conservation and Natural Resources but this evidently occurs in only a few cases. Enforcement of this type of legislation is regarded as difficult if not impossible.

The release of live fish into the State's natural waters is controlled under legislation and thought to be effective. Stocking natural waters with fish comes under three categories—Government, commercial

and amateur—each with permit provisions and prohibitions. The stocking of non-indigenous species will only be allowed in the future in areas where there is no chance of escape.

Trout are an exception to this general principle, and are stocked at Departmental expense. However, they may not be stocked where there is a threat to a species of special concern or where a unique faunal assemblage exists, or east of the Snowy River catchment, or in waters identified as unacceptable habitat, or where natural reproduction adequately supports a fishery.

The European carp is listed on the noxious species list and is defined as a pest when the fish occur in numbers and biomass greater than 450 kg/ha in ecologically, recreationally or economically valuable water bodies, unless there are strong arguments for taking action at lower biomass levels.

Aquaculture in Victoria is governed by permits issued by the Department of Conservation and Natural Resources. Species deemed to present a threat to health or the environment are prohibited for aquaculture purposes. These include marron, redclaw, tilapias, snakeheads and redfin.

South Australia

Fisheries management, fish farming, fish diseases and exotic fish are controlled under the *Fisheries Act 1982* and by regulations under the *Fisheries Act of 1984*. These regulations are currently under review. The main live imports of fish into South Australia are for the aquarium trade. No stocking is undertaken in the State except limited numbers of trout by a recreational fishing group. There are no hatcheries in South Australia although a barramundi nursery has operated since 1991 hatching eggs transported from Queensland.

Aquaculture on a commercial basis involves barramundi, trout, yabbies and marron. Farmers stock Murray cod, silver perch and golden perch in dams but not for commercial growout. Barramundi and marron farmers must take precautions to avoid escapes into natural waterways, but this requirement is less stringent for trout and yabby farms. Fish farms are not permitted to release water into natural waterways.

Northern Territory

The Department of Primary Industry and Fisheries regulates, conserves and manages fisheries and

fishery resources under the *Fisheries Act 1988*. Live fish may not be moved into or released into waters of the Northern Territory unless in accordance with a permit issued under the Fisheries Act (Section 16). Disease and ecological issues receive the most attention in relation to the issuing of permits. It is illegal to import or possess a noxious fish, or to trade in live exotic fish or exotic aquatic life, or to release an exotic fish or exotic aquatic life except under permit. The Northern Territory does not allow the stocking of impoundments with exotic species. Barramundi are imported for aquaculture growout purposes.

Western Australia

In Western Australia, the *Fisheries Act 1905* governs issues of fish management, stocking and aquaculture. This Act and the Stock Diseases Act allow both Fisheries Inspection and Stock Inspection to have some powers in the event of a fish disease outbreak. Translocation protocols for transfer of wild and hatchery stock were revised in 1993–1994 and general translocation policies of the Western Australian Fisheries Department are in the process of finalisation (Discussion Paper, Lawrence 1993). At present, any importation requires a permit or licence to be issued by the Fisheries Department.

Horwitz (1994) reviewed key concepts of particular significance to the prevention of unwanted or inappropriate introductions of fauna to Western Australia, drawing from international documents and practices—the IUCN’s 1987 position statement on translocations of living organisms, the European code of practice and manual of procedures for marine and freshwater organisms (Turner 1988) and the Western Australian Fisheries Department’s Discussion Paper (Lawrence 1993).

Australian Capital Territory

The *Australian Capital Territory Fishing Act 1991* provides a range of controls and regulations for freshwater species (Wager & Jackson 1993).

Tasmania

No responses to the request for information were received from Tasmania within the time frame for preparation of this review, and the resources required to obtain information at a later date could not be made

available through the State of the Environment reporting program.

The *Fisheries Act 1959* provides a range of controls and regulations for freshwater species (Wager & Jackson 1993). Issues of significance within Tasmania have been discussed throughout this review (e.g. regulations concerning the importation of Cyprinidae). Kailola et al. (1993) reported that the European carp had been eradicated from Tasmania but populations of carp were recently discovered in Lake Crescent and Lake Sorell in the headwaters of the Clyde River, a tributary of the Derwent system. 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.

4.3 Catchment management

Many of the problems associated with introduced fish species (and probably also invertebrate species) are the result, at least in part, of changes to the aquatic habitat brought about by human activities. Under the aegis of Integrated Catchment Management (and Total Catchment Management), strategies for the management of exotic species should be developed and integrated with those directed towards other catchment problems, such as protection of the vegetated riparian zone, water quality management and river flow management.

The catchment is universally recognised as the appropriate landscape unit for aquatic resource management (Hynes 1975, 1989; Dodge et al. 1989) and is also relevant to the management of most terrestrial resources. Integrated Catchment Management strategies and infrastructure have been established in most Australian States and Territories.

Plans for the integrated management and monitoring of natural resources are being developed in many major river basins, although frequently only a limited range of issues is addressed (e.g. water quality, riparian vegetation, fish distributions). *The Action Plan for Australian Freshwater Fishes* (Wager & Jackson 1993) recommends that landcare and integrated catchment management infrastructures be used to implement community education and involvement in species recovery actions and to address threatening processes.

Natural resource management issues transcend political boundaries. One of the difficulties of

managing some inland aquatic resources effectively is the lack of concordance between local and State legislation and responsibility and catchment boundaries.

This problem extends to the national scale where one or more State or Territory has responsibility for a catchment or Australian drainage division (see Figures 1 and 2). Aquatic resources could be managed and monitored more effectively basin by basin, rather than by State and Territory. State of the Environment reporting on aquatic resource issues has of necessity to draw upon incomplete and inadequate information collected at many spatial scales and crossing catchment, basin and political boundaries. A more rational approach is needed, and, it is suggested, should be based on the Australian drainage divisions.

The Natural Resources Management Strategy for the Murray–Darling Basin could serve as a model for resource assessment and management at the levels of the catchment and sub-catchment.

4.4 Water conservation and management

Water conservation is taken to mean the protection of the physical resource. The general state of Australian inland waters in terms of physical alterations to river flow regimes, groundwater resources and the water resource values of lakes and wetlands are to be treated elsewhere as part of state of the environment reporting. Systems now experiencing highly modified flow regimes include much of the Murray–Darling Basin, most coastal rivers of south-eastern Australia, coastal rivers of southern Queensland (the Brisbane, Mary, Burnett, Fitzroy and Burdekin Rivers), and some waterways in Western Australia, South Australia, Tasmania and the Territories.

Many systems known to be adversely affected by physical alterations to aquatic systems, especially in terms of altered flow regimes, are affected as well by exotic fish and plant species. Often the changes made to aquatic systems provide conditions that are suitable or ideal for exotic species, facilitating their range expansion and exacerbating their impacts (Courtenay 1990; Arthington et al. 1990; Gehrke, pers. comm.).

Societal responses to the physical degradation of Australia's freshwater resources have been numerous over the past decade. Examples include the development of integrated or total catchment

management, and various programs to protect wetlands through national and international agreements and conventions (e.g. Ramsar). Most recently, the Council of Australian Governments (COAG) has agreed to include an assessment of the requirements of rivers and their floodplain wetlands for special water allocations to meet environmental objectives. It remains to be seen how the issue of exotic species will be addressed within this policy framework. The inclusion of special water releases for the purpose of habitat modification or prevention of spawning by an exotic species is a possibility, as yet untried in Australia.

More effective, however, will be integrated approaches to the management of exotic fish populations. Efforts to maintain the habitat integrity and water quality of aquatic systems, as well as flow regimes, may achieve suppression of exotic species by promoting the conditions required for indigenous fishes and thereby enhancing their competitive abilities and resistance to predation pressure from exotic species. Diverse aquatic communities in undisturbed systems appear to be resistant to invasion by exotic and translocated species (McKay 1984; Courtenay 1990).

4.5 Water quality and management

Australia's commitment to the concept of ecologically sustainable development requires amongst other things the maintenance of life support systems, and the maintenance and enhancement of environmental qualities. Problems of introduced and translocated species and pathogens are relevant to the protection of the quality of inland waters as the life support system for Australia's indigenous aquatic flora and fauna and as a vital aspect of environmental quality.

Several of the introduced/displaced aquatic species reported in Australian waters are considered to contribute to the impairment of aquatic habitats and water quality. The European carp in particular is the target of much discussion in relation to habitat destruction, sediment and nutrient resuspension, increases in turbidity and even the stimulation of blue-green algal blooms.

The mosquitofish, *Gambusia*, has been shown to influence the trophic structure of aquatic communities by feeding on invertebrate species apart from mosquitoes (Hurlbert & Mulla 1981; Lloyd 1990b). Changes in the abundance of invertebrate

grazers has led to the proliferation of phytoplankton species and increases in turbidity (i.e. decreases in water clarity) in some situations.

One societal response has been a call for the eradication of carp from all Australian waterways, an objective deemed impossible by the Victorian Carp Program, even in waterways of limited extent (CNR 1991). The recent formation of a National Carp Task Force to address the carp problem from all perspectives seems likely to lead to a more rational approach with firm scientific foundations. Water quality problems in carp waters appear not to be attributable solely to the presence of large carp populations (Fletcher et al. 1985; Brumley 1991).

4.6 Emerging issues

This section of this review presents a short statement on emerging issues related to exotic/displaced aquatic fauna. Most of these issues are being addressed at the present time, but require further attention.

The ecological impact of exotic and translocated aquatic invertebrates is a neglected issue in Australia with implications for human and animal health (e.g. gastropod hosts of infectious agents), water quality, habitat integrity and maintenance of genetic resources (e.g. translocation of *Cherax* species and strains), and maintenance of biodiversity (e.g. competitive displacement of indigenous invertebrates such as *Parartemia* in salt lakes).

Policies, strategies and resources are needed to implement an effective national program for monitoring the movements and ecological effects of exotic and indigenous invertebrates. Arthington and Blühdorn (1995) suggested that monitoring could be linked to the National River Health Program (Monitoring River Health Initiative), operating under the auspices of the Commonwealth Department of the Environment, the Land and Water Resources Research and Development Corporation and leading State and Territory agencies.

The transmission of diseases associated with exotic and translocated aquatic invertebrates and fish has been an issue for decades, recently addressed afresh by AQIS and ABARE through a commission to review the topic and recommend practical solutions and measures (Humphrey 1995; Nunn 1995). Exotic aquarium fishes are seen to be a particularly significant potential source of pathogenic organisms, as well as indigenous species translocated from hatcheries and aquaculture facilities to inland waters.

Problems linked to the translocation of indigenous freshwater fishes and crayfish for stocking of natural water bodies are rapidly emerging as a significant environmental issue in Australia (Wager 1994; Wager & Jackson 1994; Horwitz 1991, 1995a, b). The many positive outcomes arising from protection of the riparian zone, water quality management, the monitoring of river health and the COAG agreements regarding water allocation for environmental protection must be supported by strategies to protect the genetic resources and indigenous biota of inland aquatic systems and discrete biogeographic regions.

Increasingly, the consideration of regional biodiversity and endemism must consider the unique characteristics of populations isolated for long periods of time (Horwitz 1995b). The implications of modifying the distinctive and unique gene pools of indigenous fish and invertebrate species isolated by natural barriers include loss of fitness and reduced capacity to withstand environmental stress, both natural and anthropogenic, as well as the loss of genotypes of potential use to humans.

The most effective responses to the problems of displaced/introduced species are to prevent their initial release into inland waters or, when it is too late for this, to intervene before the species has become fully established. Eradication of new infestations may be possible if they are detected early and are localised. Efforts to manage introduced species after they become widespread are extremely costly and have invariably failed (e.g. the Carp Program in Australia). Preventive measures against the introduction and spread of exotic and indigenous species are as simple as public education backed by appropriate legislation and effective enforcement (Pollard 1990; Wager & Jackson 1993).

Effective management of an introduced species requires a sound understanding of its biology and ecology and of the ecological processes governing establishment and spread (i.e. research), plus monitoring to detect impacts and trends before serious problems develop, coupled with improved understanding of the issues at stake (i.e. education) and the political will to enforce legislation.

The greatest hindrance to management of the problems of exotic/translocated biota is lack of information on the species concerned and their interactions with indigenous species and communities. As one scientist put it 'there is a desperate need for hard data rather than anecdote and speculation'. The second difficulty is lack of technical information on practical management strategies that can be applied under Australian conditions.

Abbreviations

ABARE	Australian Bureau of Agriculture and Resource Economics
ACOLF	Advisory Committee on Live Fishes
ANZECC	Australian and New Zealand Environment and Conservation Council
AQIS	Australian Quarantine Inspection Service
BPLV	Barramundi Picornia-Like Virus
BRS	Bureau of Resource Sciences
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CNR	Department of Conservation and Natural Resources (Vic.)
COAG	Council of Australian Governments
EHN	Epizootic haematopoietic necrosis
IWRG	Inland Waters Reference Group
IUCN	World Conservation Union, formerly the International Union for the Conservation of Nature and Natural Resources
OECD	Organisation for Economic Cooperation and Development
QFMA	Queensland Fish Management Authority
Ramsar	Convention on Wetlands of International Importance

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Appendix 1: Request for information sent to State fisheries agencies

Covering letter

Dear

I have recently been commissioned to produce a technical review of the current state of knowledge on the impacts of translocated and exotic (non-Australian) fish, including their parasites and diseases, associated with inland waters. The review will contribute background and documentation to the National State of the Environment report. The primary function of this review is to develop and provide graphical and tabular summaries of information for use as indicators of impact.

For this review I require summary statistics and information on some aspects of the inland fisheries industry in each State. On the attached sheet I have listed my requests for specific information. Could you please provide complete information where possible. Where statistics are unavailable please indicate the reason, and if possible provide an alternative or the nearest statistic which is available.

Please supply these data in ASCII format files (1.2MB disc) or hard copy.

This information is required by 16 December 1994. I regret the very short time within which this information is required but final reporting for this part of the State of the Environment review is 31 December 1994. Your efforts in meeting this deadline will be much appreciated.

If you need further information about this request, or have major difficulty meeting this deadline, please contact me on (07) 875 7403.

Yours faithfully,

Professor Angela Arthington
Director
Centre for Catchment and In-stream Research

Appendix 1: Request for information sent to State fisheries agencies (cont.)

Information requested

Aquaculture industry

Please provide summary statistics from 1985 to present about:

- which species are farmed?
- what is the annual production of each species?
- what is the gross value of production?
- how many farms utilise natural waterbeds/resources?

Please provide information about:

- the State's recommendations/policies for preventing parasite/disease outbreaks from aquaculture stock into the wild
- the State's recommendations/policies for preventing escapes from aquaculture stock into the wild.

Fish hatchery industry

Please provide summary statistics from 1985 to present about:

- how many impoundments and waterways are stocked with exotic or translocated fauna?
- which species are stocked and what are the stocking rates?

Please provide information about:

- any current or potential problems issues/areas which involve both indigenous and exotic/translocated fauna.

Live fish imports

Please provide summary statistics from 1985 to present about:

- what species and how many live fishes (or other freshwater fauna) are imported into the State annually?
- what is the origin of imports?
- what are the purposes of the imports?

Please provide information about:

- the State's regulations to control the introduction of fauna from other States, indicating basic policy and priority areas, and any projects in which the State is investigating the impacts of exotic and translocated fauna.