Invasive Animals Cooperative Research Centre

Review of alien fish monitoring techniques, indicators and protocols:

Implications for national monitoring of Australia's inland river systems

Peter West, Annette Brown and Kylie Hall

National Land & Water Resources Audit

An Initiative of the Natural Heritage Trust

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Invasive Animals CRC

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"Together, create and apply solutions"

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Report to the National Land & Water Resources Audit

prepared by Peter West, Annette Brown and Kylie Hall

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This report was commissioned by the National Land and Water Resources Audit and prepared by the Invasive Animals Cooperative Research Centre (IA CRC), under project 9.D.5 'Fish scoping study'.

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Postal address: University of Canberra, ACT 2601.

Office Location: University of Canberra, Kirinari Street, Bruce ACT 2617.

Telephone: 02 6201 2887

Facsimile: 02 6201 2532

Email: contact@invasiveanimals.com

Internet: http://www.invasiveanimals.com

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Preface

This report is an advisory document that has been commissioned by the National Land and Water Resources Audit (NLWRA) and prepared by the Invasive Animals Cooperative Research Centre.

The report, *Review of Alien Fish Monitoring Techniques, Indicators and Protocols: Implications for National Monitoring of Australia's Inland River Systems*, is not intended to be an exhaustive review. It brings together fundamental information regarding alien fish to inform the National Vertebrate Pests Committee and the NLWRA regarding alien fish for monitoring and reporting under the National Natural Resource Management Monitoring and Evaluation Framework.

The document presents a summary of:

- alien fish species in Australia that have triple bottom line (environmental, economic or social) impacts
- techniques available for measuring and monitoring pest fish distribution, abundance, and impacts
- current research and management programs that measure and report fish information
- recommendations regarding fish monitoring and reporting under the National Monitoring and Evaluation Framework.

This report also identifies knowledge gaps in the monitoring of alien fish and their impacts.

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Executive summary

In Australia, the number and abundance of pest fish species in freshwater rivers and wetlands has risen significantly in recent years (Koster et al 2002a, Koehn and Mackenzie 2004). New pest fish species are increasingly being detected by management authorities (Koehn and Mackenzie 2004). Presently, there is estimated to be up to 34 established pest fish species on mainland Australia. However, there are a large number of species currently in captivity that could have significant negative triple-bottom-line consequences in the wild.

Pest fish cause a wide range of adverse impacts to environmental, economic and social values/assets in Australia. The main environmental impacts of alien fish include ecosystem damage and reduced biodiversity; social impacts include aesthetic damage (Bomford and Glover 2004). Economic impacts include reduced fisheries, aquaculture and agricultural productivity; and trade and control-cost effects (Bomford and Glover 2004). However, most impacts remain largely unquantified (Koehn and Mackenzie 2004).

A number of significant impediments to the national management of pest fish in Australia have been identified, including significant gaps in research knowledge. There is a clear need for consistency in legislation and policy between state and territory jurisdictions regarding noxious species lists, and strategic planning to manage current and emerging pest fish species. A nationally coordinated, on-the-ground approach is required to manage pest fish across jurisdictions (Koehn and Mackenzie 2004). Several authorities have also recommended the development of a National Alien Fish Management Strategy that would overcome many problems currently faced by jurisdictions.

There are currently no Australian standards or a consistent approach specifically designed for measuring and monitoring the distribution and abundance of pest freshwater fish species. However, there are a diverse range of techniques and tools to detect and measure alien fish populations, including electrofishing, passive trapping and netting techniques. There are presently two recommended monitoring protocols (that recommend these techniques for sampling alien fish) that may potentially be suitable for national monitoring programs and reporting activities. They are: 'Recommended Methods for Monitoring Floodplains and Wetlands' and 'Fish Assessment Protocols' – both developed through the Murray-Darling Basin Commission.

Similarly, there are also no consistent standards and techniques specifically suited to measuring and monitoring the impacts of pest fish species. This is primarily because the impacts of pest fish (like most vertebrate pests) are highly varied and are largely dependent on site-specific circumstances. The main techniques available for measuring and monitoring alien fish impacts are intensive mesocosm or laboratory experiments and before-and-after-control trials. These techniques are primarily suited for local or regional application.

There is a genuine need for the development of standardised techniques for assessing and monitoring the impacts of alien fish species at regional, state/territory and national levels.

This report presents a brief overview of current information regarding alien fish species: their distribution and abundance, and impacts; sampling techniques and monitoring protocols; indicators; control; and monitoring and research activities throughout Australia. It highlights a number of specific recommendations that have been identified by many scientific authorities regarding the management of pest fish in Australia. We also present a number of key issues and recommendations that have emerged during the scope of this review that are directly relevant to monitoring and reporting and the National Natural Resources Management Monitoring and Evaluation Framework. These include requirements for:

- resolving inconsistencies in jurisdictional species listings
- obtaining further advice from relevant specialists, including the Vertebrate Pest Committee Pest Fish Working Group, Alien Species Committee of the Australian Society for Fish Biology, management authorities and advisory groups to identify national priorities for monitoring
- agreeing on a national priority list of alien/pest fish species for monitoring
- agreeing on standardised techniques and protocols for monitoring pest fish populations
- undertaking broadscale distribution and abundance surveys and data collation to form a baseline from which the effectiveness of management can be assessed
- undertaking broadscale surveillance monitoring for new incursions of alien fish
- developing, reaching agreement on and adopting tools and suitable techniques for assessing and monitoring species impacts – and developing accompanying protocols
- compiling detailed information on the impacts of pest fish from existing programs to present a more informed assessment of national level problems
- developing a national database of alien fish species information
- making data management and infrastructure arrangements with relevant stakeholders/ jurisdictions
- developing a rapid response plan for new pest fish incursions in Australia.

We also present recommendations for a national assessment of alien fish species in Australia.

Acronyms and abbreviations

AQIS	Australian Quarantine and Inspection Service
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPI	Department of Primary Industries
DPIFM	Department of Primary Industries, Fisheries and Mines (Northern Territory)
DPI&F	Department of Primary Industries and Fisheries (Queensland)
EPBC Act	*Environmental Protection, Biodiversity and Conservation Act 1999*
IA CRC	Invasive Animals Cooperative Research Centre
IRA	Import Risk Analysis
MDBC	Murray-Darling Basin Commission
M&E framework	National (Natural Resource Management) Monitoring and Evaluation Framework
NLWRA	National Land and Water Resources Audit
NRM	Natural Resource Management
NFS	Native Fish Strategy
NPWS	National Parks and Wildlife Service
PIRSA	Primary Industries and Resources of South Australia
SRA	Sustainable Rivers Audit
SoE	State of the Environment
VPC	Vertebrate Pests Committee

1. Introduction

1.1 Background

Intentional introduction of vertebrate species to Australia (including fish) for hunting and fishing, farming and domestic purposes, biological control, fisheries and aquaculture, the pet and aquarium industry and naturalisation/ acclimatisation reasons has led to the establishment of many wild pest populations (Vertebrate Pests Committee 2007). It has been estimated that approximately 73 introduced species of vertebrate pests have become established on mainland Australia (Bomford 2003), including mammals (23), birds (20), reptiles (4), freshwater fish (23) and 1 amphibian. Other authors suggest that up to 34 alien fish species have established populations in the wild, and there is further debate whether many other species have established but remain undetected.

Throughout Australia, the distribution and abundance of pest fish have risen significantly in recent years, and new species are increasingly being detected by management authorities (Koehn and Mackenzie 2004). Pest species are known to have a detrimental effect on native fish and macro-invertebrates, they can cause damage to river health and degrade environmental systems, they can threaten biological diversity and they may cause losses to agricultural and aquaculture industries. While there are many fish species that have established populations in the wild (Kailola 2000, Lintermans 2004), there are also a large number of fish species currently in captivity that, if released or escape, could have significant negative environmental, social and economic consequences in the wild.

There is a volume of literature on the techniques developed and applied to counteract the impacts of pest fish within Australia and overseas. However, details on the current and emerging threats posed by invasive pest fish in Australia remain largely unknown. There are significant gaps in research knowledge, inconsistencies in policy and legislation and a lack of problem definition required to strategically manage current and emerging pest fish species throughout Australia. There is also a lack of nationally coordinated on-the-ground management actions and effective strategies required to address the problems caused by alien fish in Australia (Koehn and Mackenzie 2004). These deficiencies make it difficult to manage pest fish and their impacts.

In 2006, the National Vertebrate Pests Committee's (VPC) mandate broadened to include pest fish species. The VPC has become responsible for providing coordinated policy and planning solutions for alien fish. The VPC is establishing a Pest Fish Working Group to coordinate programs concerning pest fish management and the implementation of the Australian Pest Animal Strategy. The National Land and Water Resources Audit (NLWRA), as a major government initiative under the Natural Heritage Trust, has a key area of activity in collating natural resource information and linking regional, state/territory and national datasets. The NLWRA is also currently developing various indicators and standards for monitoring resource condition under the recently developed National Natural Resource Management Monitoring and Evaluation Framework (M&E framework). The

VPC recommended that pest fish be included in the invasive species areas of this framework. The NLWRA Advisory Council, before seeking approval from the Natural Resource Management Policies and Programs Committee for pest fish to be included, agreed to produce a scoping study to identify issues and recommendations for monitoring and measurement of pest fish and their impacts. This report provides this scoping study.

This report is a valuable step towards identifying whether the recommended monitoring, evaluation and reporting protocol for significant invasive terrestrial vertebrate pests is also suitable for aquatic vertebrate pests, to address the ongoing requirements under the M&E framework. It contains information derived from literature, reports, strategies and pest animal planning documents, as well as information from discussions with state and federal government agencies.

The report provides:

- a summary and review of the techniques available for measuring and monitoring pest fish distribution, abundance, and impacts
- an outline of the current research programs and management activities that measure and report fish information, including impacts information
- a series of recommendations for monitoring and reporting pest fish at various levels under the M&E framework.

1.2 Purpose of review for national monitoring

Monitoring of invasive species is fundamental to the development of effective and efficient management strategies to reduce pests and their impacts throughout Australia. Monitoring of invasive species populations is required to:

- identify priorities for immediate and future management (ie planning)
- evaluate previous management activities and make changes
- improve understanding and knowledge
- raise awareness and provide education on current and potential problems and opportunities.

Monitoring and evaluation are vital for the effective management of invasive animals in Australia. Monitoring, evaluation and reporting provides an environment to identify and collect information to help determine if management actions are producing desired results. Monitoring, evaluation and reporting is also required to establish whether changes in resource

condition have resulted from management actions. They are also vital at the local and regional level to identify control priorities and allow communities to initiate and practise sound management. Accurate information is needed to ensure that investment (at national, state and regional levels) is directed to the areas of highest priority and to assess what sort of difference investment is making. This is the case at the national and state scale where information is required to help make policy decisions, and at the regional and local scale where resource managers need meaningful information to make informed management decisions.

This report presents an overview of research, monitoring and management issues regarding alien fish throughout the jurisdictions of Australia, largely identified from federal and state government research and management programs. This report addresses key issues that need to be considered for the inclusion of alien fish within a national monitoring and evaluation framework.

1.3 National monitoring and evaluation framework

The M&E framework has been developed by the federal and state/territory governments to facilitate monitoring and reporting on the impact of the National Action Plan for Salinity and Water Quality and the Natural Heritage Trust. The framework identifies natural resource topics (Matters for Target) with the aim of assisting the assessment of the effectiveness of various programs. Each Matter for Target has a set of indicators that will be used as the guideline to monitor and report on the topic. The Invasive Species Matter for Target topic comprises vertebrate pests (invasive animals) and weeds themes. Alien fish have recently been considered for incorporation under the invasive species theme.

An important component in achieving a viable monitoring and evaluation framework to report on invasive species involves the development of standards and guidelines including the adoption and use of core monitoring and reporting attributes for surveying and mapping. The NLWRA in conjunction with the Invasive Animals Cooperative Research Centre; Department of Agriculture, Fisheries and Forestry; Department of the Environment and Water Resources (formerly the Department of Environment and Heritage); and the VPC recently developed and implemented a National Invasive Animals Work Plan. The work plan involved collaboration with all states and territories to report on the status of invasive animals in Australia, and progress information to facilitate ongoing monitoring, reporting and evaluation activities. The work plan focuses on coordination and national reporting under the invasive species theme, and includes:

- establishment of national indicators for monitoring and reporting
- collation of existing state-based information
- development of information products under the M&E framework.

The inclusion of pest fish within the scope of the VPC and the M&E framework requires an evaluation of the suitability of existing indicators, protocols and monitoring framework for pest fish, to address the huge environmental problems stemming from pest fish.

1.4 Project terms of reference and definitions

The specific objectives of the review are to:

1. Identify the major pest fish species in Australia that have economic, environmental or social impacts.

2. Review the techniques available to measure and report the impacts, distribution and abundance of these fish species.

3. Present an overview of the current management, research and monitoring programs for fish species throughout Australia.

4. Provide recommendations for monitoring and reporting, and the requirements for a national assessment of introduced fish for the VPC and NLWRA.

There are a number of key terms used to describe pest fish; many are often used interchangeably leading to some confusion among readers. For this report, the following terms and definitions are used relevant to fish species and their management in Australia (modified from Clunie et al 2002):

alien	belonging to a foreign country; that has been intentionally or accidentally introduced as a result of human activities
established	a self-sustaining population, breeding successfully
exotic	originating from a foreign country; imported species that is not found outside captivity
feral	in a wild state, especially after being domesticated or cultivated
imported	brought into the county from a foreign location
invasive	alien that produces reproductive offspring, often in large numbers and at great distance from parents
introduced	found in the wild; feral; released but not breeding successfully
naturalised	alien that reproduces and sustains populations without human intervention, often close to parent individuals, not necessarily invasive

noxious	harmful or poisonous; often has a specific meaning in legislation in relation to non-native species
pest	an animal that has, or has the potential to have, a detrimental effect on economic, social or conservation values or resources.

2. Which inland fish species are pests in Australia?

2.1 History of introduction of pest fish to Australia

Almost all of the pest fish species established in Australian freshwaters today were deliberately introduced (Arthington and McKenzie 1997), and while their introductions fulfilled a range of needs, in some cases these needs have since been overshadowed by their significance as pest species. There have been three distinguishable phases of introductions: the acclimatisation movement in the mid-late 1800's (Arthington and McKenzie 1997, Lintermans 2004), liberation of eastern gambusia in the 1920s to control mosquito populations (Arthington and McKenzie 1997, Lintermans 2004) and introductions for aquaculture and aquarium purposes. Many of the deliberate introductions of alien fish species have occurred in the south-eastern and south-western regions of Australia, while most pest aquarium species currently inhabit the tropical and subtropical parts of the country (Kailola 2000).

Recent research suggests that there are approximately 34 alien fish species from eight families that have established populations in the wild (Table 1) (Kailola 2000, Lintermans 2004). Some species are widely distributed across several states/territories (eg carp), while others are localised in a specific region (eg Mozambique tilapia). Twenty-two species have resulted from ornamental/aquarium releases, eight from acclimatisation practices, one from aquaculture (common carp), one for biocontrol (eastern gambusia) and two species from ballast water (Lintermans 2004). Several salmonid species (in particular, brown trout and rainbow trout) are currently maintained by regular fish stocking activities. Despite these general findings, accurate distributional data for many species is often severely lacking. Of particular concern is that there has been a steady increase in the number and fish species being introduced and becoming established in Australia in recent years (Koehn and Mackenzie 2004, Lintermans 2004). There are also a number of additional species that are considered 'emerging' or kept in captivity but have not yet become established (ie having self-sustaining populations) in the wild (eg Rosy barb in Queensland). Some of these species are not yet included in priority species lists (eg Kailola 2000) as their reproductive status in the wild remains uncertain (Allen et al 2002).

Although most pest fish species in Australia were intentionally introduced for the aquarium and ornamental fish trade (McNee 2002, Lintermans 2004), many species have spread or have been dispersed throughout the country. There are a variety of pathways for the transportation and dispersal of fish and an understanding of these mechanisms is essential to prevent or reduce opportunities for their establishment (Crooks and Soule 1999 in Lintermans 2004). Fish are most often relocated into new areas through human intervention (Arthington and McKenzie 1997, Kailola 2000, Lintermans 2004). There are numerous mechanisms of human-assisted dispersal of alien fish (Lintermans 2004), including fish stocking; discarding of aquarium fish; deliberate introduction for biocontrol; recreational/commercial fishing practices; escapees from ponds, dams and aquaculture; and accidental contaminants (Lintermans 2004).

Table 1: Freshwater fish species introduced to Australia and reasons for introduction
(adapted from Arthington and McKenzie 1977, Lintermans 2004)

Family	Common name	Species	Reason for introduction
Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	Acclimatisation
	Atlantic salmon*	*Salmo salar*	Acclimatisation
	Quinnat or Chinook salmon*	*Oncorhynchus tshawytscha*	Acclimatisation
	Brown trout	*Salmo trutta*	Acclimatisation
	Brook trout	*Salvelinus fontinalis*	Acclimatisation
Cyprinidae	Goldfish	*Carassius auratus*	Ornamental
	Carp	*Cyprinus carpio*	Ornamental, aquaculture
	Tench	*Tinca tinca*	Acclimatisation
	Rosy barb	*Puntius conchonius*	Unsure
	Roach	*Rutilus rutilus*	Acclimatisation
	White cloud mountain minnow	*Tanichthys albonubes*	Ornamental
Percidae	Redfin perch	*Perca fluviatilis*	Acclimatisation
Poecilidae	Eastern gambusia	*Gambusia holbrooki*	Acclimatisation, biological control
	One-spot livebearer	*Phalloceros caudimaculatus*	Ornamental
	Sailfin molly	*Poecilia latipinna*	Ornamental
	Guppy	*Poecilia reticulata*	Ornamental
	Green swordtail	*Xiphophorus hellerii*	Ornamental
	Platy	*Xiphophorus maculatus*	Ornamental
Cichlidae	Oscar	*Astronotus ocellatus*	Ornamental
	Convict cichlid	*Archocentrus nigrofasciatus*	Ornamental
	Black mangrove cichlid	*Tilapia mariae*	Ornamental
	Redbelly tilapia	*Tilapia zillii*	Ornamental
Cichlidae	Three-spot cichlid	*Cichlasoma trimaculatum*	Ornamental
	Victoria Burtons Haplochromis	*Haplochromis bimaculatus*	Ornamental
	Jewel cichlid	*Hemichromis bimaculatus*	Ornamental

Table 1: Freshwater fish species introduced to Australia and reasons for introduction
(adapted from Arthington and McKenzie 1977, Lintermans 2004)

Family	Common name	Species	Reason for introduction
	Mozambique tilapia	*Oreochromis mossambicus*	Ornamental
	Blue acara	*Aequidens pulcher*	Ornamental
	Jack Dempsey	*Cichlasoma octofasciatum*	Ornamental
Cobitidae	Oriental weatherloach	*Misgurnus anguillicaudatus*	Ornamental
Belontiidae	Three-spot gourami	*Trichogaster trichopterus*	Ornamental
Gobiidae	Streaked goby	*Acentrogobius pflaumii*	Accidental (ballast-water/shipment)
	Yellowfin goby	*Acanthogobius flavimanus*	Accidental (ballast-water/shipment)

For more information on alien freshwater fish species in Australia, see Appendix 1.

2.2 Problems caused by alien fish

Freshwater environments worldwide are significantly threatened by the introduction of alien species (Moyle and Light 1996). Long-term climate change on a global and regional scale is also expected to alter the distributions and life histories of many species (McLaughlin et al 2002) and may affect the number of new invasions of pests. Exotic species are likely to continue to increase worldwide over the next century (Moyle and Light 1996, Sala et al 2000). In Australia, freshwater systems, although diverse in range from tropical to alpine, are particularly susceptible to invasion because of the country's arid climate and geographic isolation (Lintermans 2004). Invasive fish species are known to cause a number of adverse environmental, economic and social impacts. However, there is a lack of quantified data about the impacts of most pest fish species (Kailola 2000, Koehn and Mackenzie 2004).

Although most evidence about the impacts of alien fish is circumstantial, some of the problems identified from introduced fish include:

- damage to biodiversity (Arthington and McKenzie 1997, Bomford and Glover 2004)
- decline of macro-invertebrates and gastropods (Arthington and McKenzie 1997)
- habitat change (Arthington and McKenzie 1997, Keller and Lake 2007)

- significant alterations to freshwater ecosystems (Bomford and Glover 2004)
- competition with native species, including threatened and vulnerable species (Townsend 1996, Arthington and McKenzie 1997, Kailola 2000)
- introduction of parasites (Keller and Lake 2007)
- negative impact on agricultural and aquaculture industries (Kailola 2000)
- degradation of aquatic habitats and water quality (Kailola 2000).

The introduction of alien fish has also been implicated in causing significant declines in the diversity, range and abundance of freshwater fish within Australia's rivers (Smith and Hammer 2006). Alien fish, such as carp, can also reduce the suitability of habitats for native fish species (Bomford and Hart 2002). In New South Wales, the introduction of alien fish has been listed as a key threatening process (NSW Department of Primary Industries 2005b).

There is generally a lack of detailed knowledge about the impacts of pest fish because of a limited amount of research. Historically, research programs have tended to focus mainly on determining the environmental impacts of recognised pest fish species (mosquito fish, swordtails, redfin perch, brown trout, rainbow trout, carp, goldfish and oriental weatherloach) in key locations (ie specific rivers and wetlands), or on specific environmental variables (eg threatened species). There has been some research on the interactions between native and non-native species such as predation, competitive displacement, habitat modification and disease transmission (Kailola 2000). However, there is a significant lack of quantified research on the economic and social impacts of pest species, particularly across jurisdictions. As a result, there is often an inadequate presentation of triple-bottom-line impacts of pest fish across state and territory jurisdictions.

There are a number of adverse impacts of alien fish in Australia that are further discussed in Chapter 6.

2.3 Aquarium and ornamental fish

In Australia, the trade in aquarium fish represents a significant industry estimated to be worth up to $90 million (McNee 2002). An estimated 800 pet stores nationwide trade in aquarium fish, supporting an estimated total pet fish population of 22 million (McNee 2002). The import of live fish into Australia is regulated by the Commonwealth *Environment Protection and Biodiversity Conservation Amendment (Wildlife Protection) Act 1999* (EPBC Act) and stringent quarantine and importation policy. Under this Act, live specimens are listed in two parts including those that do not require an import permit and those that do require an import permit (Kailola, undated). The number

and diversity of exotic fish species traded by domestic aquarium fish keepers in the past has been estimated at 1181 species, of which only 481 species are currently permitted to be imported into Australia. Biosecurity Australia's import risk analysis process identifies potential quarantine risks and develops policy to manage them (eg ornamental finfish www.daff.gov.au/ba/ira).

Within Australia, current state and territory legislation regulates domestic breeding, possession and movement of fish species within the aquarium trade (McNee 2002). However, inconsistency between legislation has also made it difficult to control trade and movement of aquarium fish between jurisdictions. 'Backyard breeding' of banned species is common, and these fish are widely traded (Arthington and McKenzie 1997). Of the fish species supplied for the aquarium trade, approximately 60% are bred and supplied domestically and 40% are imported. However, illegally imported fish also account for up to 10% of the fish imported into Australia, and smuggling is largely commercially driven (AQIS in McNee 2002). Some reports suggest there are many species illegally traded that are not listed under permitted species import lists of the EPBC Act (McNee 2002).

Aquarium and ornamental fish, if deliberately or accidentally released in Australia, present significant risks. These risks include the potential to become pests in Australia's freshwater rivers and wetlands, and to be vectors for the transmission of a number of serious exotic diseases that may threaten the commercial aquaculture industry (McNee 2002).

Several aquarium species, such as oriental weatherloach and goldfish, have become established in the wild as a result of accidental or deliberate release from aquariums (PIRSA 2007). For this reason, state and territory authorities typically impose penalties for the release of live fish into waterways without a permit (McNee 2002).

There have been more than 1,000 exotic fish species imported into Australia over the past 40 years (McNee 2002), around 50% of introductions have resulted in new populations establishing in the wild (Bomford and Glover 2004). The potential for aquarium and ornamental fish species to become pests in the wild is considered extremely high. A list of fish permitted to be imported into Australia (225 species in total) is maintained by the Australian Department of Environment and Water Resources under the EPBC Act 1999 (See www.daff.gov.au/aquis/icon). However, a list of additional species currently occurring in Australia is not presented. As a result, there is a need to resolve inconsistencies regarding regulations for the keeping and trade of freshwater fish species, and a need for agreement at a national level on a list of alien fish species that should continue to be made available/permitted for the domestic aquarium trade (McNee 2002).

2.4 Recreational fishing activities

Freshwater recreational angling is a major industry in Australia (Kailola et al 1993, see also Henry and Lyle 2003) and the demand for recreational fishing has been a significant cause of deliberate introductions of many fish species (Arthington and McKenzie 1997). There is a long history of deliberate releases and fish stocking of many alien fish species, particularly salmonids for

recreational fishing and aquaculture. Inland fisheries are currently managed by state and territory governments, and only a small number of species support the multimillion dollar recreational fishing industry in Australia (Arthington and McKenzie 1997).

The two main recreational fishing activities that have been identified as contributing to the introduction of alien species to many areas are direct translocation of fish species by recreational anglers, and use of live fin-fish as bait (Tempest in Lintermans 2004). The use of exotic species to feed cultivated fish stocks, and escape of fish have also been identified as practices that lead to the introduction of alien species (Arthington and McKenzie 1997).

Human-assisted dispersal is a serious issue regarding the spread of exotic fish throughout areas suitable for recreational fishing or commercial aquaculture activities. Despite the value of the recreational fishing industry, based largely on the use and introduction of alien species, there is no other instance in Australia where alien species are deliberately released where their pest potential is so well documented (Lintermans 2004).

Consistent with the scenario presented by aquarium and ornamental fish, there are risks presented by the introduction and translocation of alien fish to rivers for recreational fishing pursuits. These risks include direct and indirect ecological and environmental impacts, and introduction of various diseases that may threaten native aquatic species or impact on aquaculture industries.

In recent years there has been an alarming increase in the number of new alien fish species being detected in the rivers of many states and territories. Controlling the release of species for recreational activities, and reducing the risk of accidental release is imperative to slow the establishment of new species in the wild. While recreational fishing represents a major industry in Australia, there is a critical need to regulate the introduction of alien fish for recreational activities to reduce further problems caused by alien species as pests in Australia. In 1999, the Ministerial Council on Forestry, Fisheries and Aquaculture prepared a national policy for the translocation of live aquatic organisms.

Recreational anglers can make a valuable contribution to the management and control of pest fish and waterways. They can play an integral role in the monitoring and reporting of pest fish by reporting any sightings/capture of alien species to relevant local and state authorities. They can also help to control alien fish by destroying any alien fish that are caught.

2.5 Legislation relating to introduced fish

In Australia, introduced fish have traditionally been excluded from vertebrate pest management policy and legislation. However, there are a number of important legislative frameworks and accompanying Acts that regulate the keeping, transportation, trade and release of freshwater fish species.

The importation of fish is regulated by Australian importation and quarantine policy at a national level. However, domestic activities are regulated by state

and territory governments, and there are many inconsistencies in legislation regarding introduced fish across state and territory jurisdictions (Arthington and McKenzie 1997). Many exotic species are openly traded across jurisdictions, increasing the risk of new incursions in the wild (McNee 2002). All state, territory and federal governments are responsible for the management of fish, and there is an urgent need for uniformity in legislation to reduce the problems of alien fish in Australia (Arthington and McKenzie 1997, Koehn and Mackenzie 2004). Table 2 presents relevant legislation in each jurisdiction used to regulate and control exotic fish.

2.6 National priority species list

Throughout Australia, the number of alien freshwater fish being identified in the wild is rising.

There are several impediments to the national consistent management of alien/pest fish in Australia. These impediments include:

- differences between the current permitted import species list and the species currently kept by aquarium keepers (McNee 2002)
- inconsistencies in legislation and application of policy across federal and state/territory jurisdictions (Koehn and McDowall 2004) particularly regarding permitted and 'noxious' species, which means many species are openly traded and by-pass border surveillance
- lack of a rapid response plan for new pest fish incursions in Australia
- lack of a national priority species list to regulate and control exotic/alien freshwater fish, and monitoring and reporting.

To address these issues regarding alien fish management in Australia, a number of recommended priority actions were presented by Koehn and Mackenzie (2004). They suggested that the national management of alien/pest fish in Australia requires:

- development and implementation of a national alien fish management strategy
- national consistency in jurisdictional legislation and management approaches
- revision of existing national permitted and 'noxious' fish species lists

Table 2: Summary of relevant state/territory and Commonwealth legislation	
National (Commonwealth) Regulated by Department of Environment and Water Resources Australian Quarantine Inspection Service Australian Fisheries Management Authority	*Environmental Protection and Biodiversity Conservation Act 1999* *Fisheries Management Act* and *Regulations 1991* *Quarantine Act 1908* *Endangered Species Protection Act 1992*
New South Wales Regulated by Department of Primary Industries	*Fisheries Management Act 1994* *Stock Diseases Act 1923*
Queensland Regulated by Department of Primary Industries	*Fisheries Act 1994* *Fisheries Regulation 1995*
South Australia Regulated by Primary Industries and Resources South Australia	*Fisheries Act 1982* *Livestock Act 1997* *Fisheries Regulations (Exotic fish, fish farming and fish diseases) 2000*
Victoria Regulated by Department of Primary Industries	*Fisheries Act 1995* *Livestock Disease Control Act 1994*
Western Australia Regulated by Department of Fisheries, Dept of Agriculture and Food	*Fish Resources Management Act 1994* *Exotic Diseases of Animals Act 1993*
Northern Territory Regulated by Department of Primary Industry, Fisheries and Mines	*Fisheries Act 1988 and Regulations*
Tasmania Regulated by Department of Primary Industries and Water	*Inland Fisheries Act 1995* *Inland Fisheries Regulations 1996*
Australian Capital Territory Regulated by Department of Territory and Municipal Services	*Fisheries Act 2000* *Nature Conservation Act 1980* *Pest Plants and Animals Act 2005*

- recognition of national and state vertebrate pest policies and legislation
- dedicated alien fish monitoring at local and regional levels
- a national survey to collate distribution data for alien fish and a national distribution database for alien fish
- inclusion of alien fish distribution and abundance as an indicator of river health.

In 2006, the 'Strategic Approach to the Management of Ornamental Fish in Australia' (Department of Agriculture Fisheries and Forestry 2005) was released. It highlights the inconsistency between mechanisms and controls across regulatory agencies to deal with serious alien pests, and predicts that unless consistency is reached at a national scale, further alien invasions and disease threats will emerge. It recommends the need for a nationally recognised noxious species list, and presents a proposed national alien species list.

We recommend that advice be sought regarding a national noxious species list that can be used to regulate management across jurisdictions, and represent a national priority list for monitoring, from the Vertebrate Pests Committee, relevant Australian Government agencies (Department of Agriculture, Fisheries and Forestry; Department of Environment and Water Resources and Australian Fisheries Management Authority), state/territory government authorities, as well as research and industry groups (including recreational fishing and ornamental fish industries).

3. Management strategies relevant to pest fish

The management of alien fish in Australia requires a coordinated approach between government, industry, research and the broader community. Consistency in legislation, policy, management, monitoring and control is also needed to manage alien fish and their impacts. There are presently a number of management strategies that have been developed for the management of pest animals in Australia, and others that directly address alien fish and their impacts. Here, we present a brief summary of strategies relevant to the management and control of alien fish at national, state/territory and regional levels.

3.1 National strategies

The Australian Pest Animal Strategy was developed in 2006, and is the first national strategy to address vertebrate pest animals including fish. It provides a national framework for the management of pest animals and their impacts over the next 5 years.

There are presently three main fish-specific management strategies relevant to alien fish in Australia. They are:

1. The National Management Strategy for Carp Control 2000-2005
2. The Strategic Approach to the Management of Ornamental Fish
3. The Native Fish Strategy for the Murray-Darling Basin 2003-2013.

The Native Fish Strategy (NFS) was approved by the Murray-Darling Basin Ministerial Council in 2003 for release in 2004. The NFS is a 50-year plan implemented in 10-year stages, which aims to rehabilitate native fish populations to 60% of pre-European levels in 50 years. The strategy operates in conjunction with other major initiatives and is driven by six actions that promote an integrated approach to rehabilitating native fish populations in the broader context of riverine restoration. There is a NFS coordinator in each jurisdiction, and a working group of the NFS agreed on the need for a Basinwide Pest Fish Plan. The plan will aim to:

- establish a framework for the management of alien fish species
- protect native fish populations and habitats by minimising risks
- incorporate alien species management into the broader framework of river rehabilitation
- limit the further spread of alien species and prevent the introduction of new alien species

- apply an integrated approach to the management of alien species, with the focus on reducing the impacts of alien species rather than their density.

Each of these strategies aims to provide coordination and direction through an integrated approach to the management of alien fish at a national or basinwide level. The goals that are common to each management strategy include:

- prevention of the establishment and spread of pests
- control, management and reduction of pest impacts
- best practice vertebrate pest management
- monitoring and evaluation
- education and awareness.

Although these strategies collectively provide an important step towards the management of pest species in Australia, many authorities have recommended the development of a national alien/pest fish management strategy. Development and implementation of such as strategy, like the Basinwide Pest Fish Plan, would seek to reach agreement of a consistent, cost-effective and integrated approach to managing alien fish throughout Australia.

3.2 State/territory strategies

Many states and territories have developed statewide pest animal strategies that address alien fish. There are strategies that have been developed for the direct stocking of game fish and fisheries development in inland waters (eg NSW Department of Primary Industries 2003, Northern Territory Fisheries Research Advisory Board 2004). There are also strategies that have been simultaneously developed for control of pest fish.

The state-based management strategies that address pest animals and alien fish located as part of this review include the following:

1. The Queensland Pest Animal Strategy 2002-2006 (Department of Natural Resources and Mines 2002). This strategy aims to reduce the level of impact of pest and problem animals on environmental, social and production values. It presents a statewide planning framework to provide direction to government, industry and managers. It supports the prevention of establishment and spread of pests, reduction of the impacts of emerging and existing populations, and education, through effective management and planning.

2. The Control of Exotic Pest Fishes – An Operational Strategy (MacKenzie et al 2001). This strategy was developed as a

complement to the National Carp Strategy 2000-2005 (see 3.1) and the Queensland Pest Animal Strategy 2002-2006 (MacKenzie et al 2001). This strategy has seven goals and supports similar objectives to the Queensland Pest Animals Strategy. At present, the Control of Exotic Pest Fishes Strategy is the only strategy that addresses a number of species simultaneously (MacKenzie et al 2001, Murray-Darling Basin Commission 2004b).

3. The Victorian Pest Management – a Framework for Action (or VPMF) (Department of Natural Resources and Environment 2002). This is the first strategy of its kind in Victoria. It has been developed to provide strategic direction for the management of declared and potential pests. It also identifies key actions, responsibilities, timelines and collaboration required for effective management. Specific management strategies have been developed for weeds and other terrestrial species, while exotic invasive fish are included under the VPMF (For further information, see http://www.dse.vic.gov.au/DSE)

4. The ACT Pest Management Strategy (Environment ACT 2002). This strategy similarly addresses terrestrial and aquatic pest species (including alien fish) through a regulatory framework that is designed to maintain or increase management efficiency and effectiveness. It lists seven pest fish species that are relevant to the Australian Capital Territory.

5. The Northern Territory Strategic Plan for Fisheries Research and Development 2005-2009 (Northern Territory Fisheries Research Advisory Board 2004). This strategy is designed to ensure sustainable fisheries industries in the Northern Territory and fisheries resource development. It provides a platform for a number of control-based projects on alien species and prevention of further species establishment.

6. The Guidelines for Assessing Translocations of Live Aquatic Organisms in Victoria 2003. These guidelines provide a framework for Victoria to meet national requirements for a consistent approach to manage fish translocations. The guidelines use a risk-based framework to assess proposals for the translocation of aquatic organisms within and between water bodies in Victoria, and work with specific protocols (see 7 below) to regulate translocations of aquatic organisms.

7. Protocols for the Translocation of Fish in Victorian Inland Public Waters were developed and released in 2003 to address proposals that require approval under the *Fisheries Act 1995*. They are used with the guidelines listed above (see 6).

3.3 Regional strategies

Strategic planning and management of alien fish at a regional scale requires further attention from relevant regional authorities and regional groups. The establishment of 56 natural resource management (NRM) regions across Australia provides a platform for region-specific strategies and management plans for pest fish. Regional strategies can also be based on existing major river basins, catchment areas and national park regions. Collectively, they require coordination between the relevant regional jurisdictions and the respective state strategies.

Examples of regional management strategies that address pest animals and alien fish include the following:

1. The South Australian Arid Lands NRM Pest Management Strategy 2005-2010 (Pitt et al 2006). This strategy is an example of a regional pest strategy that incorporates invasive fish. Through prevention and early detection, and effective management of pest impacts, the strategy seeks to provide a framework for improved pest management.

2. Management Strategies for New South Wales National Parks and Wildlife Service (NPWS). Strategies were prepared for five NPWS regions throughout New South Wales that identify pest populations and establish priority control programs. These strategies provide good models for the development of alien fish strategies at the regional level, and potentially allow for the inclusion of alien fish as a pest species of major concern (for more information, see http://www.nationalparks.nsw.gov.au/ > Nature and conservation > Pests and other threats > Pest management programs).

3.4 Further information

1. The National Management Strategy for Carp Control, available from the Murray-Darling Basin Commission website http://www.mdbc.gov.au

2. The Strategic Approach to the Management of Ornamental Fish, available at http://www.affashop.gov.au/product.asp?prodid=13332

3. The Native Fish Strategy for the Murray-Darling Basin, available at http://www.mdbc.gov.au/NFS.

4. Queensland Pest Animal Strategy and Control of Exotic Fishes Strategy, available at http://www.dpi.qld.gov.au/ > Fisheries > Exotic pest fish http://www.nrw.qld.gov.au/pests/management_plans/plans/state/index.html

4. Indicators of pest fish in Australia

4.1 Indicators of river condition and the impacts of alien fish

There are two types of indicators regarding alien fish:

1. Indicators that measure and report the condition of a particular natural resource attribute (river health).

2. Indicators that measure and report the impacts of a particular alien fish species.

Alien fish are often used as indicators of the biological integrity of rivers (or river health) (Kennard et al 2005) because they are assumed to be a symptom of river condition, and fluctuate in response to changes in disturbances (such as turbidity). Fish are also highly mobile, exhibit long lifespans and occupy high trophic levels, making them suitable measures of long-term change. The use of alien fish as an indicator of river health assumes a correlation between alien fish species and disturbed environments (Kennard et al 2005); however some alien fish, such as salmonids, prefer undisturbed rivers (W. Fulton, pers comm 2007). In most cases, the presence of an alien species indicates a deviation from the natural condition of the aquatic environment and thus infers some level of decline in aquatic biodiversity (Kennard et al 2005). For this reason, a suite of indicators including the occurrence of introduced species, exotic species richness, relative abundance of exotic species and biomass of exotic species are often used in river bioassessment studies to report river health (Kennard et al 2005).

Indicators can also be categorised as being direct (or primary) or indirect (secondary or surrogate). Direct indicators are those that directly demonstrate the effects of introduced species on rivers and wetlands and their associated ecosystems (Arthington and McKenzie 1997): for example, change in the population demographics (age structure) of native fish (in Arthington and McKenzie 1997). Indirect indicators are those that measure alternative attributes that are assumed to correlate with the resource/species in question. Examples of indirect indicators are measurements of species distribution and abundance where impacts are not easily measured, or rates of introduction of exotic species into Australia (Arthington and McKenzie 1997).

4.2 National indicators for significant invasive vertebrate pests

Monitoring and evaluation are vital to effectively manage invasive animals in Australia. In recent years, a national natural resource management (NRM) monitoring and evaluation (M&E) framework was established by the state, territory and Commonwealth governments to facilitate monitoring and reporting on the condition of natural resources and the impact of the investment programs. The M&E framework was approved by the Natural Resource Management Ministerial Council (NRMMC), and was established to assess progress towards improved natural resource condition through

the development of accurate, cost-effective and timely information on the condition of natural resources and the performance of programs, strategies and policies providing national approaches to the conservation, sustainable use and management of natural resources.

The national M&E framework sets out broad key issues or 'Matters for Target' that can be reported against using a range of indicators, with the aim of assisting the assessment of the effectiveness of various programs. Each matter for target has a set of indicators to be used as a guideline to monitor and report on the topic. The Invasive Species Matter for Target comprises weeds and vertebrate pests (invasive animals) themes. Under the vertebrate pests theme of the M&E framework, two national indicators were agreed to by all states and territories and endorsed by the national Vertebrate Pests Committee during 2006:

1. Distribution and abundance of significant invasive vertebrate pests.

2. Impacts of significant invasive vertebrate pests.

All states and territories, through NRM regional bodies, are presently reporting against these indicators, and advice is required to determine whether alien/pest fish should be included within the vertebrate pests theme under the M&E framework.

Alien species (in particular fish) are incorporated in two natural resource themes under the M&E framework. These themes are:

'Integrity of Inland Aquatic Ecosystems'

'Invasive Species – Significant Invasive Vertebrate Pests'

As mentioned in Section 4.1, alien fish are used as an indicator of river condition/health (Kennard et al 2005), and can be used (in combination with measurements of other environmental attributes) to assess river health. However, alien fish (like terrestrial vertebrate pests) are also directly responsible for adverse impacts, particularly to biodiversity and primary production. As such, they are simultaneously listed under a separate pest indicator (invasive species) in the M&E framework.

The invasive species theme relies on measurements of vertebrate pest distribution, abundance and direct measures of impact to assess the effectiveness of investment programs, and to set management priorities. Alien fish are measured and reported with other terrestrial species, including rabbits and introduced birds. Initial reporting of invasive species distribution, abundance and impacts has recently been finalised and includes common carp.

4.3 Indicators from national and state programs

Alien fish have been used as an indicator of the health of rivers and streams (as a symptom of poor ecological condition) or to measure the impacts of alien fish (as a cause of river degradation) in several programs throughout Australia. However, there has been no standardised approach across these initiatives/ programs to support consistency and comparability of outcomes. Each program has varied in its goals and implementation. The following is a summary of programs that have used alien fish as indicators to assess river health, or assess the impacts of alien fish on the environment.

4.3.1 State of Environment (SoE) Reports

http://www.environment.gov.au/soe/index.html

SoE reports provide information about environmental and heritage conditions, trends and pressures for the Australian continent, surrounding seas and Australia's external territories. National, state and territory SoE reports are based on data and information gathered and interpreted against environmental indicators, as a basis for ecologically sustainable development. SoE reports regularly assess indicators of changes in environmental condition and facilitate monitoring of the performance of government policies against definite outcomes (Whittington et al 2001). There were 263 indicators used to report on 174 critical issues across a number of reporting themes in the most recent national SoE report (Beeton et al 2006). One indicator is 'current research into pressures and contributions of naturalised introduced species'. It uses alien fish data to inform four reporting themes including 'Biodiversity' and 'Inland Waters'. The New South Wales SoE report (Department of Environment and Climate Change NSW 2006) used 71 environmental indicators to provide information on 37 environmental issues that were reported through six key themes. Exotic/alien and introduced fish are included as part of a number of indicators that fall under two themes: 'Biodiversity' and 'Water'. River health, as assessed by macro-invertebrates and fish assemblages, used introduced fish data compiled from various programs. Fish-related river health indices derived from these other programs, such as the Department of Primary Industries' fish community integrity index, were incorporated with other information to generate the SoE indicator.

4.3.2 Assessment of River Health / River Condition

Under the National Water Initiative, the Australian Water Resources 2005 (formerly the BWRA) was developed to provide a baseline model of water management and resource issues. It operates through five major themes, including 'River Health' (National Water Commission 2006a). Under the river health theme, the Assessment of River Health – Biota will include fish as an indicator of biotic condition (National Water Commission 2006b). Using comparable indicator data from the Sustainable Rivers Audit and the South-East Queensland Ecosystem Health Monitoring Program (see below), a fish-based indicator (based on alien species presence, richness and relative abundance) is being considered to be compared with the reference condition (ie no alien fish) (National Water Commission 2006b).

4.3.3 Murray-Darling Basin Sustainable Rivers Audit (SRA)

http://www.mdbc.gov.au/SRA

The Sustainable Rivers Audit Pilot (2002-2003) developed a number of indicators, grouped under five themes, including 'Fish', to be used in the implementation of the SRA (see Section 8.1). Thirteen fish indicators were recommended, eight of which relate directly to alien fish, as described in Table 3. Fish indicators are to be measured once every three years at 23 sites in the Murray-Darling Basin and the information gathered will be used to determine the effectiveness of current management practices in sustaining river health (Murray-Darling Basin Commission 2003).

4.3.4 South-East Queensland – Ecosystem Health Monitoring Program

http://www.ehmp.org/freshwater_methods_and_indicators.html

The South-East Queensland Ecosystem Health Monitoring Program was developed as an integrated regional ecosystem health assessment program to monitor management of the region's aquatic ecosystem assets. A range of biological, physical and chemical indicators are measured to provide information about the condition of waterways. The 'Freshwater' component uses fish as an indicator 'because they reflect a number of natural and human-influenced disturbances through changes in abundance and species composition' (Ecosystem Health and Monitoring Program 2006). Fish are also used because they present an integrated measure of stream condition (due to their mobility, long lifespan, and high trophic level). Three metrics were developed for the fish indicator, including 'Proportion of alien fish'.

4.3.5 Integrated Monitoring of Environmental Flows

http://www.dnr.nsw.gov.au/care/water/imef/index.html

The New South Wales Integrated Monitoring of Environmental Flows scheme was designed to assess ecological responses to changed river flows following the introduction of flow rules for major regulated rivers (Egerrup and Growns 2001, Whittington et al 2001). Freshwater fish are one of the environmental indicators that are measured as part of the monitoring program. Improved environmental flows are expected to assist the recovery of native fish populations, therefore the presence of alien fish and their associated impacts (eg predation) can indicate the outcomes of the scheme.

4.3.6 Victorian Water Resources Data Warehouse

http://www.epa.vic.gov.au/water/environment/default.asp

Since the completion of the 1996 Review of Environmental Water Quality Monitoring in Victoria, the Victorian Catchment Management Council, in partnership with the Department of Sustainability and Environment and Environmental Protection Agency, has improved environmental water quality assessment in Victoria, An integrated, coordinated and resource efficient approach to water quality monitoring has been implemented by:

Table 3: Alien fish related indicators recommended for the Sustainable Rivers Audit (adapted from Murray-Darling Basin Commission 2003).	
Indicator (alien and native)	**Description**
Total species richness	Compares total species richness with a predicted maximum species richness
Benthic species richness	Compares species richness of benthic fishes to a predicted species richness
Pelagic species richness	Compares the species richness of pelagic fishes to a predicted species richness
Intolerant species richness	Compares the occurrence of species known to be intolerant to various disturbances (eg low water quality) to a predicted number of species
Proportion macro-carnivores	Measures the proportion of individual fish that are macro-carnivores
Porportion mega-carnivores	Measures the proportion of individual fish that are mega-carnivores
Total abundance	Compares the total number of fish caught with the predicted number expected
Fish with abnormalities	Measures the number of fish with diseases, parasites or abnormalities.

- removal of duplication between monitoring programs
- statewide coordination of methodologies
- a change to annual reporting to provide interpretation and management information at both a statewide and catchment management authority scale
- provision of a statewide database of water quality information on the internet.

All water quality information for Victoria's rivers, streams, lakes and water storages is incorporated into the statewide network, with data accessible in raw and summary form online via the Victorian Water Resources Data Warehouse.

5. Monitoring techniques for detecting and measuring alien fish populations

5.1 Summary of alien fish distribution and abundance information

Information of the distribution of alien species throughout Australia has been summarised and presented by many authors (see Table 4; Arthington and McKenzie 1997, Arthington et al 1999, Lintermans 2004, Kailola undated). However, while broadscale distribution information has been recorded for the more abundant alien fish species (including carp, brown trout, rainbow trout, mosquito fish/gambusia, redfin and oriental weatherloach) there is little, if any, published information on the distribution and abundance of lesser-known alien fish species such as rosy barb and one-spot livebearer (Dawson 2005). Furthermore, the methods used to measure and report alien fish have varied, particularly in scale and rigour, leading to incomparable outputs. Accurate distributional data for many of the less abundant alien fish species is severely lacking, and there is a need for a national survey of alien fish distribution and abundance using consistent methods and sampling techniques (Koehn and Mackenzie 2004). There are a number of initiatives that present information on the distribution and abundance of alien fish from surveys and river assessments in Australia. The main sources are as follows:

- The National Water Commission (NWC) developed Australian Water Resources 2005 to assess a range of performance indicators in regard to the management of Australia's water resources. Fish have been nominated for inclusion in surveys for the River Health theme (National Water Commission 2006b), and results could potentially generate presence-abundance data, and distributional information for alien fish that are detected.

- The Sustainable Rivers Audit (SRA) is an ongoing river health assessment program being implemented by the Murray-Darling Basin Commission (MDBC). To date, the SRA has produced presence, abundance and distributional data for native and alien fish across the Murray-Darling Basin. The Pilot SRA developed indicators and methods for river health assessment (see Section 4.3) while the Fish theme trialled standardised methods for fish bioassessment (see Section 6.3) (Murray-Darling Basin Commission 2003, Davies 2004).

- The River Murray Wetlands Baseline Surveys are major biological and physical surveys conducted within 38 wetlands along the Murray River in South Australia (http://murraywater.skmconsulting.com/, accessed May 2007). Survey projects that were undertaken in 2003/04 (Smith 2006a) and 2005/2006 (Smith 2006b) collected seasonal data on physical site characteristics and aquatic life, including fish.

- The NSW Rivers Survey was a collaborative project between NSW Fisheries and the Cooperative Research Centre (CRC) for Freshwater Ecology that addressed several objectives, including determining the abundance, distribution and habitat use of carp and other alien species in New South Wales rivers (Harris and Gehrke 1997). The statewide survey monitored presence and abundance of native and alien fish in New South Wales rivers, providing a comprehensive overview of river communities.

There are also a number of other sources of information on the distribution and abundance of alien fish in Australia (Table 5).

Table 4: Current known distribution of pest fish in Australia (adapted from Lintermans 2004, Kailola, undated, Arthington et al 1999, Arthington and McKenzie 1997).

Common name	**State / Territory**								
		NSW	QLD	VIC	ACT	TAS	SA	NT	WA
Rainbow Trout	*Oncorhynchus mykiss*	●		●	●	●	●		●
Atlantic Salmon*	*Salmo salar*	●		●		●			
Quinnat or Chinook Salmon*	*Oncorhynchus tshawytscha*			●					
Brown Trout	*Salmo trutta*	●	●	●	●	●	●		●
Brook Trout	*Salvelinus fontinalis*					●			
Goldfish	*Carassius auratus*	●	●	●	●		●		●
Carp	*Cyprinus carpio*	●	●	●		●	●		●
Tench	*Tinca tinca*	●		●		●	●		
Rosy Barb	*Puntius conchonius*								
Roach	*Rutilus rutilus*	●		●					
White Cloud Mountain Minnow	*Tanichthys albonubes*	●	●						
Redfin Perch	*Perca fluviatilis*	●		●	●	●	●		●
Eastern Gambusia	*Gambusia holbrooki*	●	●	●	●	●	●	●	●
One-spot Livebearer	*Phalloceros caudimaculatus*								●
Sailfin Molly	*Poecilia latipinna*		●						
Guppy	*Poecilia reticulata*		●						
Green Swordtail	*Xiphophorus hellerii*		●						
Platy	*Xiphophorus maculatus*		●						

Table 4: Current known distribution of pest fish in Australia (adapted from Lintermans 2004, Kailola, undated, Arthington et al 1999, Arthington and McKenzie 1997).

Common name	**State / Territory**								
Oscar	*Astronotus ocellatus*		•						
Convict Cichlid	*Archocentrus nigrofasciatus*			•					
Black Mangrove Cichlid	*Tilapia mariae*		•	•	?				
Redbelly Tilapia	*Tilapia zillii*								•
Three-spot Cichlid	*Cichlasoma trimaculatum*		•						
Victoria Burtons Haplochromis	*Haplochromis bimaculatus*		•						
Jewel Cichlid	*Hemichromis bimaculatus*		•					•	
Mozambique Tilapia	*Oreochromis mossambicus*		•						•
Blue Acara	*Aequidens pulcher*			•					
Jack Dempsey	*Cichlasoma octofasciatum*	•?							
Oriental Weatherloach	*Misgurnus anguillicaudatus*	•	•	•	•		?		?
Three-spot Gourami	*Trichogaster trichopterus*		•						
Streaked Goby	*Acentrogobius pflaumii*			•					
Yellowfin Goby	*Acanthogobius flavimanus*	•							

- • Confirmed to have established populations
- * Not reproducing but maintained by constant releases
- ? Unconfirmed reports, conflicting evidence in literature

5.2 Sampling techniques for freshwater fish

There are a number of techniques that have been employed throughout the inland waters of Australia to detect fish species and measure their abundance. The main techniques include electrofishing, traps and cages and netting. Other techniques include spotlighting, radio-telemetry, hook-and-line techniques and destructive sampling such as poisoning. Most techniques are labour intensive and require a number of trained staff to set up, maintain, check and operate. The specific sampling technique selected and used is largely dependent on the objective of sampling and the species likely to be present in an area. Other issues that influence the techniques used include operator expertise and skills, availability of equipment, costs and feasibility to site-specific circumstances (eg accessibility). The behaviour and activity of particular species is also an important variable to consider during the

Table 5: Sources of information on the distribution and abundance of alien fish in Australia

Title / Project	Date	Species	Data type	Location	Reference
National					
National compilation of significant vertebrate pest information	2006-7	Invasive vertebrate pests Carp	Spatial data, maps Distribution Abundance	Australiawide	NLWRA, IA CRC, States and Territories
Review of impacts of displaced/ introduced fauna		Introduced species	Distribution	Australiawide	Arthington and McKenzie 1997
Development of an alert list		Introduced species	Distribution	Australiawide	Kailola 2000
Fishes of the Murray-Darling Basin	2007	Native and introduced species	Distribution Abundance	Murray-Darling Basin	Lintermans 2007
Baseline environmental data - import of ornamental finfish	June 1999	Ornamental fish species	Climatic range Distribution	Australiawide	Arthington et al 1999
State / Territory					
Lake Eyre Basin Rivers Assessment		Native and Introduced	Surveys River condition	Lake Eyre - SA, QLD	http://www.environment.gov.au/
The distribution ... of carp in the upper Murray River		Carp	Distribution Abundance	Upper Murray River	Gilligan and Rayner 2007
Mapping the current distribution of fish in South-Australian Murray-Darling Basin		Carp, goldfish, tench, redfin perch, rainbow and brown trout, gambusia	Surveys and maps Distribution Abundance	SA Murray-Darling Basin	Smith and Hammer 2006
A biological survey of the Murray Mouth Reserves		Native and Exotic	Distribution Abundance	SA Murray River	Brandle 2002
Fish in the Upper Murrumbidgee catchment		9 introduced species	Distribution Abundance	Upper Murrumbidgee	Lintermans 2002
Fisheries Long-term Monitoring Program: Freshwater Report	2000-2001	Native and Exotic	Survey data	Selected Qld river systems	Jebreen et al 2002. See: http://www2.dpi.qld.gov.au
Distribution of introduced freshwater fishes in WA		10 introduced species	Distribution Maps	WA	Morgan et al 2004
Lakes Sorell and Crescent Carp Management Program	ongoing	Carp	Abundance	Lake Sorell and Crescent	Inland Fisheries Service 2000
Lake Richmond Fish Survey - 2nd survey		2 introduced species	Presence Abundance	Lake Richmond WA	Rose et al 2004
Dept. of Territory and Municipal Services (ACT) report series	> May 2005	Native and introduced	Distribution Abundance		http://www.tams.act.gov.au/live/environment/native_plants_and_animals/report_series

design of sampling programs. The level of fish activity may be influenced by biological and environmental variables such as behaviour, time of day and water temperature (Faragher and Rodgers 1997, Poos et al 2007). Variables such as population size, structure, behaviour, and habitat preference may necessitate the use of a wide range of sampling techniques and equipment to obtain a representative sample from an area.

Some techniques present a number of risks that operators need to be aware of during the design and application of sampling. Careful evaluation of the advantages and disadvantages (such as potential non-target species' impacts and longer term adverse effects) of each technique needs to be undertaken prior to application of sampling techniques.

5.2.1 Electrofishing

Electrofishing is a non-lethal active sampling technique, most effective in clear, shallow waters (less than 4 metre depth; ie rivers and lake margins). Electrofishing can be undertaken from a boat for large stream and water bodies, or from portable backpack or bank-mounted systems for smaller creeks and ponds. Both approaches use a controlled electric current applied to a water body using electrodes that induces a physiological reaction in the nervous system of fish. Depending on distance and orientation of the fish from the anodes, the reactions can range from mild muscular movements to electronarcosis and result in affected fish exhibiting involuntary swimming patterns, irregular orientation, immobilisation or floating to the water surface (Backiel and Welcomme 1980).

Regarding the suitability of electrofishing, it is best to undertake electrofishing at sites where water turbidity is low and water conductivity is mid-range (100-500 μ S cm^{-1}) (Faragher and Rodgers 1997). Sampling can involve a number of electric shocks or multiple passes of a river channel. The practice often varies with habitat type and area. All species and sizes of fish are susceptible to the electric field, but some species are more sensitive to the electric current than others. Other factors that influence the effectiveness of electrofishing include: operator experience, fish size, water conductivity and degree of electric stimulation (Faragher and Rodgers 1997). Understanding the sensitivity of species is important when designing and implementing sampling, for instance, the oriental weatherloach does not float when shocked (Keller and Lake 2007). Once immobilised, fish are usually collected from the water using a dip net or equivalent, and temporarily stored for identification, examination and recovery before being released.

5.2.2 Electroseining

A method not widely employed in Australia, electroseining involves the use of a modified electrofishing system consisting of two arms that extend out from each side of an electrofishing vessel (Gilligan et al 2005). Haul nets are used simultaneously to herd fish along the waterway to facilitate the harvest of shocked fish. Operation of an electroseine requires a minimum of four personnel to operate the boat, support boats and the setting and retrieval of the haul net (Gilligan et al 2005).

5.2.3 Traps and cages

There are a number of trap designs and techniques that can be implemented to detect the presence of a pest fish species in waterways. Traps and cages are usually constructed from wire, timber, metal, netting or plastic products which can be stationary (fixed location) or portable. Traps have been used to sample adults and juveniles of both migrating and resident fish species (Food and Agriculture Organisation of the United Nations 2001, Smith 2006a).

5.2.4 Gee traps

Gee traps are small oval funnel traps (approximately 350 mm long and 200 mm in diameter) often constructed from galvanised wire mesh (3 mm square mesh) with a funnel-style entrance in each end that tapers to a narrow 15 mm opening. Gee traps are suitable for detecting the presence of small fish (ie <150 mm length) and can be used in a variety of habitats. While it is not essential to bait Gee traps, baiting has been identified as significantly increasing trap success. They are a non-destructive sampling method, involving trap and release principles (Faragher and Rodgers 1997). Gee traps can be modified to trap a range of different sized fish species.

5.2.5 Bait traps

Baited fish traps are generally small traps (approximately 40 cm long, 24 cm deep and 24 cm wide) with large entrance holes (approximately 7 cm in diameter) (Smith 2006a). A wide variety of bait types have been used to lure fish into bait traps. Some bait types include flavoured cat or dog food, cyalume chemical light sticks and soap (Baldwin et al 2005, Smith 2006a). This method has been reported as being effective among submerged vegetation and grasses but can be used in a variety of waterbodies (Baldwin et al 2005, Smith 2006a).

5.2.6 Williams' cage

The Williams' cage is a low-cost automated trap/drafting device suitable for installation in vertical slot fishways (Stuart et al 2006a, Stuart et al 2006b, Gilligan and Rayner 2007). It has been designed as a tool for carp management, allowing native fish to proceed upstream while trapping carp (Stuart et al 2006a). The carp-specific design of the Williams' cage capitalises on the natural jumping behaviour of carp and their regular movement through fishway bottlenecks (Gilligan and Rayner 2007). The trap consists of two compartments separated by an adjustable-height jumping baffle. The first compartment entraps a range of fish, but the second stage entraps carp only in a secure holding cage (Stuart et al 2006a). A lifting false floor and native fish exit gate allow non-jumping fish to be released (Stuart et al 2006a).

While the Williams' cage is primarily used as a control technique for carp, it can be used to monitor the presence of species, and has the potential to be modified for other species.

The MDBC is currently developing and testing a number of designs of the Williams' cage that have been developed through a cooperative project

between the Arthur Rylah Institute (Victorian Department of Sustainability and Environment), Goulburn Murray Water and the MDBC (Stuart et al 2006a).

5.2.7 Netting

There are a number of netting techniques available for monitoring fish species. Netting designs are highly varied in a range of sizes, colour, mesh size and material, and they also range in how they are suspended (hanging and rigging) (Backiel and Welcomme 1980). These aspects are known to influence the size and species they catch. There are a number of additional net design features. Nets can be erected perpendicular or parallel to the water edge, looped or in a straight line, anchored or drifting with water current, or used in combination with other techniques such as scaring techniques to drive fish towards them (Backiel and Welcomme 1980). There are five main net types used for fish sampling, described below.

a. Seine nets

Seine nets are large, robust nets that are usually several metres long with a width equal to or greater than the water depth (Adamus and Brandt 1990). A seine net is usually dragged through the water by people or powered watercraft, entrapping fish as it is pulled through the water and when the net is finally enclosed or dragged onto shore (Baldwin et al 2005). The length of a seine net can be modified to sample larger areas of habitat (Baldwin et al 2005).

b. Gill /panel nets

Gill or panel nets characteristically consist of a series of gillnet panels constructed from monofilament or multifilament line joined to form a wall of netting which entangles fish around the head or body (Faragher and Rodgers 1997). Gill/panel nets can be highly selective for a particular size of fish, depending on mesh size.

c. Trap nets

Trap nets are effective, non-destructive capture methods and include fyke nets (large and small) and drum nets. These nets often consist of either one or several wings that guide fish into a funnel from which they enter into a holding chamber. Drum nets are most effective in flowing waters and principally used in rivers. Fyke nets are used in both lentic and lotic waters. Drum nets are generally used for the larger inland native species while fyke netting is useful for collecting smaller specimens.

d. Pound nets

Pound nets are fish traps that have guide walls that lead fish into aggregation chambers (Gilligan et al 2005). Pound nets are rarely used due to their ineffective harvest capabilities; or if so, are implemented in conjunction with other methods (Gilligan et al 2005).

e. Dip nets

A dip net is a handheld net usually no larger than one metre in diameter (Food and Agriculture Organisation of the United Nations 2001). They are used when sampling shallow waters, or in combination with other techniques, such as electrofishing, where they are used to scoop stunned fish from the water.

5.2.8 Other techniques

There are a number of additional techniques that can be used to detect fish species, described below.

a. Spotlighting

Spotlighting is considered a non-invasive method that is used infrequently for fish sampling. This technique usually involves scanning a premarked area of waterway from bank to bank using a 12 Volt 100 Watt spotlight (with a narrow beam) (Hickey and Closs 2006).

b. Radio telemetry

Radio telemetry uses electronic radio tags that are implanted into individual fish. Radio telemetry requires the use of receivers and antennae to locate the tagged individual. It is not a widely used technique for sampling fish species, but can be used to relocate individuals.

c. Hook and line

The simple hook-and-line approach can be used to detect the presence of fish species in an area. Fishing catch, or creel data, from recreational anglers is another method used to sample fish populations. Anecdotal evidence suggests that a number of factors may influence sample success: these factors include the specific methods used, bait type, line and rigging type, angler experience and fishing effort.

d. Sampling design

While there are a variety of techniques available for sampling and detecting fish species, there are also many sample design issues that can significantly influence the probability of detecting species. Furthermore, to measure fish abundance there are a number of ways these techniques can be implemented. Mark-recapture involves catching, marking, releasing and recapturing individuals, and uses recapture rates to estimate population size (Koehn et al 2000). Sequential depletion involves sampling without replacement, whereby individuals are caught and not released. Estimates of population abundance are derived from capture rates (which typically decline with sampling effort and duration) (Koehn et al 2000). Destructive sampling involves total removal of individuals from an area using techniques such as piscicides (chemical

poisons) whereby the number of fish killed can be used to determine the total population abundance/size. Draining water from a habitat (such as a dam) can also be used to count total numbers of fish in an area.

5.3 Monitoring techniques and protocols for measuring distribution and abundance of alien fish

There are currently no Australian standards specifically designed for fish sampling (Baldwin et al 2005). There are a number of techniques that can be used for sampling fish species; however they are not all suitable for monitoring (Baldwin et al 2005). This review located two recommended sampling protocols that have the potential for monitoring and reporting of alien fish in Australia.

1. Recommended Methods for Monitoring Floodplains and Wetlands (Baldwin et al 2005).

   These guidelines aim to provide an agreed set of methods to collect information and a consistent approach to evaluation and reporting of ecological changes to better understand the decline in river health, and to assess the impact of management actions within the floodplains and wetland systems that are dependent on the Murray River. Chapter 8 of these methods presents recommended sampling procedures for native and introduced fish, and describes techniques for sampling fish.

   The recommended methods presented in this report for fish sampling include electrofishing (boat and backpack) and passive gear (baited trapping, seine netting and fyke netting).

   Electrofishing should be carried out in accordance with the Australian Code of Electrofishing Practice (in Baldwin et al 2005). It is recommended as the primary method, depending on the size and depth of water bodies, but can underestimate small fish species, thus 'passive techniques' (namely bait traps, seine nets and fyke nets) are recommended to be used in combination with electrofishing (Baldwin et al 2005).

   There were no recommendations on the sampling methodology and sample design regarding electrofishing and passive baiting and netting techniques presented within this report.

2. Fish Assessment Protocols – as a component of Development of a Framework for the Sustainable Rivers Audit: A report of the Murray-Darling Basin Commission (Davies 2004).

   The MDBC's Sustainable Rivers Audit (SRA) was established to overcome the lack of consistent and detailed information on the health of the Murray-Darling Basin.

   Among a number of priorities, they recognised the need for standardised sampling methods and protocols for sampling fish species and

bioassessment, and standardised variables and derived measures to describe fish communities (see Davies in Whittington et al 2001).

In partnership with the CRC for Freshwater Ecology, the SRA have progressed development of fish bioassessment protocols that recommend two sampling approaches for basinwide adoption (that still require some trial and evaluation). These were electrofishing (boat and backpack) and passive gear (baited trapping, fyke netting and gill netting).

While there has been considerable research on developing techniques to support standardised methodologies, there are further refinements needed to the protocols before they can be recommended for broadscale implementation. Further development and evaluation are planned through the SRA (Whittington et al 2001). The MDBC are also conducting a basinwide assessment of river health that includes alien fish, and foresee annual reporting as a realistic target to review the condition of the basin's waterways (Whittington et al 2001). For more information see http://freshwater.canberra.edu.au/Publications.nsf/0/f52fb94d8e5d2a20ca256f0f0014b431?OpenDocument.

5.4 Implementation of monitoring protocols for alien fish

The Recommended Methods for Monitoring Floodplains and Wetlands and the Fish Assessment Protocols recommended by the MDBC present a combination of active and passive sampling techniques for measuring and monitoring fish assemblages (including alien fish). These techniques are most suited for monitoring at the local scale. However, with refinement and planning of a sampling design, they can potentially be adopted for broadscale monitoring and reporting across regional, catchment and state/territory or Commonwealth jurisdictions. Further work is required regarding interpreting and reporting sampling outcomes for statewide and national reporting.

Continued development of sampling procedures, together with development of sampling design for broadscale regional and state/territory application would be required. Adoption of these protocols would facilitate the consistent monitoring and reporting of alien fish required to manage pest fish in Australia. Endorsement of these relevant protocols (following refinement) would be recommended prior to broadscale adoption.

6. Monitoring techniques for measuring the impacts of pest fish

6.1 Summary of environmental, economic and social impacts

There are a large number of alien fish species that have established populations in Australia. While information on the distribution and abundance of many alien species is well documented (at least the common pests), information on the impacts of pest fish species has not been well researched in comparison. Of the research that has been conducted, most has centred on identifying the environmental impacts of pest fish, while the social and economic impacts have often been overlooked. It should be noted that the impacts of pest fish are often difficult to measure and report, and there are a number of reasons for this:

- information on the conditions present prior to alien fish introductions is virtually non-existent (Smith and Hammer 2006)
- concurrent human influences and other threatening processes are often hard to differentiate from pest-specific impacts (Wager and Jackson 1993, Lintermans 2000)
- most studies of the impacts of pest species have begun after many of the impacts have occurred
- significant impacts of pest fish do not always manifest themselves in the extinction of species or other tangible quantities (Townsend 1996)
- experiments utilising pest fish often present ethical dilemmas (Lintermans 2000)
- identifying the impacts of pest fish often requires intensive measurements and sampling
- the impacts of pest fish species can be inconspicuous, or subtle over extended periods
- pest fish species are often mobile and are not easily detected unless dedicated surveys are conducted
- methods and techniques to accurately report the impacts of pests are often not readily available.

Despite these constraints, information about the impacts of species has been obtained from a number of approaches described in Section 6.2. Herein, we present a brief overview of some of the impacts associated with alien fish.

6.1.1 Environmental impacts

There are a wide range of environmental impacts attributed to alien fish. The known environmental impacts of alien fish can be categorised as biological, ecological, physical and chemical (Arthington and McKenzie 1997). Some of the adverse biological impacts attributed to alien fish include: predation on native species and their offspring, competition for food and breeding sites, hybridisation with native species and disease transmission to native species (Arthington 1991, Kailola 2000, Gillespie 2001). Some species may also have cascading effects. For example, oriental weatherloach can reduce macro-invertebrates that could have various flow-on effects such as depriving native species of food resources (Keller and Lake 2007).

The adverse ecological impacts attributed to alien fish are equally significant and include: reduced survival of native species (particularly the survival of larvae of various species); effects on native fish foraging behaviour, reproduction and population structure; ecosystem processes alteration;reduced native species abundance and distribution; effects on zooplankton grazing and biofilm production; loss of aquatic vegetation; disruption of aquatic communities; native fish population decline; and spread of disease caused for example, by gambusia's fin-nipping behaviour that can result in disease (Arthington 1991, Schiller and Harris 2001 in Gilligan and Rayner 2007).

Physical and chemical impacts attributed to alien fish include: alteration or degradation of habitat, erosion of stream banks, and increased turbidity (eg from the resuspension of fine sediment due to carp foraging behaviour) (Koehn et al 2000, Gilligan and Rayner 2007). Alien fish can also reduce water quality by disturbing sediment that releases nitrogen and phosphorous and can lead to algal blooms (Koehn et al 2000).

A number of research studies have revealed adverse environmental impacts of specific alien fish species on native fishes, including impacts from gambusia (Howe et al 1997, Komak and Crossland 2000), swordtails, redfin, brown trout (Cadwallader 1996, Townsend 1996, Jackson et al 2004), rainbow trout (Cadwallader 1996, Lintermans 2000, Jackson et al 2004), carp (Koehn et al 2000, Koehn 2004, Gilligan 2005, Gilligan and Rayner 2007), goldfish and oriental weatherloach (Koster et al 2002a, Keller and Lake 2007).

6.1.2 Economic impacts

Alien fish cause a range of impacts to primary production and economic values/ assets. However, there have been very few estimates of the economic impacts of alien freshwater fish in Australia, other than carp (McLeod 2004, Dawson 2005) and trout. Alien fish are often claimed to be the cause of the degradation of rivers that are relied on for agricultural productivity, thus reducing the productive potential of surrounding or downstream landscapes. However, there are very few studies that have actually verified these claims. Only one research study was identified in the course of this review that detailed the

costs associated with the impacts of carp (McLeod 2004), and other species' cost impacts remain largely undocumented. At an estimated social cost of $9 million per year, carp contribute to losses in the native fish recreational fishing industry and impact on tourism and local commerce (McLeod 2004). Carp may also pose an economic threat by affecting industries that depend on pristine water quality and aquatic habitats, including domestic and irrigation water supplies, aquaculture and agriculture.

Loss of production associated with hybridisation of alien fish in aquaculture may cause significant social and economic impacts, however these impacts have not been well quantified. While commercial harvesting of carp presents employment opportunities for rural and regional Australia, and a potential export market overseas (Brumley 2003), there are a number of costs associated with carp production that should not be overlooked (McLeod 2004).

Some alien species also transmit serious exotic disease and parasites, some of which may have economic consequences for aquaculture industries. Redfin have been known to transmit serious viral diseases, such as epizootic haematopoietic necrosis (EHN) that has caused mass mortality of juvenile redfin (Lintermans 1991). A large number of native fish are also highly susceptible to EHN (including Macquarie perch, silver perch and mountain galaxias). Carp have been implicated in the transmission of the exotic bacteria *Aeromanas salmonicida* (Hindmarsh 1994 in Gilligan and Rayner 2007), and parasites (Rowland and Ingram 1991 in Gilligan and Rayner 2007). Goldfish ulcer disease is another disease that has been introduced with live imported fish and can affect other species, including trout and native species (Lintermans 1991). While the disease status of wild populations of oriental weatherloach in Australia is largely unknown, they have been found overseas to carry three types of parasitic trematodes (Lintermans 1991).

However, not all alien fish or pest fish have adverse economic impacts – the value of salmonids and redfin to the recreational fishing industry is undisputable (Henry and Lyle 2003), and the commercial harvesting of carp presents employment opportunities for rural and regional Australia and a potential export market overseas (Brumley 2003).

6.1.3 Social impacts

There are a number of ways that alien fish may impact on social values/ assets in Australia; however many of these impacts are poorly understood in comparison to other forms of impact. Most of the social impacts of alien fish are indirect and are often not easily identified. Some indirect adverse social impacts of alien fish may be detectable through economic indicators. For instance, the introduction of disease and parasites may have adverse effects on primary production or enterprises (Dawson 2005). Other impacts from alien fish include aesthetic damage (Bomford and Glover 2004), and impacts on tourism and community recreation that can sometimes be measured through economic information (Dawson 2005). The impacts of alien fish species on native fish may cause the decline of fish species suitable for recreational and commercial activities (McLeod 2004). Similarly, the control of alien fish can reduce recreational fishing opportunities and tourism. For example, Lake Sorell and Lake Crescent (Tasmania) were temporarily closed to recreational

angling several years ago to allow a carp eradication program to occur (Diggle et al 2004).

The adverse impacts of alien fish may also include indirect human health or ethical issues (Dawson 2005). For instance, carp have been implicated in the decline and extinction of native fish species, and there may be long-term social consequences from these outcomes (McLeod 2004). The decline of native populations or aquatic communities, temporarily or permanently, also has implications for future generational use and is directly opposed to the principles of ecologically sustainable development.

Quite obviously though, alien fish may also impact on social values/assets in positive ways, particularly through aquarium fish keeping and sportfishing.

6.2 Techniques for measuring impacts

Section 6.1 highlights the broad range of impacts attributed to alien fish in Australia. There are a number of techniques that have been used to measure the impacts of alien fish on social, environmental and economic values/assets, including impacts on native species, water quality and aquaculture. Most techniques have been developed for local-scale application, providing inferences at a broader scale (Table 6). Some techniques used to measure impacts are summarised in this section.

Evidence of the impacts of alien fish can be classified under three broad categories: anecdotal evidence (gathered without supporting data and subject to uncertainty), circumstantial evidence (supported by data but is inconsistent with other theories), and experimental evidence (derived from well-designed experimental procedures that generates reliable data) (NSW Department of Primary Industries 2003). While there is a growing body of research that presents scientific and experimental evidence of the impacts of alien fish, most of the information regarding alien impacts is anecdotal or circumstantial.

Much of the evidence of the impacts of alien fish has been determined from studies and observations using the following approaches (adapted from Cadwallader 1996, NSW Department of Primary Industries 2003):

- experimental manipulations
- evidence from spatial patterns
- before/after studies
- modelling.

6.2.1 Experimental manipulations

This approach is possibly the most robust and intensive of methods, and delivers the most meaningful information about the impacts of alien fish. It

uses experimental introduction studies; feeding studies; analysis of dietary overlap, competition and predation data; behavioural studies and mesocosm experiments.

a. Mesocosm and instream trials

A mesocosm is an experimental enclosure that simulates natural conditions while allowing manipulation of environmental factors (National Environment Research Council 2006). This type of approach, whether instream or ex situ, enables the manipulation of variables and environmental conditions; however it sometimes oversimplifies natural conditions (Cadwallader 1996). Instream trials are another approach that typically involves partitioning control and treatment areas within a river that are monitored over time. Instream trials must consider many variables (NSW Department of Primary Industries 2003, Gilligan et al 2005).

b. Predation studies

Predation studies often involve gut content analysis to provide information about a target species' feeding preferences and indicate dietary overlap and predatory behaviour (Ivantsoff and Aarn 1999, Smith and Hammer 2006).

c. Snapshot surveys

Surveys can be conducted over a limited time frame, which provide 'snapshots' of the impact situation being investigated (Lincoln Smith 1991). The timing of these surveys can be critical, depending on the season and the lifecycle or migration phase of the target species. Snapshot surveys might only assess the impact site, or a combination of the impact site and control sites. The benefit of using control sites is that the impact site can be assessed in a broader context and it facilitates the use of standardised sampling techniques (Lincoln Smith 1991). Alternatively, an issue-oriented approach can examine specific predictions of impact at various sites before, during or after changes to the fish community.

6.2.2 Before / after studies

This approach uses studies undertaken before, during and after the invasion of new areas by alien fish or following eradication or removal of alien fish (recovery trials), before-after-control-impact (BACI) trials, disease impacts, and environmental impact assessment. Some flexibility in this approach is required to accommodate for the specific objectives of the study (Lincoln Smith 1991).

For example, there are a range of techniques available for measuring physical and chemical impacts of alien fish, including measurements of turbidity, dissolved oxygen, and the conductivity of waterways. Many support the formation of broader inferences about the impacts of pest fish on aquatic environments (Waterwatch Australia 2003).

Table 6: Summary of the techniques and approaches used to detect and measure impacts of alien fish on a local, regional and national scale		
Local scale	**Regional scale**	**State/territory and national scale**
Recovery trial	Recovery study	National PAC CRC study
Instream trial	Review existing information	Review existing information
Mesocosm experiment		Indicators of impact(s)
Environmental Impact Assessment	Environmental Impact Assessment	
Experiment – ex situ/ in situ	Laboratory trial	
Laboratory trial, gut analysis	Replicated lab experiment	
Replicated laboratory experiment		
BACI		
Pre-arrival studies		
Examples: • (Lintermans 2000) • (Gillespie 2001) • (Keller and Lake 2007) • (Lincoln Smith 1991) • (Ivantsoff and Aarn 1999) • (Robertson et al 1997) • (King et al 1997) • (Komak and Crossland 2000) • (Koehn et al 2000)	Examples: • (Lintermans 2000) • (Arthington 1991) • (Kennard et al 2005) • (Lincoln Smith 1991) • (Ivantsoff and Aarn 1999) • (Komak and Crossland 2000) • (Arthington and McKenzie 1997)	Examples: • (McLeod 2004) • (Arthington 1991) • (Arthington and McKenzie 1997) • (Kennard et al 2005)

a. BACI trials

BACI studies compare the differences between sites with target alien fish species (impact treatment) and without target species (control), before and after they have been introduced (Koehn et al 2000). BACI trials are often impractical because there are often no comparable sites without the target species to use as 'controls', and there is little or no data available on the pre-invaded state of the environment (Koehn et al 2000).

b. Recovery studies and removal trials

Recovery studies are similar to BACI designs; however the controls are the disturbed sites containing the target species, and sites where the target species are removed are used as the impact treatment (Koehn et al 2000). An important distinction between BACI and recovery studies is that the changes following removal of a target species are not necessarily the reverse of the changes that might occur following invasion. The reliability of data can be increased through replicated or repeated sampling. Recovery studies can also be used to demonstrate the benefits or outcomes of management or control actions (Koehn et al 2000).

6.2.3 Evidence from spatial patterns

Spatial pattern studies are essentially distributional studies, including distributions of fish observed during fish surveys, before and after observations, comparisons of the distributions of particular species in the presence or absence of alien fish species, and statistical analyses of distributional data sets for alien fish and native fauna.

Non-overlapping distributions between alien fish and native aquatic species have been reported as evidence of the impacts of alien fish. While there are a number of drawbacks from using in this approach, information from spatial studies can be used to identify areas for further investigation (NSW Department of Primary Industries 2003). For example, trout are present in all but one of the 14 locations where the spotted tree frog occurs; the one site where trout are not present is the only site where the frog is found in high densities (Gillespie 2001). This approach relies on assumptions and does not take into account other possible contributing factors. However, it does provide strong inferences about the impacts of alien fish on the distribution and abundance of native species.

6.2.4 Modelling studies

This approach includes predictive modelling and habitat modelling techniques that are diverse and particularly detailed.

Predictions can be made about the impacts of alien fish by comparing the outcomes from multiple introductions of a species in different ecosystems, to see if the effects are consistent across different environments (in Bomford and Glover 2004). Reviewing the history of a species introduced to other areas, and its impacts, can be used to formulate predictions about the likely impacts of a species.

Habitat modelling studies often use a combination of direct surveys and predictive modelling to present a series of possible scenarios and outcomes about the impacts of alien fish (NSW Department of Primary Industries 2003). While this approach has not been widely used in Australia, there are a diverse range of options for habitat and predictive modelling for determining the impacts of alien species.

6.3 Risk assessment models and bio-assessment

Risk assessments and bio-assessments are approaches taken to measure and predict the impacts of fish species, and may use an assessment of fish species to determine the condition of river health.

6.3.1 Risk assessments

Two forms of risk assessment were identified relevant to the scope of this review. These were risk assessments relevant to the import and keeping of alien ornamental fish, and risk assessments of the impacts of alien species (including animals and plants).

a. Risk assessments for importation

The Risk Assessment Model for the Import and Keeping of Exotic Freshwater and Estuarine Finfish (Bomford and Glover 2004) addresses the establishment risk of exotic fish that have been successfully and unsuccessfully introduced to Australia. It distinguishes between species that pose a high risk and those species that pose a low risk based on overseas information and previous introductions (Bomford and Glover 2004).

In a similar fashion, the Risk Assessment of Ten Ornamental Fish Under the *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999* (Kailola, undated) addresses ten species currently prohibited from importation under the 'permitted imported live fish list' under the EPBC Act, and reviews known information to determine their risk of importation.

b. Risk assessments for impacts

Two approaches have been undertaken to assess the impacts of alien species using a risk assessment framework.

The Risk Assessment of the Impacts of Pest Species in the Riverine Environment in the Murray-Darling Basin (Clunie et al 2002) focuses on 22 potential pests and presents recommendations for alien fish. It highlights the need to develop a consistent methodology to assess the potential threats associated with alien species, applying a risk assessment procedure to these 22 alien fish to determine their possible impacts (Clunie et al 2002).

The Wet Tropics Vertebrate Pest Risk Assessment Scheme (Harrison and Congdon 2002) assesses the risks and impacts of alien fish. It was developed

to assess the risks of existing and potential vertebrate pest species within the Wet Tropics bioregion of Australia. This procedure used risk assessment criteria to assess the effects and potential effects of pest species, including vertebrate pests and alien fish species.

c. Bio-assessment

Fish are commonly used in large river biological assessment programs, or bio-assessments to measure river health. Bio-assessments are an effective way of measuring the aggregate impact of various factors (Flotemersch et al 2006). Fish bio-assessments use a number of structural and functional attributes of fish assemblages to provide an evaluation of biological condition. Bio-assessments may include:

- sampling fish using standardised methods
- species identification
- analysis using biological attributes such as biomass
- metric calculations (eg tolerance measures, feeding types).

There are two approaches to fish bio-assessment that have been piloted in Australia (Davies 2004). They are:

- multimetric analysis – eg Index of Biotic Integrity (IBI) (see http://www.epa.gov/bioindicators/html/multimetric.html)
- multivariate 'predictive' modelling – eg AUSRIVAS and regression tree models (see http://ausrivas.canberra.edu.au/index.html).

Each of these methods requires the use of a 'reference condition' as a baseline for assessing change. Several bio-assessment methods from overseas are currently being adapted and trialled for use in Australia.

Further information:

- AUSRIVAS web site: http://ausrivas.canberra.edu.au/index.html
- Fish and rivers in stress: the NSW Rivers Survey (Harris and Gehrke 1997)
- National Water Commission - Australian Water Resources 2005: http://nwc.gov.au/science/water_resources.cfm
- US Environmental Protection Agency - Key concepts for using bio-indicators:http://www.epa.gov/bioindicators/html/key.html

6.4 Recommended monitoring protocols

There are currently no Australian standards or consistent approaches specifically designed for measuring and monitoring the impacts of alien freshwater fish species in Australia. The main reason is that there is no single approach (or series of methods) considered suitable to measure the direct, indirect, cumulative and long-term impacts of all alien fish species on the environment, economy and society. The impacts of alien species are often difficult to differentiate from other causal factors. There has also been a limited amount of research on identifying the impacts of alien fish in Australia. Most information relates to species that are well established or widespread, and those identified as causing problems elsewhere. The lesser known and inconspicuous species and emerging pests are often not so well studied.

A number of techniques have been developed (and are well tested) for measuring alien fish populations, and two protocols for monitoring have been prepared by the Murray-Darling Basin Commission (defined in Section 5.3). These methods present an indirect indicator of alien fish impacts, but are reliant on density-damage relationships between pests and resources.

A number of field based trials, experimental techniques, modelling, and risk assessment approaches have been listed in this chapter that have been undertaken to measure and report the impacts of alien fish throughout Australia. However, most rely on intensive measurements to reveal specific impacts of alien species on parameters or environmental attributes. Most techniques also have limited capacity to monitor and report broadscale impacts of alien species across regions, states and territories and the country.

Previous attempts to measure and report impacts of alien fish have relied largely on reviews of existing information. To accurately measure and report the overall impacts of alien fish in Australia, to facilitate assessment of the effectiveness of various investments, would require adoption of a number of techniques and approaches that measure a suite of impact types (as defined above). This may also require the development of innovative techniques and methods (or a series of techniques) to measure species impacts. It would also rely heavily on significant investment to support information collation.

Impacts information might also be obtained for monitoring and reporting activities from existing research programs and existing experimental trials that present information through a series of case studies. However, careful planning would be required to assess the feasibility of this option for ongoing monitoring and reporting activities.

7. Control techniques and research priorities for control of pest species

7.1 The importance of control in monitoring pest impacts

The main purpose of control programs should be to reduce the damage or impact caused by pests to an acceptable level (Olsen 1998). The strategic approach to pest control recommends defining the problem(s), setting objectives, identifying and evaluating options, developing a management plan and implementing appropriate control(s). It also recommends monitoring of pests (and their likely impacts) before and after control programs. As a result, monitoring alien fish abundance and their impacts before and after the implementation of control techniques is another way that the impacts of alien fish species can be determined.

7.2 Techniques to control pest fish and their impacts

There are a wide range of techniques that can be used to control alien fish to manage (or measure) their impacts. The control techniques available for pest fish species in Australia can be categorised as either mechanical (physical - including habitat manipulation), biological, or chemical control (Roberts and Tilzey 1996, Olsen 1998). These techniques directly remove individuals, indirectly remove individuals, or indirectly modify systems to reduce populations (Choquenot et al 2004).

There are many issues that need to be considered when selecting or implementing control techniques, including animal welfare, possible harm to non-target species or values, contamination of water, and control costs (Olsen 1998). Before undertaking control, techniques should be compared for their humaneness, target specificity, secondary effects, efficacy, cost effectiveness, safety and overall acceptability (Treadwell 2004). The effectiveness of a control program is largely dependent on the susceptibility of individuals to the technique(s) used, fish behaviour, the life stage of the targeted species (Roberts and Tilzey 1996), and the rate of recruitment to the area after control (Treadwell 2004). Effectiveness can also be improved by using complementary approaches such as the 'Judas' method, where a number of males are radio tracked to identify spawning aggregations (Gilligan and Rayner 2007).

7.2.1 Mechanical control options

Many of the techniques outlined as fish sampling methods (see Chapter 5) are also suitable for removing unwanted species from a given area. Pest fish can be removed using boat and backpack electrofishing, various traps and cages, as well as seine, gill and other nets (Gilligan et al 2005). The Williams' cage is also an effective removal technique for pest fish. It has been developed primarily for carp and capitalises on their jumping behaviour, but can potentially be adapted for other species (Stuart et al 2006a). It is a low -cost automated trap suitable for installation in vertical slot fishways (Stuart et al 2006a, Stuart et al 2006b, Gilligan and Rayner 2007).

7.2.2 Commercial and recreational fishing

Commercial fishing can provide a means of removal for larger fish species such as salmonids, carp and perch. Subsidised commercial harvest has the potential to rapidly reduce pest fish populations (Gilligan and Rayner 2007). Incentive schemes, such as the one implemented by the New South Wales Government in 1998, can generate large-scale harvests by offering commercial fishing licences to parties who demonstrate their ability to catch and sell the target species (eg carp utilised in fertilisers, bait and smoked products) (Koehn et al 2000, Gilligan et al 2005, Gilligan and Rayner 2007).

Recreational fishers/anglers can also play a significant role in the removal of pest fish species. Fishing competitions, such as 'Carpathon' in Narrandera, and the 'Carp Round-Up' in Lake Cargelligo, Moree and Brewarrina (Gilligan et al 2005), can be used to catch and remove pest fish using a hook-and-line approach. This technique is biased towards larger specimens, as smaller fish are unlikely to be caught on a line.

7.2.3 Habitat manipulation

Changing the environmental conditions in an area can be used to totally remove target species or reduce their biomass (Gilligan et al 2005). Water levels may be manipulated to exclude pest fish from spawning areas (Diggle et al 2004), and fish screens can be constructed to create an exclusion zone preventing entry of any adult fish to breeding areas (Gilligan and Rayner 2007). Destructive methods, such as draining/drying of wetlands can also be used (Koehn et al 2000, Gilligan et al 2005).

7.2.4 Biological control options

There are three main potential biological control agents for pest fish in Australia. These include spring viraemia of carp virus (SVCV), koi herpesvirus (KHV) and genetic modification (including 'daughterless' carp technology).

SVCV, or *Rhabdovirus carpio* is a naturally occurring infectious disease, exotic to Australia. SVCV has the potential to reduce carp populations; however some properties of the virus and the disease it causes suggest that it would not be suitable for use in Australia.

KHV, or cyprinid herpesvirus-3 (CyHV-3), is a highly contagious viral disease also exotic to Australia, causing significant morbidity and mortality in common and koi carp (Hedrick et al 2000 in Gilligan and Rayner 2007). The properties of this virus (including host specificity and high pathogenicity for both wild and farmed carp in the absence of stress factors) indicate that it would be more suitable than SVCV as a biological control agent for carp in Australia. The Invasive Animals Cooperative Research Centre (IA CRC) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australian Animal Health Laboratory are undertaking research on aspects of the disease (establishment of specific and sensitive tests, excretion of the virus from clinically-affected and carrier carp, persistence of the virus in the environment and carcasses, the susceptibility of non-target species) to assess

KHV's potential as a biocontrol agent for carp in Australia (Gilligan and Rayner 2007).

The IA CRC and CSIRO Marine and Atmospheric Research are undertaking research on the development of daughterless technology; that is, an inherited genetic construct that biases offspring sex ratios towards males. Current research is testing the efficacy of existing daughterless constructs, designing improved versions, testing their efficacy for population control and species-specificity in the laboratory, building and beginning the process of integrating the first carp-specific construct and developing an effective risk framework for implementation of the technology.

7.2.5 Chemical control options

Piscicides, or fish poisons, represent a highly effective control option for aquatic species and can be used to control or eradicate new and localised pest species incursions or for the restoration of small to medium-sized water bodies. Some piscicides can be lethal or toxic to reptiles, amphibians, birds and mammals, and there are often restrictions on piscicide use within catchments used to capture water for human consumption. Their use is regulated by state and national authorities. The action of piscicides is rapid, and in sufficient concentrations they are non-selective between species and size classes of fish (Backiel and Welcomme 1980). Rotenone is presently the only option available to chemically control invasive species in Australian freshwater environments, though antimycin has also been identified as having potential.

Rotenone is a naturally occurring ketone that affects gill-breathing animals by inhibiting their use of oxygen at the cellular level (Rayner and Creese 2006). It is considered to be the most environmentally friendly of available fish poisons. Sensitivity to rotenone can vary between species (Backiel and Welcomme 1980). It is most successful in small, static, easily accessible water bodies (McEnnulty et al 2001, Rayner and Creese 2006), and is less effective in systems subject to currents (in McEnnulty et al 2001). Rotenone is delivered in either powder, liquid or synergised liquid form, and non-target fish mortalities downstream have been observed. Permits for use are governed by the Australian Pesticides and Veterinary Medicines Authority. Environmental Protection Agency permits are also required for the release of this chemical.

The delivery of rotenone via oral baits has been demonstrated as an effective control technique, particularly for carp (Gilligan et al 2005). The size of baits can also be designed to reduce ingestion by smaller non-target species. The effectiveness of baiting can be increased with the use of trainer pellets (free feed) to attract and habituate fish before poisoned pellets are introduced (Gilligan et al 2005). In Australia, rotenone has been used to successfully eliminate carp from Tasmania in the 1970s and for the local eradication of trout from streams in south-eastern Australia.

Although antimycin is not currently registered for use throughout Australia (Roberts and Tilzey 1996), it is a potential chemical control technique that has been used overseas. It is an antibiotic that is relatively specific to fish, but its toxicity to Australian native fish remains largely unknown (Roberts and Tilzey 1996). Concentrations of antimycin required to control fish are reportedly

harmless to other aquatic life and mammals (Lennon 1970, McEnnulty et al 2001).

7.3 Research priorities for control

A number of key research priorities regarding control techniques for pest fish have been highlighted by researchers over recent years (Roberts and Tilzey 1996, Lapidge 2003, Jackson et al 2004, Gilligan et al 2005, Smith and Hammer 2006, Smith 2006a, Gilligan and Rayner 2007). Areas of research being funded by the IA CRC aim to:

- develop gender manipulation via genetic technology such as daughterless carp technology
- develop poisons/piscicides (eg antimycin)
- develop chemical and biological attractants/pheromone attractants for control
- develop techniques for detecting and controlling fish at low densities
- identify 'hot spots' for carp spawning and recruitment
- identify methods to exploit instinctual spawning and dispersive movements in carp
- continue experiments using separating barriers
- investigate the potential of Koi herpesvirus as a biocontrol agent for carp
- increase community awareness of alien fish and their negative impacts.

8. Management, monitoring and research

8.1 Current situation

There are a number of organisations that are involved in the management, monitoring and research of alien fish species and their impacts. There has been little national or interstate coordination of management activities regarding alien fish to date (Lintermans 2004). Management, monitoring and research activities regarding pest fish have historically been implemented through collaborations or initiatives that met specific needs and agendas at a certain time and place. While these actions have somewhat increased the awareness of alien fish as a major threat to Australia's environmental assets, their value and application on a broader scale have essentially been overlooked.

Onground management of aquatic ecosystems has largely been the responsibility of state government Fisheries departments and involves stocking of fish for recreational activities (Lintermans 2004). Hence, there is a need to move forward nationally to resolve issues regarding the importation and trade of alien ornamental fish species and national agreement for dealing with pest fish species that are already present in Australia (McNee 2002). Clarification of the scale of the problem is needed to develop nationally coordinated onground management actions (Koehn and Mackenzie 2004).

Documenting the current distribution of native and alien freshwater fish in Australia is also required to enable the identification of critical regions for management, and form a baseline against which the effectiveness of management programs can be assessed (Smith and Hammer 2006). Below is an overview of some of the management, monitoring and research activities that key agencies throughout Australia are undertaking to address pest fish and their impacts.

Information contained in the following section provides a very brief summary of each agency's activities based on information available at the time of this review. It is not intended to be exhaustive and mainly contains information from agency websites. As such, it may not contain the most current activities of agencies/groups.

8.2 National initiatives and collaborations

8.2.1 Invasive Animals Cooperative Research Centre (IA CRC) (2005-2012)

www.invasiveanimals.com

The IA CRC was funded by the Australian Government in the 2004 CRC selection round and aims to counteract the impact of invasive animals through the development and application of new technologies and integrated approaches. A total of 41 organisations are participating in the IA CRC, as either core or supporting partners. The total comprises 34 Australian government agencies, industry bodies and small-medium enterprises, as well as seven international organisations from New Zealand, Britain and the USA. By combining national

and international skills in science, management, commerce and industry, this unique partnership will deliver the means to combat existing high-profile invasive animal pests as well as those that have the potential to cause catastrophic impacts in the future.

The IA CRC is structured around six central programs. The Freshwater Products and Strategies Program of the IA CRC aims to develop and deliver short, medium and long-term tools and techniques for managing Australia's freshwater invasive fish. With strong enduser focus and direction, the Freshwater Program will achieve its aim through binding and coordinating existing research bodies and groups, and focussing efforts in an efficient manner to produce a tried and tested manual for managing freshwater invasive fish.

8.2.2 National State of the Environment (SoE) reporting

http://www.environment.gov.au/soe/index.html

SoE reporting is a program for regular, systematic analysis and evaluation of Australia's environment. Information gathered for SoE reports includes data available on the distribution and abundance of alien species at the time of reporting. Records are collated for each species, based on information sourced from the literature, museum collections and specialists.

In the 2002 Australian SoE report (Department of Environment and Water Resources 2002) environmental freshwater pest species identified were brown trout, rainbow trout, redfin perch, carp, goldfish, guppy, mosquitofish and Mozambique tilapia (Clarke et al 2000). In the 2006 Australian SoE, expanding distributions of carp, eastern gambusia and oriental weatherloach were noted (Beeton et al 2006), with alien species in the Lower Murray–Darling catchment constituting 56% of the total biomass of fish (Gilligan 2005).

8.2.3 Murray-Darling Basin Commission (MDBC)

http://www.mdbc.gov.au/

The MDBC was established as part of the Murray-Darling Basin Initiative (Murray-Darling Basin Commission 2006). The MDBC is responsible for a number of activities under the agreement, including the implementation of several fish-related projects and programs (Barrett 2004), such as:

- The Living Murray – River Murray's river restoration program
- The Native Fish Strategy – rehabilitation of the basin's native fish communities (see Chapter 3)
- Under the auspices of the Native Fish Strategy, a number of current alien fish projects include:
    - developing and testing the Williams' cage in cooperation with Arthur Rylah Institute (see Section 8.3), Goulburn Murray Water, and the MDBC (Stuart et al 2006a)

- integrating pest management of carp populations using existing control techniques (eg water level manipulations, commercial fishing, carp separation cages)

- reviewing the efficacy of carp screens at wetland inlets in the southern Basin

- convening a workshop in May 2006 on 'Emerging issues in pest fish management in the Murray-Darling Basin' with a focus on redfin, tilapia and oriental weatherloach

- mapping the spatial distribution of individual fish species.

- The Sustainable Rivers Audit (see below and Chapter 4).

The MDBC has recently published a book (launched July 2007) on the fishes of the Murray-Darling Basin (Lintermans 2007), which provides basinwide distribution maps for alien and native species in the basin, based on state and territory agency and museum records. The MDBC is also the major funding organisation for the IA CRC.

8.2.4 Sustainable Rivers Audit (SRA)

http://www.mdbc.gov.au/SRA

An initiative of the MDBC, the SRA is the largest assessment of river health in the Murray-Darling Basin; designed to measure the health of rivers across the basin. The SRA aims to:

- determine the ecological condition and health of river valleys in the Murray-Darling Basin

- provide an understanding of the variability of river health indicators across the basin over time

- detect trends in river health over time

- instigate changes to natural resource management by providing a more comprehensive overview of river health than is currently available (Murray-Darling Basin Commission 2006).

Fish are used as one indicator of river health. Other indicators include macro-invertebrates, hydrology, and vegetation. The SRA has developed a standard methodology for fish bioassessment across the Murray-Darling Basin (Davies 2004), and will undertake the first full basin assessment of river health, including fish, during 2007 for reporting to the Murray-Darling Basin Ministerial Council in 2008. Of 13 indicators proposed for the assessment, three relate to alien species: proportion native biomass, proportion native abundance, and proportion native species. Assessments are subsequently expected every three years.

8.2.5 National Water Commission

http://www.nwc.gov.au/

The National Water Commission is responsible for the promotion of national water reform, and advises the federal Minister for the Environment and Water Resources and state and territory governments on water issues. The commission is also responsible for managing the implementation of the National Water Initiative and other programs under the Australian Government Water Fund, including the Australian Water Resources 2005 (formerly BWRA) conducted under the federal and state collaborative National River Health Program that follows on from earlier river health assessments, including the:

- Monitoring River Health Initiative (1993-1996)
- First National Assessment of River Health (1997)
- Australia Wide Assessment of River Health (1998-2000).

Under the National Water Initiative, in collaboration with the Water Resources Observation Network Alliance, river health is being assessed (using alien fish as an indicator of river health) for the Australian Water Resources 2005. As there is currently no Australiawide biological assessment that monitors freshwater fish communities as standardised indicators, development of an alien fish indicator (that is based on presence, richness and relative abundance of alien species) is being considered (Section 4.3) (National Water Commission 2006b).

8.2.6 Australian River Assessment System – AUSRIVAS

http://ausrivas.canberra.edu.au/

The AUSRIVAS program was developed as an Australiawide tool to assess the health of freshwater rivers and streams. It aims is to provide information needed to reverse degradation of inland waters and to assess biological health of Australian rivers. States and territories conducted comprehensive surveys of river and stream health as part of the program. The AUSRIVAS program has previously provided the best available information for a statewide assessment of river/stream health. Most states and territories and the MDBC have better data sets on fish species. AUSRIVAS has used only one indicator of river health (macro-invertebrates), and other indicators or a multi-indicator approach are being considered to provide a more useful assessment of river health. Although there were some references to 'fish bioassessment' being a component of the Bioassessment module of AUSRIVAS, it was not clear at the time of this review whether alien fish were incorporated in the overall assessment program, or whether the project is ongoing.

8.2.7 Australian Quarantine and Inspection Service (AQIS)/ Biosecurity Australia

http://www.daff.gov.au/ba

AQIS manages inspection and quarantine services for Australia, and protects against the entry and spread of alien pests and diseases of plants and animals

(Arthington and McKenzie 1997). Biosecurity Australia, within AQIS, develops import risk analyses (IRA) for new commodities that have not previously been imported into Australia, and for commodities to be imported from new locations that may pose a pest and disease risk.

The IRA process identifies the pest and disease risks associated with animal and plant commodities (including freshwater fish), and in collaboration with the Department of Environment and Water Resources (under the *Environment Protection and Biodiversity Conservation Act 1999*) assesses proposals for the importation of species to Australia. The IRA process also develops risk management procedures. An IRA has been developed for the importation of live ornamental finfish, which incorporated findings from a comprehensive baseline environmental data study (Arthington et al 1999).

8.3 States and territories

8.3.1 State of the Environment reporting

http://www.environment.gov.au/soe/index.html

Most state and territory governments prepare SoE reports on a regular basis, and it is a legislative requirement in New South Wales, Australian Capital Territory (ACT), Tasmania, Queensland and South Australia. In New South Wales, local governments are required to prepare regular SoE reports and the Queensland Government is committed to producing SoE reports every four years, with two reports completed to date: 1999 and 2003. SoE reporting generally includes distribution and abundance data for alien fish species (see Figure 1). For example, the ACT SoE 2003 highlighted that oriental weatherloach has become widely established in ACT streams, with new populations becoming established in some locations.

8.3.2 New South Wales

a. New South Wales Invasive Species Plan 2007-2015

This newly developed plan aims to minimise the impacts of all invasive species through the combined efforts of all stakeholders using a risk-based approach. Stakeholders include government agencies, authorities, catchment management authorities, industry, landholders and community members. Based on best management principles; the NSW Invasive Species Plan is consistent with existing strategies such as the Australian Pest Animal Strategy, the Australian Weeds Strategy, and the NSW Biodiversity Strategy. The plan provides overall goals and direction for coordinated and cooperative invasive species management in New South Wales.

b. NSW Department of Primary Industries (NSW DPI)– Science and Research

Fish communities are routinely used to monitor the health of aquatic ecosystems in New South Wales (Growns et al 2003). NSW DPI– Science and Research is involved in two ongoing large-scale fish monitoring programs:

- The Integrated Monitoring of Environmental Flows (IMEF) (see also Section 4.3)

- The Sustainable Rivers Audit.

The IMEF is a scientific program for assessing the ecological benefits of the environmental flow in the major rivers of New South Wales (NSW Department of Natural Resources 2006). As part of the IMEF project, NSW DPI conducts regular monitoring of freshwater fish, which are one of several environmental indicators to be examined for the project (Egerrup and Growns 2001). Alien and native fish were recorded during the initial survey during 1999-2000. Ten of the sixty sample sites were also sampled as part of the NSW Rivers Survey (below).

The Snowy River Benchmarking and Environmental Flow Response Monitoring Project is an associated program, which also samples native and alien fish as an indicator of ecological response to changes in flow regime (NSW Environmental Protection Agency 2003, Rose and Bevitt 2003). Ongoing sampling for the IMEF is carried out annually.

NSW DPI – Science and Research has also been involved in other monitoring and research programs (past and present) including:

- The NSW Rivers Survey (1994-1999) (Harris and Gehrke 1997, Egerrup and Growns 2001), which tested and established a standardised predictive model for monitoring river health using fish community assessment, and which can be applied in future studies. NSW Rivers Survey sites are now included as part of other monitoring programs.

- Reporting under state natural resource indicators and targets (through the Natural Resources Commission) where fish monitoring is conducted at approximately 500 sampling locations throughout New South Wales.

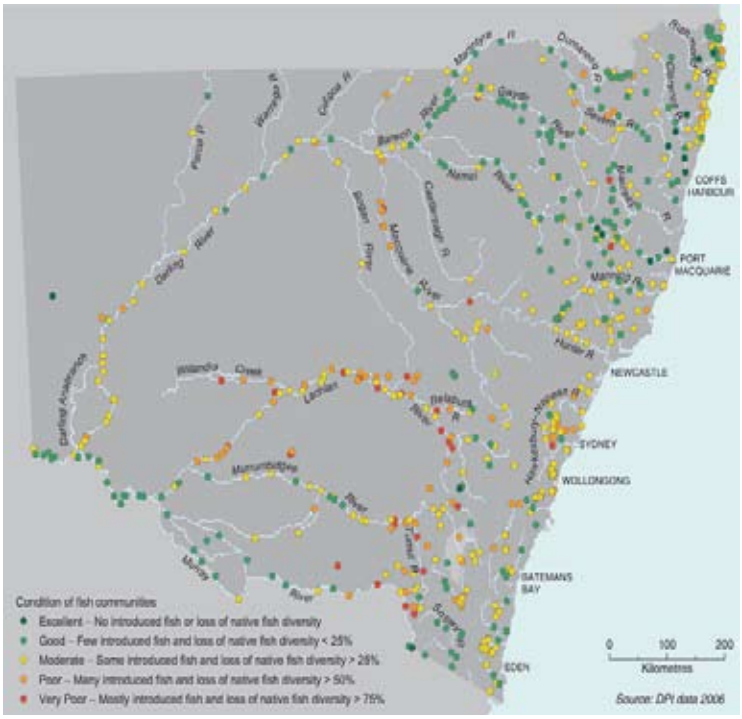
c. NSW DPI – Aquatic Biosecurity Unit

The Aquatic Biosecurity Unit undertakes targeted management actions to minimise the threats posed by pest fish and aquatic disease in both fresh and marine waters. The Aquatic Biosecurity Unit maintains a 24-hour aquatic pests hotline and the aquatic.pests@dpi.nsw.gov.au email address, where members of the community can report suspected aquatic pest sightings in New South Wales.

The Aquatic Biosecurity Unit also:

- works closely with the Aquatic Ecosystems Unit of the DPI Science and Research Division to ensure research and monitoring objectives support aquatic pest management programs

Figure 1: Example of statewide map showing locations where the health of fish communities were assessed based on distributional data *(Department of Environment and Climate Change NSW 2006)*



- represents NSW DPI on a number of national committees and groups, including the National Ornamental Fish Implementation Group
- maintains and updates the New South Wales list of noxious fish under the *Fisheries Management Act 1994*
- develops management plans for aquatic pest species; for example, a Carp Control Plan is currently being drafted for community consultation
- recently secured a national 5-year permit from the Australian Pesticides and Veterinary Medicines Authority to use rotenone for pest fish control
- undertakes eradication attempts of contained populations of pest fish; for example, Jack Dempsey cichlids on the north coast of New South Wales (using explosives) and speckled mosquitofish in northern Sydney (using rotenone)

- is currently developing a Pest Fish Control Kit that can be loaned out to external groups for humane removal of species such as carp from suitable water bodies

- develops educational materials for key stakeholder groups and the general community regarding aquatic pests; for example, a redfin poster ('Say NO to feral fish', June 2007) and ornamental fish brochure ('Don't dump that fish', May 2005).

8.3.3 Queensland

a. Queensland Department of Primary Industries and Fisheries (DPI&F) www.dpi.qld.gov.au

DPI&F manages the state's fish, mollusc and crustacean populations (and their habitats). The departments' main aims include protecting and conserving fisheries resources to maintain profitable commercial and recreational fishing industries. DPI&F also develops policy for the management of fisheries resources and the development of a profitable fisheries industry. To fulfil its responsibilities, DPI&F collects data on the state of key commercial and recreational species and their habitats, using this information to identify trends and assess the effectiveness of fisheries management strategies.

The DPI&F also developed a statewide long-term monitoring program that started in 1999 and uses non-destructive electrofishing to conduct annual freshwater fish surveys. The surveys form part of the statewide monitoring program to collect information on the types, sizes and abundance of fish species (including pests) living in freshwater rivers. The results of the freshwater surveys are primarily used to assess changes in populations of recreational species. Noxious fish caught such as carp, tilapia and gambusia are also monitored.

A major initiative of the Queensland Government is the South East Queensland Healthy Waterways Partnership (http://www.healthywaterways.org). The partnership involves more than 100 stakeholders from a variety of fields. The South East Queensland Healthy Waterways Strategy has been developed under the partnership, which aims to complement, support and give effect

to other strategies and plans that influence natural resource management and water quality in this region, including the:

- South East Queensland Regional Plan

- Regional Water Supply Strategy

- Natural Resources Management Plan.

The strategy has 10 key themes, with the Monitoring, Modelling and Management Framework and Protection and Conservation Programs incorporating ongoing monitoring of waterway health under the Ecosystem Health Monitoring Program.

b. Ecosystem Health Monitoring Program
http://www.ehmp.org/index.html

The Ecosystem Health Monitoring Program is a comprehensive marine, estuarine and freshwater monitoring program that undertakes a regional assessment of the ecosystem health for 18 catchments in south-east Queensland. Detailed surveys provide data on alien fish presence and abundance under the Freshwater program module. The information collected in the program is used to:

- advise councils and land managers on areas of declining health (as shown by the indicators)
- report on the effects of different land uses
- evaluate the effectiveness of management actions aimed at improving and protecting aquatic ecosystems.

8.3.4 South Australia

a. Primary Industries and Resources South Australia (PIRSA)
http://www.pir.sa.gov.au/

PIRSA contribute to the sustainable planning and development of South Australia's natural, industrial and community assets, with PIRSA Fisheries playing a leading role in research and development through the South Australian Research and Development Institute (SARDI).

As the commercial and the recreational fishing industry in South Australia relies on a healthy, well-managed fisheries resource, PIRSA Fisheries acts as the caretaker of fishing resources to ensure maximum economic gain from the resource, sharing of resources, long-term sustainability of resources, protection of biological diversity and maintenance of essential ecological systems. PIRSA Fisheries Division is responsible for: fisheries management and planning, licensing and permits, services to ensure compliance with legislation for recreational fishers and the commercial fishing industry, and providing information on fisheries resources. PIRSA Fisheries also provides a range of services for both commercial and recreational fishers. Fisheries management policies are informed by research and development undertaken by SARDI.

b. South Australian Research and Development Institute
http://www.sardi.sa.gov.au/

SARDI has established the Inland Waters and Terrestrial Ecology Program to provide key scientific and technical support to government, industry and the community for the conservation, management and rehabilitation of Australia's freshwater dependent ecosystems. The program has a number of subprograms including Habitat Ecology and Fish Monitoring and Invasive Species. Each of these programs are involved in various research activities, with the Invasive Species program currently focussing on the control of invasive pest fishes in collaboration with the IA CRC and the MDBC.

c. South Australian Murray-Darling Basin Natural Resources Management (SAMDB NRM) Board
http://www.samdbnrm.sa.gov.au/;
http://www.rivermurray.sa.gov.au/;
ttp://murraywater.skmconsulting.com

The SAMDB NRM Board is a recently formed union of organisations that includes the former River Murray Catchment Water Management Board (RMCWMB) that also assists with the River Murray Wetlands Baseline Surveys. The NRM Board coordinates and manages natural resources in the Murray-Darling Basin.

The Baseline Survey is a partnership between the RMCWMB, the South Australian Department for Water, Land and Biodiversity Conservation and the Riverine Local Action Planning Committees. The surveys of biological and physical components of 38 wetlands along the Murray River in South Australia, from the Victorian/New South Wales border to the Murray mouth, have a number of key objectives. These objectives include:

- establishing a basic knowledge of existing conditions of 38 wetlands in the River Murray catchment and how they relate to the region
- assessing priorties for future management
- identifying threatened wetland species and/or communities for protection
- providing for future wetland monitoring by community groups.

Surveys that were undertaken in 2003/04 and 2005/06 collected a range of data including distribution and abundance of alien and native fish. The surveys provide a benchmark against which all future change can be measured. Ongoing monitoring by wetland managers will identify the impacts and beneficial outcomes of the management of the wetlands.

8.3.5 Tasmania

a. Inland Fisheries Service (IFS)

The IFS is Tasmania's inland fisheries authority. The IFS is responsible for administering the *Inland Fisheries Act 1995*, Inland Fisheries Regulations 1996 and subsequent Orders. They are responsible for the following functions:

- managing, controlling, protecting, developing, improving, maintaining and regulating salmon fisheries, fisheries in inland waters and freshwater fish
- stocking inland waters with fish

- creating, improving and maintaining access to inland waters
- providing facilities in respect of access to inland waters
- researching and investigating into matters relating to salmon fisheries and fisheries in inland waters
- collecting, publishing and disseminating information relating to freshwater fish and inland waters.

Two fish species classified as 'controlled' under the *Inland Fisheries Act 1995* include carp and gambusia.

The IFS recently implemented a Carp Management Program (CMP) to eradicate carp from Tasmanian waters and 'minimise the impact of carp on Tasmania from economic, recreational and ecological points of view' (Inland Fisheries Service 2005). Ongoing monitoring as part of the program has indicated that the CMP has achieved all objectives except complete eradication (Diggle et al 2004, Inland Fisheries Service 2005), and has subsequently provided carp-specific spatial and temporal data for the sites where the program was implemented.

The ongoing program has been developed and funded by the state government to deal with the problem of carp in Tasmania, and has the following objectives:

- containing carp to their current known distribution in lakes Sorell and Crescent
- reducing the current carp population by all methods, including radio tracking, netting and electrofishing
- protecting native flora and fauna threatened by carp or carp management
- gaining an understanding of the factors controlling the success of the carp
- reviewing all options for carp eradication as they are developed
- developing guidelines for recreational and commercial access to both lakes.
- educating the public regarding the threat of carp, its possible spread and re-introduction (http://www.ifs.tas.gov.au/ifs/fisherymanagement/pestfish).

8.3.6 Victoria

a. Victorian Department of Primary Industries
http://www.dpi.vic.gov.au/

Fisheries Victoria is a division of the DPI and is the agency responsible for fisheries management in Victoria. Fisheries Victoria manages the fisheries resource by developing and implementing policies and projects and delivering a wide range of services. Victoria's commercial and recreational fisheries are diverse and geographically extensive. The business of Fisheries Victoria can be characterised as securing fisheries resources, sharing fisheries resources and growing or developing the value of the resource for the benefit of the community.

The research section of Fisheries Victoria has centres at Snobs Creek (freshwater) and Queenscliff (marine). Snobs Creek is the present base for the IA CRC Freshwater Program and this centre has considerable past experience in research on carp population dynamics.

b. Victorian Department of Sustainability and Environment (DSE)
http://www.dse.vic.gov.au/dse/nrenari.nsf

The DSE is the organisation responsible for conservation of threatened species under the *Flora and Fauna Guarantee Act 1988*.

The DSE Arthur Rylah Institute for Environmental Research is a major centre for applied ecological research. With a focus on providing strategic research and management advice in regards to flora, fauna and biodiversity, this institute is involved in a number of projects centred on key themes such as Invasive Species. Projects conducted under this theme have included the development of the Williams' Carp Separation Cage.

8.3.7 Australian Capital Territory

a. Department of Territory and Municipal Services
http://www.tams.act.gov.au/

Fish monitoring by the Research and Monitoring Unit of the Department of Territory and Municipal Services currently takes place as part of regular and irregular stream survey programs and other initiatives, providing distribution and abundance data for both native and alien fish in the upper Murrumbidgee catchments (Lintermans 2002, Gilligan 2005). Much of the existing data for the distribution and abundance of native and alien freshwater fish in the ACT region/upper Murrumbidgee catchment to date has been collated from a series of individual stream survey programs conducted since the late 1980s, or species specific monitoring programs (Lintermans 2002).

The Department of Territory and Municipal Services also conducted a series of ecological surveys following bushfires in 2003, where alien and native fish were sampled at various sites throughout the affected regions (Carey et al

2003). Other sources of fish monitoring have included surveys of recreational fishers in the ACT region, which indicated that alien fish such as redfin perch and carp are abundant (ACT State of Environment 2003).

8.3.8 Western Australia

a. Department of Fisheries, Western Australia
http://www.fish.wa.gov.au

The Department of Fisheries manages Western Australia's fish, marine and aquatic resources. The Research Division within the Department provides expert scientific knowledge and advice to make the informed management decisions essential for the conservation, sustainable management and development of aquatic resources and habitats.

Annual State of the Fisheries reports are prepared to present an overview of fisheries industries, resources and activities (mainly relating to marine, coastal and estuarine systems). Current research being funded by the Department of Fisheries includes invasive species in freshwater ecosystems, the environmental impacts and geographic spread of introduced fishes, and parasites of native and introduced freshwater fish.

The Centre for Fish and Fisheries Research, part of Murdoch University in Western Australia, provides advice and research services on marine and freshwater fish to many stakeholders.

8.3.9 Northern Territory

a. Department of Primary Industry, Fisheries and Mines (DPIFM)
http://www.nt.gov.au/dpifm

DPIFM is responsible for developing, advancing and servicing the needs of vital economic sectors in the Northern Territory. DPIFM works with commercial and recreational fishing industries, the aquaculture industry, indigenous communities and stakeholders to achieve sustainable utilisation of the Northern Territory's aquatic resources. Some aims of DPIFM relevant to the scope of this review are:

- protection and management of all aquatic resources, with particular emphasis on vulnerable fish stocks
- implementation of innovative research programs to develop fisheries technology and assessment techniques to monitor aquatic resources
- monitoring to protect local fishing, aquaculture, tourism and marine-based industries from aquatic pest incursions

- provision of fishing infrastructure projects and access arrangements to enhance recreational fishing in the Northern Territory. For more information see http://www.nt.gov.au/dpifm.

The Aquatic Pest Management unit was recently established by the Northern Territory Fisheries Group to conduct activities in environmental monitoring and public education.

8.4 Regional NRM groups

As part of the Australian Government's National Action Plan for Salinity and Water Quality and the Natural Heritage Trust, and the development of the National NRM Monitoring and Evaluation Framework, 56 NRM regions of Australia are developing and implementing natural resource management plans. These plans are required to consider all the environmental, social and economic impacts of natural resource management decisions at a regional scale. Under this scheme, monitoring and reporting are required to measure natural resources, and assess the effectiveness of programs with respect to the desired outcomes. Specific themes provide the basis for reporting, including Ecologically Significant Invasive Species, and Inland Aquatic Ecosystems Integrity, which will be monitored using appropriate techniques and methods. Alien fish information will be collected under these two themes.

8.5 Additional research organisations/ professional societies

eWater CRC
http://www.ewatercrc.com.au/

eWater is a technology development initiative established after the merging of two former CRCs – the CRC for Catchment Hydrology and the CRC for Freshwater Ecology. They are a joint venture consisting of 45 Australian water-cycle management, consulting and research organisations. eWater, through enterprise, environment and education, aims to provide water management research and product development for Australia's water systems. There are six product development programs operating under eWater. Aims of the River and Catchment Restoration and Integrated Monitoring and Assessment programs include:

- designing integrated monitoring and assessment systems for freshwater
- developing the National Water Resources Observation Network
- ensuring better understanding of river and floodplain ecosystems and processes through ongoing research.

Murray-Darling Freshwater Research Centre
http://www.mdfrc.org.au/

The Murray-Darling Freshwater Research Centre is a multidisciplinary research centre whose projects include the study of environmental flows, fish and invertebrate ecology, and water quality assessment through biological and chemical monitoring programs. Research is structured around six themes, with three themes (Water Quality and Ecological Assessment, Conservation Ecology, and Restoration Ecology) involving the assessment of aquatic, river and wetland health. Ongoing projects and collaboration with other agencies such as the MDBC have produced information regarding alien and native fish in this region.

Australian Society for Fish Biology
http://www.asfb.org.au/

This society is a professional, independent, non-profit, non-commercial organisation that seeks to promote research, education and management of fish and fisheries in Australia, and to provide a forum for the exchange of information. The society has an Alien Species Committee, involving state and territory representatives and publishes a bi-annual newsletter about alien fish in Australia. The committee aims to maintain a current list of distribution and status of alien fish species and subspecies in Australian waters and encourages the study and management of alien fishes in Australia (Lintermans pers comm 2007).

9. Management, research and monitoring priorities

Management, monitoring and research activities regarding pest fish have been implemented through a number of national, state and territory collaborations and research programs. There has been a lack of national coordination and leadership (Lintermans 2004), and there is a recognised need for the development of a national alien fish management strategy in Australia (Koehn and Mackenzie 2004).

There are a number of key issues and recommendations that have emerged through this review process regarding the monitoring and management of alien fish in Australia. The recommendations are listed below.

9.1 Management recommendations

- Develop a national approach/ framework for managing the impacts of alien fish species in Australia.
- Ensure national consistency in jurisdictional legislation and management approaches, and national permitted import lists (McNee 2002, Koehn and Mackenzie 2004, Lintermans 2004).
- Review and revise national 'noxious' fish species lists (Koehn and Mackenzie 2004) to reduce the introduction of additional species, and state and territory legislation to limit the spread of existing species.
- Develop and implement a national alien fish management strategy (Koehn and Mackenzie 2004), and complementary state/territory alien fish management strategies (Lintermans 2004).
- Consider alien fish within vertebrate pest management frameworks (strategies, policies, programs and legislation) and use pest management principles as a basis for management (Koehn and Mackenzie 2004).
- Identify from research, the adverse impacts of alien fish to facilitate management planning, policy development and appropriate management strategies.
- Ensure adverse impacts of alien fish are listed within legislative framework at Commonwealth and state/territory government levels (Koehn and Mackenzie 2004).
- Develop criteria for alien fish species prioritisation regarding management actions.
- Prepare contingency plans for rapid response to alien fish

incursions, that may be species- or site-specific (Koehn and McDowall 2004, Lintermans 2004, Smith and Hammer 2006).

- Document the current distributions of native and alien freshwater fish through monitoring to enable the identification of critical regions for management, and to form a baseline from which the effectiveness of management can be assessed (Smith and Hammer 2006).

9.2 Monitoring recommendations

- Prepare national and state/territory priority alien fish species monitoring lists that complement national 'noxious' species lists, to facilitate immediate and long-term monitoring and reporting activities under national and state/territory frameworks.

- Develop and adopt techniques for broadscale monitoring and reporting of alien fish impacts for reporting activities under Commonwealth and state/territory frameworks for resource condition monitoring.

- Ensure adoption of consistent monitoring protocols (consider those developed by the Murray-Darling Basin Commission [MDBC] and Sustainable Rivers Audit programs) for monitoring the distribution and abundance of alien fish species throughout Australia.

- Develop a national database of alien fish distribution and abundance information (species and fish translocation information) (Koehn and Mackenzie 2004).

- Undertake broadscale surveillance monitoring in all states/ territories for new incursions of alien species (Lintermans 2004).

- Actively engage community and research groups in regional planning and management (Koehn and Mackenzie 2004).

- Ensure alien fish are included in regional natural resource management (NRM) monitoring frameworks (Koehn and Mackenzie 2004).

9.3 Research recommendations

- Identify which alien fish species cause adverse impacts, and which species may present themselves as 'pests' in the future.

- Determine the quantitative impacts of alien fish on environmental values, economic productivity and aquaculture, and society/

communities (Jackson et al 2004, Koehn and McDowall 2004).

- Identify human-assisted dispersal pathways and mechanisms, and development of policies and practices to reduce the dispersal of pest fish (Lintermans 2004).

- Continue to develop risk assessment techniques to assess the current and likely impacts of alien fish species in Australia.

9.4 Recommendations for monitoring, evaluation and reporting and the National Monitoring and Evaluation Framework

9.4.1 Species prioritisation – Agreement on national and state listings

1. A national 'noxious' fish species list is required to facilitate consistent management across state/territory and Australian Government jurisdictions, including domestic trade and movement (Koehn and MacKenzie 2004).

2. Agreement needs to be reached on a national priority list of alien/pest fish species for monitoring (that complements the national 'noxious' species list), to facilitate immediate and long-term monitoring and reporting activities under state and national frameworks.

3. Advice is required from relevant specialists to identify which alien fish species may cause adverse impacts, and which species may present themselves as 'pests' in the future.

9.4.2 Indicators – Existing indicators

Connect existing national indicators under the National NRM Monitoring and Evaluation Framework (both 'Integrity of Inland Aquatic Ecosystems', and 'Invasive Species - Vertebrate Pests' themes) to monitor and report alien fish species information, thereby addressing two themes from a single monitoring action.

9.4.3 Monitoring protocols and techniques

a. Distribution and abundance

1. Agreement is required on standard techniques/protocols for detecting and monitoring of alien fish species. Existing recommended methods and protocols developed by the MDBC (see Section 5.3) should be considered for consistent data collection, collation and reporting across state and territory jurisdictions.

2. Protocol refinement is required to the MDBC fish monitoring protocols to ensure they are suitable for broadscale application,

by developing a tool to consolidate survey data to present state/territory and national data in consistent and meaningful products.

b. *Impacts*

1. Further research is required to develop tools and approaches to measure the environmental, economic and social impacts caused by alien fish species.

2. Techniques need to be developed and adopted for broadscale monitoring and reporting of alien fish impacts on environmental, economic and social values/assets.

3. Protocols need to be prepared (using these techniques) for collection, collation and reporting of impacts information for reporting under state and national frameworks.

c. National protocol for monitoring alien fish and their impacts – development and adoption

1. Ensure adoption of existing MDBC fish monitoring protocols for consistent monitoring of the distribution and abundance of alien fish (see MDBC protocols) with refinements to allow regional and state application.

2. Develop protocols for measuring and monitoring the impacts of alien fish for regional and state application.

d. Implementing national protocols and techniques

1. Engage and seek collaboration with relevant groups to facilitate adoption and ownership of information collected and collated from implementing protocols.

2. Develop a national database of alien fish distribution and abundance information (species and fish translocation information) (Koehn and MacKenzie 2004).

3. Undertake distribution and abundance surveys and collate data on alien fish species (Koehn and MacKenzie 2004).

4. Simultaneously undertake broadscale surveillance monitoring in all states/territories for new incursions of alien species (Lintermans 2004), and actively engage community and research groups in regional planning and management.

5. Ensure alien fish are included in regional NRM monitoring frameworks and associated activities.

e. Requirements of a national assessment of alien fish species

To undertake a national assessment of invasive alien fish species in Australia, nine steps have been identified:

1. Indicators – Reach agreement with relevant regional, state/territory and Australian Government stakeholders on key species information to collect and collate.

2. Species – Clarify the species required to be monitored under federal and state/territory resource monitoring commitments in accordance with national 'noxious fish' listings.

3. Techniques – Assess the suitability of current techniques for measuring and monitoring the distribution, abundance and impacts of alien fish species.

4. Monitoring – Refine techniques (where required) for measuring and monitoring the distribution, abundance and impacts of alien fish species.

5. Protocols – Develop, adopt or refine protocols for measuring and monitoring and reporting of alien fish distribution, abundance and impacts.

6. Work plan – Develop a work plan of projects for relevant stakeholders to undertake.

7. Coordination – Coordinate implementation of the work plan through relevant specialist groups and stakeholders.

8. Data management – Establish suitable data management and infrastructure requirements for national data.

9. Data collation and reporting – Undertake data collation from relevant state agencies utilising existing information, and reporting of relevant products to stakeholders.

Links to relevant groups	
National	Australian Quarantine and Inspection Service http://www.daffa.gov.au/aqis
	Department of Agriculture, Fisheries and Forestry http://www.affa.gov.au
	Commonwealth Scientific and Industrial Research Organisation http://www.csiro.au
	National Water Commission http://www.nwc.gov.au
New South Wales	NSW Department of Primary Industries – Fisheries http://www.dpi.nsw.gov.au/fisheries
	NSW Department of Environment and Climate Change http://www.environment.nsw.gov.au
	NSW Department of Water and Energy (formerly Department of Natural Resources) http://www.dnr.nsw.gov.au/
	Catchment Management Authorities http://www.cma.nsw.gov.au
Victoria	Department of Sustainability and Environment http://www.dse.vic.gov.au/dse
	Department of Primary Industries – Fishing and Aquaculture http://www.dpi.vic.gov.au
Australian Capital Territory	Department of Territory and Municipal Services http://www.tams.act.gov.au
Queensland	Department of Primary Industries and Fisheries www.dpi.qld.gov.au
Tasmania	Inland Fisheries Service http://www.ifs.tas.gov.au/ifs
	Department of Primary Industries and Water www.dpiw.tas.gov.au
South Australia	Primary Industries and Resources South Australia http://www.pir.sa.gov.au/index.shtml

Links to relevant groups	
	South Australian Research and Development Institute http://www.sardi.sa.gov.au
	Department of Water, Land and Biodiversity Conservation http://www.dwlbc.sa.gov.au
	Department for Environment and Heritage http://www.environment.sa.gov.au
Northern Territory	Department of Primary Industry, Fisheries and Mines http://www.nt.gov.au/dpifm/Fisheries
	NT Department of Natural Resources, Environment and the Arts http://www.nt.gov.au/nreta
Western Australia	Department of Fisheries, Western Australia http://www.fish.wa.gov.au/index.php
	Department of Agriculture and Food http://www.agric.wa.gov.au
	WA Department of Environment and Conservation http://portal.environment.wa.gov.au
Other relevant groups	Murray-Darling Basin Commission http://www.mdbc.gov.au
	Sustainable Rivers Audit http://www.mdbc.gov.au/SRA
	eWater Cooperative Research Centre http://www.ewatercrc.com.au
	Invasive Animals Cooperative Research Centre http://www.invasiveanimals.com
	Waterwatch http://www.waterwatch.org.au

Further Reading

Relevant strategies

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Permitted live species import list

AQIS: List of permitted live freshwater fish suitable for import http://www.daff.gov.au/aqis/import/icon-icd

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Appendix: Species information

Selected major species

There are 34 alien fish species present and established in Australian freshwater rivers and streams (Kailola, undated), and in excess of 1,000 alien species have been recorded in Australia over the past 40 years (Arthington et al 1999, McNee 2002). For detailed information about selected species, see the following web-links and associated reference material. The feral.org.au database also provides links to a range of material on major pest species, including pet fish (www.feral.org.au).

Carp (*Cyprinus carpio***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- National management strategy for carp control 2000-2005.

  Available from the Murray-Darling Basin Commission http://www.mdbc.gov.au/
- NSW Department of Primary Industries – Fisheries http://www.fisheries.nsw.gov.au/threatened_species/general/content/fn_carp.htm
- Australian Museum – Fish site: carp http://www.amonline.net.au/FISHES/fishfacts/fish/ccarpio.htm
- Department of Agriculture, Fisheries and Forestry: Bureau of Rural Sciences http://www.daffa.gov.au/brs/land/feral-animals/species/carp
- Biotechnology Online: Carp, a case study http://www.biotechnologyonline.gov.au/enviro/carp.cfm

Eastern Gambusia/mosquitofish (*Gambusia holbrooki***)**

- Allen et al (2002) Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Murray-Darling Basin Commission – Alien species: Fish information sheet

  http://www.mdbc.gov.au/NFS/alien_species_information/eastern_gambusia
- NSW National Parks and Wildlife Service (2003) NSW Threat Abatement Plan for predation by Gambusia holbrooki – The Plague Minnow. Available at: http://www.nationalparks.nsw.gov.au/npws.nsf/content/threat_abatement_plan_plague_minnow
- Australian Museum – Fish site: Gambusia holbrooki www.amonline.net.au/fishes/fishfacts/fish/gholbrooki.htm

- Department of Primary Industries Victoria – Information Series: freshwater fish www.dpi.vic.gov.au

Tilapia/Mozambique mouth brooder (*Oreochromis mossambicus*)

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- NSW Department of Primary Industries – Fisheries. http://www.fisheries.nsw.gov.au/threatened_species/general/content/fn_tilapia.htm
- Queensland Department of Primary Industries and Fisheries. http://www2.dpi.qld.gov.au/fishweb/14477.html#2
- Australian Society for Fish Biology (ASFB). http://www.asfb.org.au/research/es/cichlida.htm#TopOfPage
- Department of Primary Industries, Fisheries and Mines, Northern Territory. http://www.nt.gov.au/dpifm/Fisheries/Content/File/aquatic_pests/tilapia.pdf

Oriental weatherloach (*Misgurnus anguillicaudatus*)

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Australian Museum Fish Site – Oriental weatherloach. http://www.amonline.net.au/FISHES/fishfacts/fish/manguili.htm
- Queensland Department of Primary Industries and Fisheries. http://www2.dpi.qld.gov.au/fishweb/2377.html
- ACT Department of Territory and Municipal Services – Introduced fish information sheet: Oriental weatherloach. http://www.tams.act.gov.au/live/environment/water/water/fisheries_management/fish_information_sheets/introduced_fish
- Department of Primary Industries Victoria - Information Notes: freshwater fish. Available at http://www.dpi.vic.gov.au

Redfin/European perch (*Perca fluviatilis*)

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Australian Museum Fish Site – Find a Fish. http://www.amonline.net.au/fishes/fishfacts/fish/pfluviat.htm
- Murray-Darling Basin Commission – Alien Species: Fish information sheet. http://www.mdbc.gov.au/NFS/alien_species_information/redfin_perch
- NSW Department of Primary Industries – Fisheries: Alien fish. http://www.fisheries.nsw.gov.au/aquatic_habitats/aquatic_habitats/alien_fish

- Murray-Darling Basin Commission – Alien species fish information sheet. http://www.mdbc.gov.au/NFS/alien_species_information/redfin_perch
- Inland Fisheries Service Tasmania – Fact sheet for redfin perch. http://www.ifs.tas.gov.au/ifs/IFSDatabaseManager/SpeciesDatabase/redfin
- Department of Primary Industries Victoria – Information Series: freshwater fish. http://www.dpi.vic.gov.au

Goldfish (*Carassius aurautus***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Tasmania Inland Fisheries Service – Fact Sheet for Goldfish. http://www.ifs.tas.gov.au/ifs/IFSDatabaseManager/SpeciesDatabase/goldfish
- Queensland Department of Primary Industries and Fisheries. http://www2.dpi.qld.gov.au/fishweb/2402.html
- NSW Department of Primary Industries – Fisheries: Alien fish. http://www.fisheries.nsw.gov.au/aquatic_habitats/aquatic_habitats/alien_fish

Tench (*Tinca tinca***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Victoria Department of Primary Industries – Freshwater fish information note. http://www.dpi.vic.gov.au/ Online Services menu > Information Notes Series > Fisheries and Aquaculture > Freshwater Species > Tench
- Inland Fisheries Service Tasmania – Fact sheet for Tench. http://www.ifs.tas.gov.au/ifs/IFSDatabaseManager/SpeciesDatabase/tench

Roach (*Rutilus rutilus***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Victoria Department of Primary Industries – Freshwater fish information note. http://www.dpi.vic.gov.au/ Online Services menu > Information Notes Series > Fisheries and Aquaculture > Freshwater Species > Roach

Family Salmonidae

Rainbow trout (*Oncorhynchus mykiss***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Murray-Darling Basin Commission – Alien fish species. http://www.mdbc.gov.au/NFS/alien_species_information/rainbow_trout

Atlantic salmon (*Salmo salar***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Murray-Darling Basin Commission – Alien fish species. http://www.mdbc.gov.au/NFS/alien_species_information/atlantic_salmon

Quinnat / Chinook salmon (*Oncorhynchus tshawytscha***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Victoria Department of Primary Industries – Freshwater fish information note. http://www.dpi.vic.gov.au/ Online Services menu > Information Notes Series > Fisheries and Aquaculture > Freshwater Species > Chinook Salmon

Brown trout (*Salmo trutta***)**

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Australian Museum Fish Site – Find a fish. http://www.amonline.net.au/FISHES/fishfacts/fish/strutta.htm

Brook trout (*Salvelinus fontinalis*)

- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.
- Inland Fisheries Service Tasmania – Fact sheet. http://www.ifs.tas.gov.au/ifs/IFSDatabaseManager/SpeciesDatabase/brook-trout

Other species

Rosy barb (*Puntius conchonius***)**

- Queensland Department of Primary Industries and Fisheries note. http://www2.dpi.qld.gov.au/fishweb/2219.html
- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.

Platy (*Xiphophorus maculatus***)**

- Queensland Department of Primary Industries and Fisheries note. http://www2.dpi.qld.gov.au/fishweb/14087.html
- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.

Swordtails (Green swordtail) (*Xiphophorus hellerii***)**

- Queensland Department of Primary Industries and Fisheries note. http://www2.dpi.qld.gov.au/fishweb/14087.html
- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.

One spot livebearer/speckled mosquitofish (*Phalloceros caudimaculatus***)**

- NSW Department of Primary Industries – Fisheries. http://www.fisheries.nsw.gov.au/threatened_species/general/content/fn_mosquito_fish

Banded grunter (*Amniataba percoides***)**

- NSW Department of Primary Industries – Fisheries. http://www.fisheries.nsw.gov.au/threatened_species/general/content/fn_banded_grunter.htm
- Allan, G. R (1989). Freshwater fishes of Australia. T.F.H. Publications, New Jersey.

Guppy (*Poecilia reicultata***)**

- Queensland Department of Primary Industries and Fisheries. http://www2.dpi.qld.gov.au/fishweb/2404.html
- Department of Fisheries, Government of Western Australia. http://www.fish.wa.gov.au/docs/pub/IMPFreshwater/IMPFreshwaterPage06.php?0506

Oscar (*Astronotus ocellatus***)**

- Northern Territory Government Department of Primary Industries, Fisheries and Mines: Fishnote publication. http://www.nt.gov.au/dpifm/Fisheries/Content/File/aquatic_pests/oscar.pdf
- Gulf States Marine Fisheries Commission: Non-native Aquatic Species summaries. http://nis.gsmfc.org/nis_factsheet2.php?toc_id=166

Sailfin molly (*Poecilia latipinna***)**

- Queensland DPI and Fisheries - Fish note. http://www2.dpi.qld.gov.au/fishweb/14272.html
- Allen et al (2002). Field guide to the freshwater fishes of Australia. Western Australia Museum, Western Australia.

Three spot gourami (*Trichogaster trichopterus***)**

- Australian Centre for Tropical Freshwater Research – pest fish profile. http://www.actfr.jcu.edu.au/Projects/Pestfish/Profiles/ProfileGourami.htm
- Queensland Department of Primary Industries and Fisheries – Fish note. http://www2.dpi.qld.gov.au/fishweb/14074.html

White cloud minnow (*Tanichtyys albonubes***)**

- Queensland Department of Primary Industries and Fisheries. http://www2.dpi.qld.gov.au/fishweb/14082.html

Pearl cichlid (*Geophagus brasiliensis***)**

- Arthington et al (1999). Baseline environmental data relevant to an evaluation of quarantine risk potentially associated with the importation to Australia of ornamental finfish.