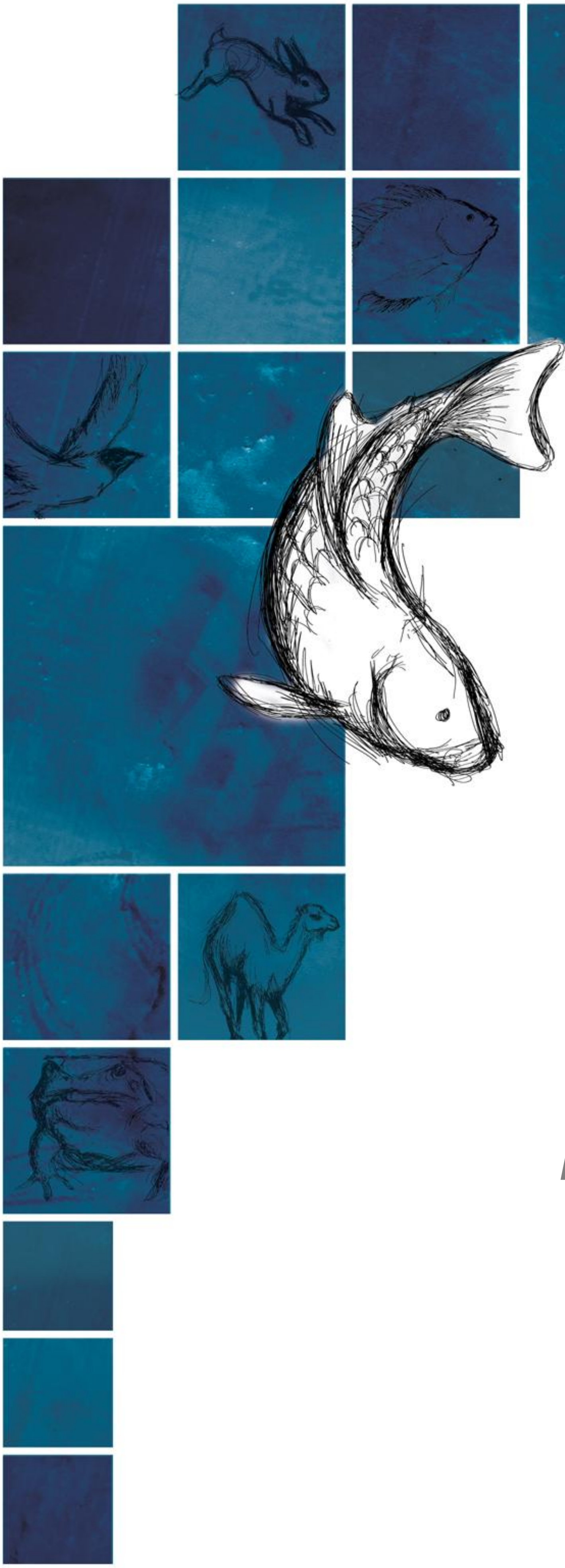

PESTSMART

Management of freshwater fish incursions

a review

R. Ayres and P. Clunie

Invasive Animals CRC

State Government Victoria
Department of Sustainability and Environment

Management of freshwater fish incursions: a review

Renae Ayres

Pam Clunie

Arthur Rylah Institute for Environmental Research

123 Brown Street,
Heidelberg, Victoria 3084

2010

An IA CRC Project

Disclaimer: The views and opinions expressed in this report reflect those of the authors and do not necessarily reflect those of the Australian Government or the Invasive Animals Cooperative Research Centre. The material presented in this report is based on sources that are believed to be reliable. Whilst every care has been taken in the preparation of the report, the authors give no warranty that the said sources are correct and accept no responsibility for any resultant errors contained herein, any damages or loss whatsoever caused or suffered by any individual or corporation.

Published by: Invasive Animals Cooperative Research Centre.

Postal address: University of Canberra, ACT 2600.

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

ISBN: 978-1-921777-20-2

Web ISBN: 978-1-921777-21-9

© Invasive Animals Cooperative Research Centre 2010

This work is copyright. The Copyright Act 1968 permits fair dealing for study, research, information or educational purposes. Selected passages, tables or diagrams may be reproduced for such purposes provided acknowledgement of the source is included. Major extracts of the entire document may not be reproduced by any process.

This document should be cited as: Ayres R and Clunie P (2010). *Management of freshwater fish incursions: a review*. PestSmart Toolkit publication, Invasive Animals Cooperative Research Centre, Canberra, Australia.

Contents

Acknowledgements vi

Summary 1

Scope 3

Aim 3

Approach 3

Outline 3

1. Introduction 5

1.1 What is an alien species? 5

1.2 Alien fish introductions in freshwater ecosystems 5

1.2.1 Alien fish introductions in Australian freshwater ecosystems 6

1.3 Reasons for the introduction of alien freshwater fish 15

1.3.1 Reasons for the introduction of alien freshwater fish in Australia 16

1.4 The invasion process 17

1.4.1 Stages of invasion 17

1.4.2 Factors influencing invasion success 18

1.5 Impacts of alien freshwater fish 19

1.5.1 Environmental impacts 20

1.5.2 Economic impacts 20

1.5.3 Social impacts 21

1.6 Management of alien species 22

1.6.1 Early detection 23

1.6.2 Rapid assessment 24

1.6.3 Rapid response 25

1.7 Key conclusions 26

2. Review of international approaches to alien fish incursions 27

2.1 Conventions and programs 27

2.2 International approaches to new alien freshwater fish incursions 30

2.2.1 Canada 30

2.2.2 United States of America 32

2.2.3 The Great Lakes 35

2.2.4 South America 37

2.2.5 Great Britain 37

2.2.6 European Union 39

2.2.7 Africa 40

2.2.8 Asia 41

2.2.9 New Zealand 42

2.3 Common challenges of alien species management 45

2.4 Key conclusions 47

3. Existing prevention, detection and management programs and tools in Australia 49

3.1 Legislation 49

3.2 Rapid response procedures ... 52
3.3 Management plans and strategies ... 53
3.4 Surveillance programs ... 54
3.5 Community education ... 54
3.6 Reporting systems ... 55
3.7 Risk assessment/decision support procedure ... 56
3.8 Management options ... 62
3.8.1 The drought: a unique opportunity for alien freshwater fish management? . 67
3.8.2 The problems of alien freshwater fish disposal ... 67
3.9 Past eradication and control programs in Australia ... 68
3.10 Key conclusions ... 84

4. Review of international alien freshwater fish containment methods ... 87
4.1 Physical barriers ... 88
4.1.1 Barrier screens ... 88
4.1.2 Rotating drum screens ... 88
4.1.3 Rotating travelling screens ... 89
4.1.4 Barrier nets or fences ... 89
4.1.5 Floating curtains ... 90
4.1.6 Vertical drop barriers ... 90
4.1.7 Traps and cages ... 90
4.2 Behavioural barriers ... 91
4.2.1 Sound barriers ... 92
4.2.2 Light barriers ... 93
4.2.3 Electrical barriers ... 93
4.2.4 Air bubble curtain ... 94
4.2.5 Water jet curtain ... 95
4.2.6 Hydrodynamic louvre screens ... 95
4.2.7 Pheromone barriers ... 95
4.3 Considerations for fish containment ... 102
4.3.1 A strategic approach to fish barrier technology in Australia ... 102
4.3.2 Knowledge of targeted fish species biology ... 102
4.3.3 Barrier design ... 103
4.3.4 Permanent versus temporary fish barriers ... 104
4.4 Key conclusions ... 106

Appendices ... 107
Appendix 1. Objectives in various Aquatic Nuisance Species Rapid Response Plans in the United States of America ... 107
Appendix 2. The National Noxious Fish List for Australia ... 109
Appendix 3. Legislation to be considered when devising alien freshwater fish emergency response or management plans ... 112

References ... 115
Personal communication ... 141

Glossary ... 142

List of Tables

Table 1. Numbers of native and alien freshwater fish species in selected regions of the world 7

Table 2. Alien freshwater fish species recorded in Australian waterways and their reason for introduction 9

Table 3. Native freshwater fish species that have been translocated within Australia 11

Table 4.Human mediated vectors of the dispersal of alien freshwater fish with Australian examples 18

Table 5. Actions associated with components of early detection and rapid response 23

Table 6. Examples of global and regional conventions that refer to alien species or aquatic environments 28

Table 7. Themes of the CBD's 'Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species' 28

Table 8. Examples of various publications developed through GISP to foster awareness of and assist alien species management 30

Table 9. USA state and interstate aquatic nuisance species (ANS) management plans and species-specific ANS management/control plans 35

Table 10. Factors considered in MAFBNZ's Response Prioritisation Tool 44

Table 11. Challenges of alien species management 46

Table 12. Terms applied in state and territory fisheries legislation to describe alien fish..... 50

Table 13. Examples of national emergency response plans for alien species in Australia...... 53

Table 14. State and territory emergency response and management approaches to incursions of alien freshwater fish 57

Table 15. Techniques for alien freshwater fish management 63

Table 16. Summary of previous eradication and control actions for alien freshwater fish in Australia 72

Table 17. Characteristics of various physical and behavioural fish barriers. 97

Acknowledgements

This review is a component of the Invasive Animals Cooperative Research Centre (IA CRC) project, 'Development of a national rapid response plan for invasive freshwater fish in Australia' (Project No. 9.1.F), funded by the IA CRC and undertaken by the Department of Sustainability and Environment's Arthur Rylah Institute for Environmental Research (DSE ARI).

The project team thanks Belinda Cant (DSE ARI) and Julia Taranto for progressing the initial development of this review, and Ivor Stuart (Kingfisher Research) in particular for contributions to section 3.8 (management options). The project's steering committee — Wayne Fulton (IA CRC, Department of Primary Industries, Fisheries Victoria), John Koehn and Tarmo Raadik (DSE ARI), Karen Weaver and Bill O'Connor (DSE Biodiversity and Ecosystem Services), Jon Presser (Department of Primary Industries, Fisheries Victoria), John Diggle (Inland Fisheries Service, Tasmania), John Gilliland (Department of Primary Industries and Resources, South Australia), Mike Braysher (University of Canberra), Mark Lintermans (University of Canberra), Matt Britzel (Department of Territory and Municipal Services, Australian Capital Territory), Heleena Bamford (Murray–Darling Basin Authority), Helen Cribb (Department of Resources – Primary Industry, Fisheries and Resources, Northern Territory), Jane Frances, Melissa Walker and Jamie Knight (Department of Industry and Investment, New South Wales), Zafer Sarac (Queensland Department of Employment, Economic Development and Innovation), Paul Hardiman (Commonwealth Department of Environment, Water, Heritage and the Arts) and Andrew Hill (Department of Fisheries, Western Australia) — are thanked for their input and valuable comments on early versions. Steve Saddlier, Jed MacDonald and Joanne Kearns (DSE ARI) are also thanked for reviewing drafts.

Over 100 people worldwide were contacted to source information for this report. We are extremely grateful to everybody for their assistance and willingness to provide information. It highlights that alien freshwater fish are a major concern globally, and that there is enthusiasm to share knowledge, learn from each other and undertake concerted management approaches.

Summary

Biotic exchange has been predicted as the main driver of global biodiversity change in freshwater ecosystems. Activities associated with increasing globalisation are facilitating the introduction of freshwater fish outside their native range and dispersal ability. Introductions of alien freshwater fish may be accidental or intentional, and have been made for food resources, recreational fishing, ornamental purposes, aquaculture, and biological control. Introductions of alien freshwater fish can result in negative and positive environmental, social and economic outcomes. Alien freshwater fish are repeatedly associated with declines in native freshwater fish and often eventually account for a high proportion of the total freshwater fish community.

In Australian freshwater ecosystems, the number of alien fish species forming established populations has steadily increased since European settlement. Forty-four alien freshwater fish species have been recorded in Australian waterways; these include five of the eight fish species listed in the 'top 100 of the world's worst alien invasive species' (Lowe et al 2000). The majority of recent introductions (since the 1970s) are alien ornamental fish species, whereas prior to this most introductions were related to European settlement.

There are many approaches to alien freshwater fish management, including ratification of global conventions, legislation (governing, for example, quarantine, trade, movement, permitted species), plans and strategies (eg emergency response plans, management plans) and education programs. Australia can learn from countries with advanced management approaches to alien freshwater fish incursions. In particular, New Zealand and the United States of America, and to a lesser degree Great Britain and Canada, are actively undertaking management of alien freshwater fish, incorporating a combination of legislation, plans and strategies, and community education. Many developing countries are less advanced, lacking fish occurrence and distribution data and varying in the significance placed on managing alien species incursions. There are many common global challenges to alien freshwater fish management; these relate to capacity, policy, awareness, resources, information and institutional issues. Understanding and addressing these issues will be essential in developing and implementing Australian emergency response arrangements for freshwater fish incursions.

In Australia, consistency is required for legislation directly related to alien freshwater fish management, including terminology (eg the definition of 'noxious'). States and territories differ in their existing emergency responses approaches, management plans and strategies, surveillance to detect incursions, reporting systems, community education and risk assessment processes. The roles and responsibilities of federal, state and territory agencies in managing freshwater fish incursions vary, and lead agencies must be clarified. Existing national rapid response approaches and plans to other biosecurity threats, such as AUSVETPLAN and PLANTPLAN, can guide the development of national emergency response arrangements for freshwater fish incursions. It is important to align with the progress and outcomes of the Biosecurity Emergency Preparedness Working Group's work on harmonising national response arrangements for biosecurity emergencies.

Various management options are available to deal with alien freshwater fish incursions, including physical removal, chemical treatment, habitat manipulation and biological control. Each option has advantages and disadvantages, and few methods provide complete eradication even if implemented successfully.

Many alien freshwater fish eradication and control programs have been undertaken in Australia, with varying levels of success. The majority of eradication exercises used chemical

(rotenone) treatment, while control exercises involved a combination of physical removal by electrofishing, netting and screening, and habitat modification using water manipulation methods. The documentation of management programs is improving, with detailed information on aims, methods, costs, monitoring and outcomes more frequently included. A centralised database would enable the collation, analysis and interpretation of documented management programs, as well as the dissemination of information for educational purposes. A centralised decision support program would also be valuable to provide easily accessible information to responsible agencies concerning management options for alien fish, the advantages and disadvantages of various methods, and other issues to be considered.

An important aspect of alien freshwater fish management is effectively limiting the spread of alien freshwater fish to a defined geographical area (containment) or preventing their entry into a defined geographical area (exclusion). Several barrier techniques developed to prevent fish entering water intakes may be suitable for containing or excluding alien freshwater fish. In the USA, UK, Europe and New Zealand there has been significant research, development and application of fish barriers, but only limited advancement in Australia. Fish barriers can be categorised into physical or behavioural barriers. Fish barriers vary in design, effectiveness, cost, and installation, maintenance and operational requirements. Deciding which barrier to install must therefore be done on a case-by-case basis. Fish barriers applied to contain new alien freshwater fish incursions are often temporary, and must be easy and quick to deploy and provide 100% containment during the response process. The application of fish barriers to contain established alien fish is often permanent or seasonal. Research on the application of various barriers for alien fish management in Australia is required, particularly because few methods are currently in use in Australia.

Development of national emergency response arrangements for freshwater fish incursions should take into account key conclusions from this literature review. The key issues identified may continue to arise in the ongoing management of alien freshwater fish incursions in Australia. These relate to legislation, coordination, training, engagement, education, and research and development.

Scope

Aim

The aim of this review is to present current international and national information on alien freshwater fish management and emergency responses to new incursions. Summarising this information may inform the development of national emergency response arrangements for freshwater fish incursions.

The specific objectives of this review are to:

- document national and international approaches to the management of new alien freshwater fish incursions to identify the current best practice
- review surveillance, eradication and control programs in Australia to document existing response plans for alien freshwater fish incursions in all states and territories
- collate information on past eradication and control attempts of alien freshwater fish in Australia to identify weaknesses and areas for potential improvement
- review international alien freshwater fish containment methods.

Approach

The preparation of this review involved a comprehensive literature search and engagement with agency professionals to gather available information on international and national emergency response approaches to alien freshwater fish incursions, past eradication and control attempts of alien freshwater fish in Australia and potential alien freshwater fish containment methods. Relevant publications and communications were summarised and presented.

This review was written based on information gathered prior to January 2009. Attempts have been made to incorporate updated information into this document where possible.

Outline

Chapter 1 provides background information on alien fish introductions in freshwater ecosystems, the reasons for their introduction, the invasion process, and factors influencing the success of introductions. The environmental, social and economic impacts of alien freshwater fish and general emergency response procedures for alien species incursions are also outlined.

Chapter 2 reviews international management approaches to new alien freshwater fish incursions. This includes an overview of international agreements and programs relating to alien species and response approaches to alien freshwater fish incursions in selected countries.

Chapter 3 describes current emergency response approaches for alien freshwater fish incursions for each state and territory in Australia and discusses how their management could be improved. Past attempts to eradicate or control alien freshwater fish are summarised and reviewed, and their effectiveness is discussed.

Chapter 4 provides information on a range of physical and behavioural fish containment methods with potential for use in alien fish management.

1. Introduction

1.1 What is an alien species?

Defining 'alien species' can be challenging because of the breadth of terminology applied in invasion biology, and because the definitions of these terms are often used interchangeably (Colautti and MacIsaac 2004, Copp et al 2005); some examples can be found in Williamson and Fitter (1996a), Richardson et al (2000), and McNeely et al (2001). The inconsistent usage of vocabulary across jurisdictional borders continues to hinder the management of alien species worldwide, and clearly a standardised approach is required (McNeely et al 2001, Clunie et al 2002, Copp et al 2005).

Throughout this review, the definitions of terms mostly follow McNeely et al (2001). Thus an alien species (synonymous with a non-native, non-indigenous, foreign or exotic species) is defined as 'a species introduced outside its normal past or present distribution; including any parts, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce'. McNeely et al (2001) defined an invasive species as 'an alien species whose establishment and spread threatens ecosystems, habitats, or species with economic or environmental harm'. Open to interpretation, these definitions may be applicable to a native species introduced outside of their natural range and causing economic or environmental harm in their introduced range. Here we apply these terms explicitly for freshwater fish introduced from another country, unless otherwise stated.

1.2 Alien fish introductions in freshwater ecosystems

The introduction and establishment of species outside their normal range is increasing with trade, transport, travel and tourism activity as a consequence of globalisation (Olden et al 2008, Westphal et al 2008). Biotic exchange is predicted to be the leading driver of global biodiversity change in freshwater ecosystems, among other anthropogenic activities including habitat degradation, water regulation, pollution, overexploitation and climate change (Millennium Ecosystem Assessment 2005, Sala et al 2000).

A total of 624 freshwater fish species have been introduced internationally (Gozlan 2008). Table 1 provides examples of the number of native and alien freshwater fish species established in various regions of the world. Clearly, freshwater fish introductions can occur in any freshwater habitat, on continents and islands, and in tropical, subtropical and temperate regions. Many regions support large numbers of alien freshwater fish relative to the number of native fish species present (eg Ireland, South Korea, Japan and Puerto Rico) (Table 1).

The proportion of introduced alien species that successfully form established populations is frequently debated when discussing invasion biology. A commonly supported estimate (known as the 'tens rule') proposed by Williamson and Fitter (1996b) predicts that around 10% of introduced species become established and that approximately 10% of these become pests (see Bomford and Glover 2004). But research suggests that these figures are considerable underestimations when considering fish invasions in freshwater environments. Arthington et al (1999) analysed records of 2,467 introductions of alien freshwater fish around the world, finding that 51% of these formed established populations. Similar analyses by Ruesink (2005) and Casal (2006) gave comparable results. Jeschke and Strayer (2005) compared the establishment success and invasiveness of freshwater fish introductions in Europe and North America. In Europe, 36% of freshwater fish introductions formed established populations, and 56% of those subsequently became invasive. In North America, 49% formed established populations, and 63% of those became invasive. These studies support the view that approximately 50% of freshwater fish introductions result in established populations, although this varies between fish taxa and location (Bomford and Glover 2004).

1.2.1 Alien fish introductions in Australian freshwater ecosystems

In Australian freshwater ecosystems the number of alien fish species forming established populations has steadily increased, particularly since the 1970s (Lintermans 2004, Koehn and MacKenzie 2004). Forty-four alien freshwater fish species have been recorded in natural environments (Table 2). Five of these species (brown trout *Salmo trutta*, common carp *Cyprinus carpio*, rainbow trout *Oncorhynchus mykiss*, eastern gambusia *Gambusia holbrooki* and Mozambique tilapia *Oreochromis mossambicus*) are amongst eight of the world's worst alien invasive fish species (Lowe et al 2000). Nine families are represented, but most established alien freshwater fish species belong to the Cichlidae, Cyprinidae and Poeciliidae (Table 2). The greatest numbers of established alien freshwater fish occur in the eastern mainland states of Australia. Common carp, eastern gambusia and goldfish (*Carassius auratus*) are the most widely distributed alien freshwater fishes, occurring in nearly all Australian states and territories. Other species have localised distributions; for example, certain members of the Cichlidae only occur in Queensland.

Native freshwater fish species translocated outside their natural range can also be considered alien species, and therefore may be a component of alien species management programs. Table 3 provides a summary of translocations of 76 native freshwater fish and five native crayfish species within Australia; this information represents a collation of recent information and recent expert opinion. This summary includes crayfish, which are incorporated within the definition of 'fish' in some legislation within Australia. The majority of these translocations have occurred in the Murray–Darling Basin primarily due to stocking programs (SKM 2008). Silver perch (*Bidyanus bidyanus*), Murray cod (*Maccullochella peelii peelii*) and the common yabby (*Cherax destructor*) are the most broadly translocated native freshwater species, with records of each species translocated in six of the eight states and territories. Fifteen native fish species or subspecies have been translocated into states and territories where they do not naturally occur; the remainder occur naturally within a state or territory but have been translocated into areas outside their natural range within that state or territory. Furthermore, five species of freshwater crayfish (Family: Parastacidae) have been translocated outside their natural range within Australia. While little is known of the potential impacts of alien Parastacidae on indigenous fauna in Australia, overseas studies indicate that the impacts of alien crayfish introductions may be of concern (Rodríguez et al 2005, Harlioğlu and Harlioğlu 2006, Johnsen et al 2007, Gherardi 2007a). Although the native species listed in Table 3 are known to have been translocated within Australia, some have not formed established populations in their translocated range (eg eels and catfish in the Australian Capital Territory).

In the future, the number of established alien freshwater fish in Australia could continue to rise or remain stable. In the past 40 years, 1,181 alien ornamental fish species have been recorded in Australia (predominately from the freshwater aquarium trade) despite only 481 of these being legally approved for importation (McNee 2002). The potential for the release of any of these species into the wild is a very real threat. Further warning is given by Leprieur et al (2008), who recently identified Australian freshwater ecosystems as one of six global invasion hotspots for fish species.

Table 1. Numbers of native and alien freshwater fish species in selected regions of the world

Region	Native species	Alien species	% Alien species	Reference
Alaska	55	01	02	Vitousek et al (1997)
Algeria	45	16	26	Bacha (2007)
Australia	~ 300	45	13	Koehn and MacKenzie (2004), This report
Austria	na	28	na	Fureder and Pockl (2007)
Bangladesh	266	15	05	Pallewatta et al (2003)
Belgium	na	14	na	Verreycken et al (2007)
Brazil	517	76	13	Vitousek et al (1997)
California	na	56	na	Dill and Cordone (1997)
Canada	207	23	10	Dextrase and Mandrak (2006)
China	na	72	na	Ma et al (2003)
Cuba	na	10	na	Vitousek et al (1997)
England	57	17	23	Maitland (2004)
Europe	na	76	na	Lehtonen (2002)
Florida	na	50	na	Courtenay (1997)
France	na	26	na	Keith and Allardi (1998)
Germany	na	12	na	Gollasch and Nehring (2006)
Greece	na	23	na	Economidis et al (2000)
Hawaii	na	33	na	Maciolek (1984)
Ireland	14	11	44	Griffiths (1997)
Israel	na	27	na	Roll et al (2007)
Italy	na	25	na	Bianco (1998)
Japan	> 120	84	41	Chiba et al (1989)
Mauritius	na	23	na	Macdonald et al (2003)
New Zealand	38	22	36	McDowall (2006)
Norway	43	11	2	Hesthagen and Sandlund (2007)
Peru	na	12	na	Vitousek et al (1997)
Portugal	na	12	na	Almaca (1995)
Puerto Rico	03	32	91	Vitousek et al (1997)
Scotland	57	31	35	Maitland (2004)
Serbia	73	18	25	Lenhardt et al (2006)
Singapore	na	58	na	Pallewatta et al (2003)
Slovenia	70	16	19	Povz and Sumer (2005)
South Africa	na	28	na	Macdonald et al (2003)
South Korea	59	135	70	Jang et al (2002)
Spain	~ 75	25	25	Elvira and Almodovar (2001)

Region	Native species	Alien species	% Alien species	Reference
Sri Lanka	na	> 20	na	Wijeyaratne and Perera (2001)
Turkey	na	25	na	Innal and Erk'akan (2006)
Upper Mississippi River Basin	200	60	23	FishPro (2004)
USA	na	536	na	Meador et al (2007)
Wales	57	29	34	Maitland (2004)

Note: na means data was unavailable

Table 2. Alien freshwater fish species recorded in Australian waterways and their reason for introduction

Family and species	Common Name	Distribution	Reason for introduction
BELONTIIDAE			
Trichogaster trichopterus	three spot gourami	Qld	Ornamental
CICHLIDAE			
Aequidens pulchrus	blue acara	Vic, Qld	Ornamental
Aequidens rivulatus	green terror	Qld	Ornamental
Amphilophus citrinellus	midas cichlid	Qld	Ornamental
Amphilophus labiatus	red devil	Vic, Qld	Ornamental
Archocentrus nigrofasciatus	convict cichlid	Vic, Qld	Ornamental
Astronotus ocellatus	oscar	Qld	Ornamental
Cichlasoma brasiliensis	pearl cichlid	Qld	Ornamental
Cichlasoma octofasciatum	Jack Dempsey	Vic, NSW, Qld	Ornamental
Heros severus (previously known as Cichlasoma severum)	green severum or banded cichlid	Qld	Ornamental
Cichlasoma synspilum	redhead cichlid	Qld	Ornamental
Cichlasoma trimaculatum	three spot cichlid	Qld	Ornamental
Geophagus braziliensis	pearl eartheater	NSW, WA	Ornamental
Haplochromis burtoni	Victoria Burtons haplochromis	Qld	Ornamental
Hemichromis bimaculatus	jewel cichlid	Qld, NT[#]	Ornamental
Labeotropheus/Pseudotropheus	hybrid cichlid	Vic	Ornamental
Oreochromis mossambicus	Mozambique tilapia	Qld, WA	Ornamental
Thorichthys meeki	firemouth	Qld	Ornamental
Tilapia mariae	black mangrove cichlid	Vic, Qld	Ornamental
Tilapia zillii	redbelly tilapia	WA	Ornamental
COBITIDAE			
Misgurnus anguillicaudatus	oriental weatherloach	Vic, ACT, NSW, Qld[#]	Ornamental
CYPRINIDAE			
Carassius auratus	goldfish	Tas, Vic, ACT, NSW, Qld, WA, SA	Ornamental
Carassius carassius	crucian carp	Vic	Ornamental
Cyprinus carpio	common carp	Tas, Vic, ACT, NSW, Qld, WA, SA	Ornamental /Aquaculture
Puntius conchonius	rosy barb	Qld, WA	Ornamental
Puntius tetrazona	Sumatra barb	Qld	Ornamental
Rutilus rutilus	roach	Vic	Recreational angling
Tanichthys albonubes	white cloud mountain minnow	NSW, Qld	Ornamental

Family and species	Common Name	Distribution	Reason for introduction
Tinca tinca	tench	Tas, Vic, NSW*, SA	Recreational angling
CYPRINODONTIDAE			
Jordanella floridae	American flagfish	Qld	Ornamental
GOBIIDAE			
Acanthogobius flavimanus	yellowfin goby	Vic, NSW	Ballast water
Acentrogobius pflaumii	streaked goby	Vic	Ballast water
PERCIDAE			
Perca fluviatilis	redfin perch	Tas, Vic, ACT, NSW, WA, SA	Recreational angling
POECILIIDAE			
Gambusia holbrooki	eastern gambusia	Tas, Vic, ACT, NSW, Qld, NT, WA, SA	Biocontrol
Phalloceros caudimaculatus	one-spot livebearer	NSW[#], WA, SA	Ornamental
Poecilia latipinna	sailfin molly	Qld, NT[#]	Ornamental
Poecilia reticulata	guppy	Qld, NT, WA	Ornamental
Xiphophorus hellerii	green swordtail	NSW, Qld, NT[#], WA	Ornamental
Xiphophorus maculatus	platy	NSW, Qld, NT[#]	Ornamental
SALMONIDAE			
Oncorhynchus mykiss	rainbow trout	Tas, Vic, ACT, NSW, Qld, WA, SA	Recreational angling
Oncorhynchus tshawytscha	chinook salmon	Vic	Recreational angling
Salmo salar	atlantic salmon	Tas, Vic, NSW, SA	Recreational angling
Salmo trutta	brown trout	Tas, Vic, ACT, NSW, WA, SA	Recreational angling
Salvelinus fontinalis	brook trout	Tas, ACT, NSW	Recreational angling
Total species	Tas – 9, Vic - 20, ACT – 8, NSW - 17, Qld – 29, NT – 2, WA – 13, SA – 9		

Sources: Webb (1994), McKay (1989), Lintermans (2004), Koehn and MacKenzie (2004), West et al (2007), Corfield et al (2007), ASFB (June 2009), T Raadik personal communication, Jamie Knight personal communication, M Walker personal communication.

[#] Species previously established but successfully eradicated; not included in totals at foot of table.

* Presence uncertain.

Table 3. Native freshwater fish species that have been translocated within Australia

Open squares indicate species that are native to the state/territory but have been translocated within it. Closed squares indicate species that have been translocated into the state/territory and are not native there.

FAMILY		Distribution							
Species	Common name	Tas	Vic	ACT	NSW	Qld	NT	WA	SA
AMBASSIDAE									
Ambassis macleayi	Macleay's glassfish					□			
Ambassis mulleri	Mueller's glassfish					□			
Ambassis sp.	northwest glassfish*								
Ambassis agassizii	olive perchlet				□				□
ANGUILLIDAE									
Anguilla australis	short-finned eel	□	□	□					
APOGONIDAE									
Glossamia aprion	mouth almighty					□			
ARIIDAE									
Arius midgeleyi	shovel-nosed catfish					□			
ATHERINIDAE									
Craterocephalus stercusmuscarum stercusmuscarum	fly-speckled hardyhead#								
BELONIDAE									
Strongylura krefftii	freshwater longtom					□			
BOVICHTHYIDAE									
Pseudaphritis urvillii	tupong		□						
CENTROPOMIDAE									
Lates calcarifer	barramundi					□	□		
CERATODIDAE									
Neoceratodus forsteri	Queensland lungfish					□			
CLUPEIDAE									
Nematalosa erebi	bony bream					□			
ELEOTRIDIDAE									
Hypseleotris compressa	empire gudgeon					□			
Hypseleotris galii	fire-tailed gudgeon					□			
Hypseleotris klunzingeri	western carp gudgeon					□			
Hypseleotris sp. 1	Midgley's carp gudgeon								□
Hypseleotris sp. 3	Murray-Darling carp gudgeon								□
Mogurnda adspersa	purple-spotted gudgeon				□				■
Mogurnda clivicola	Flinders Ranges mogurnda*								

FAMILY		Distribution							
Species	Common name	Tas	Vic	ACT	NSW	Qld	NT	WA	SA
Oxyeleotris selheimi	giant gudgeon					■			
Oxyeleotris lineolatus	sleepy cod					□			■
Philypnodon grandiceps	flathead gudgeon#								
Philypnodon sp.	dwarf flathead gudgeon								□
GADOPSIDAE									
Gadopsis bispinosus	two-spined blackfish			□					
Gadopsis marmoratus	river blackfish	□	□			□			□
GALAXIIDAE									
Galaxias auratus	golden galaxias	□							
Galaxias brevipinnis	climbing galaxias	□	□	□					
Galaxias fontanus	Swan galaxias	□							
Galaxias johnstoni	Clarence galaxias	□							
Galaxias maculatus	common galaxias	□	□						
Galaxias pedderensis	Pedder galaxias	□							
Galaxias truttaceus	spotted galaxias		□						
Galaxiella pusilla	dwarf galaxias		□						
GOBIIDAE									
Glossogobius giurus	flathead goby#								
HEMIRAMHIDAE									
Arrhamphus sclerolepis	snub-nosed garfish					□			
KUHLIIDAE									
Kuhlia rupestris	jungle perch					□			
MELANOTAENIIDAE									
Melanotaenia eachamensis	Lake Eacham rainbowfish					□			
Melanotaenia fluviatilis	Murray-Darling rainbowfish								□
Melanotaenia splendida australis	western rainbowfish					■			
Melanotaenia splendida splendida	eastern rainbowfish					□			
Melanotaenia splendida tatei	desert rainbowfish*								
NANNOPERCIDAE									
Nannoperca australis	southern pygmy perch		□		□				□
Nannoperca obscura	Yarra pygmy perch		□						
OSTEOGLOSSIDAE									
Scleropages jardini	Gulf saratoga					□			

FAMILY Species	Common name	Tas	Vic	ACT	NSW	Qld	NT	WA	SA
		Distribution							
Scleropages leichardti	saratoga					□			
PERCICHTHYIDAE									
Maccullochella macquariensis	trout cod		□	□	□	■			
Maccullochella peelii mariensis	Mary River cod					□			
Maccullochella peelii peelii	Murray cod		□	□	□	□		■	□
Macquaria ambigua	golden perch		□	□	□	□			□
Macquaria australasica	Macquarie perch		□	□	□				
Macquaria colonorum	estuary perch		□						
Macquaria novemaculeata	Australian bass				□	□			■
Macquaria sp.	Lake Eyre callop[#]								
PLOTOSIDAE									
Neosiluroides cooperensis	Cooper Creek catfish*								
Neosilurus ater	black catfish					□			
Neosilurus hyrtlii	Hyrtl's tandan					□			
Porochilus argenteus	silver tandan*								
Porochilus rendahli	Rendahl's tandan					□			
Tandanus sp.	wet tropics tandan					□			
Tandanus tandanus	freshwater catfish		□	□	□	□			□
PROTOTROCTIDAE									
Prototroctes maraena	Australian grayling		□						
PSEUDOMUGILIDAE									
Pseudomugil gertrudae	Gertrude's blue-eye					□			
RETROPINNIDAE									
Retropinna semoni	Australian smelt	■	□						
SOLIDAE									
Brachiurus selheimi	freshwater sole					□			
SPARIDAE									
Acanthopagrus berda	pikey bream					□			
Acanthopagrus butcheri	black bream							□	
TERAPONIDAE									
Amniataba percoides	banded grunter				■	□			
Bidyanus bidyanus	silver perch		□	□	□	□		■	□
Bidyanus welchi	Welch's grunter*								

FAMILY		Distribution							
Species	Common name	Tas	Vic	ACT	NSW	Qld	NT	WA	SA
Hephaestus fuliginosus	sooty grunter					□			
Hephaestus tulliensis	khaki bream					□			
Leiopotherapon unicolor	spangled perch					□		■	
Scortum barcoo	barcoo grunter					□			
Scortum hillii	leathery grunter					□			
TOXOTIDAE									
Toxotes chatareus	archerfish					□			
PARASTACIDAE									
Cherax cainii	smooth marron		□		□	□		■	□
Cherax destructor	common yabby	■	□		□		□	■	
Cherax quadricarinatus	redclaw		■ ?		■			■	
Euastacus armatus	Murray River crayfish			□	□				
Geocherax sp.	bush yabby		■						
TOTAL		10	21	10	15	42	2	6	15

Sources: Lintermans (2004), Doupé et al (2004), Beatty (2006), Gilligan et al (2007), Lynas et al (2007), SKM (2008).

Distribution undescribed in SKM (2008).

* Actual translocated distribution yet to be described (SKM 2008).

? Presence uncertain.

1.3 Reasons for the introduction of alien freshwater fish

A range of motives exist for introducing alien fish into freshwater environments; most are associated with social or economic interests. Introductions are commonly made for recreational angling, aquaculture or biological control, or result from the accidental or deliberate release of aquarium and ornamental fish species (Leveque 1996, Elvira and Almodovar 2001, Jang et al 2002, Ma et al 2003, Lintermans 2004, Koehn and MacKenzie 2004, Cropp et al 2005, Pova and Sumer 2005, Dextrase and Mandrak 2006, Gollasch and Nehring 2006, Singh and Lakra 2006). Gozlan (2008) reported that the aquaculture industry accounts for 51% of the 624 freshwater fish species introduced worldwide, followed by the ornamental trade (21%) and recreational angling (12%). This highlights the importance of strict prevention mechanisms, such as legislation, regulation and penalties, for the aquaculture and ornamental trades.

From the 19th century until World War II, fish introductions were largely the result of colonialism, as settlers released species into their adopted homelands for sport and food (Welcomme 1984). The socioeconomic benefit of recreational fishing in many countries encourages aquaculture and stocking of alien species, thus providing several vectors for new introductions. For example, in Canada, 65% of alien species affecting threatened native fishes were introduced for sport fishing, and the majority of these were unauthorised releases (Dextrase and Mandrak 2006).

Aquaculture is considered a vital means of providing a high-value food resource, particularly in developing nations, and can be a primary reason for introducing alien freshwater fish. In 2002, global aquaculture production was largest for carp, salmon and trout, and tilapia (De Silva et al 2004). The trend of increasing global production in aquaculture is possibly best represented by figures on tilapia aquaculture, where the global amount produced between 1980 and 2002 increased around 15-fold, from 87,555 tonnes to 1,311,372 tonnes (De Silva et al 2006). In Southern Africa, the escape of the Nile tilapia (*Oreochromis niloticus*) from aquaculture facilities and its intentional introduction by anglers led to this species becoming established in many catchments in that region (Weyl 2008). Australian examples include two genetic strains of common carp that were initially introduced as sport fish in the late 1800s, while a third strain (‘Boolarra’) was introduced during the 1950s for aquaculture. This third strain rapidly and broadly dispersed following its release into the natural environment in the early 1960s (Koehn et al 2000, Lintermans 2004).

Another reason for freshwater fish introduction has been for biological control. The most prominent example is the worldwide release of the American native poeciliids eastern gambusia and western gambusia (*Gambusia affinis*) for mosquito control in countries where mosquito-borne disease is a concern. Despite being largely unsuccessful mosquito control agents, these two species are well known for their colonisation ability (one or both now occur in all continents except Antarctica) and negative impacts on native fauna (Meffe and Snelson 1989, Pyke 2008). Similarly, grass carp (*Ctenopharyngodon idella*) has been introduced into many countries because they are considered a cost-effective method for the control of aquatic macrophytes (Conover et al 2007). Nile tilapia has been suggested as a biological control agent for the aquatic fern giant salvinia (*Salvinia molesta*) (McIntosh et al 2003).

The importation of aquarium fish is a major potential source of alien fish species in many countries because thousands of species are transported and traded annually, often outside their native range (Chapman et al 1997, McDowall 2004, Rixon 2005, Chang et al 2009). The Food and Agriculture Organisation of the United Nations (FAO) estimated the global value of live ornamental fish in 2000 to be $US 900 million wholesale and $US 3 billion retail (Whittingham and Chong 2007). In Australia the ornamental aquarium fish trade, including breeding facilities, wholesale traders, retail outlets and the hobby industry, is valued at approximately $A 350 million per annum (Whittingham and Chong 2007). In 2006–07 the number of ornamental fish sold through Australian retailers was estimated to be 33.9 million, of which 95% were freshwater species (O'Sullivan et al 2008). The release of ornamental fish species into natural environments has been attributed to private individuals disposing of unwanted fish, although the pathways and vectors associated with these introductions and the frequency of release has received little attention (Copp et al 2005).

The accidental uptake and release of aquatic alien species, including freshwater fish, via ballast water in shipping vessels is also an important vector for transporting alien aquatic species worldwide (Carlton and Geller 1993). It has been estimated that many thousand species of freshwater, estuarine, and marine protists, plants and animals are being transported at any point in time in the ballast water of ships (Carlton and Geller 1993). Drake et al (2004) identified global hotspots of aquatic invasions via ballast water, based on worldwide patterns of ship traffic — South East Asia, northern Europe and the Mediterranean Sea and coastal areas of North and South America. Several other authors agree that North America in particular is susceptible to ballast water transported introductions (eg Mills et al 1993, Ricciardi and Rasmussen 1998, Ricciardi and MacIsaac 2000).

1.3.1 Reasons for the introduction of alien freshwater fish in Australia

McKay (1984) identified three distinct phases of alien freshwater fish introductions into Australia. The first phase related to the acclimatisation period associated with early European settlement. During this time colonial governments and acclimatisation societies introduced many alien freshwater fish species to make the wildlife more familiar to colonisers or for recreational angling, food or ornament. This era brought about the establishment of several sport species and an ornamental species (Lintermans 2004).

The second phase involved the release of eastern gambusia for mosquito control. From the 1920s, health authorities and army corps dispersed this species throughout all mainland states and territories. This species, which is no longer considered effective for mosquito control, has had substantial environmental impacts (Macdonald and Tonkin 2008, Pyke 2008) and is now classified as noxious in all states and territories.

The final phase involves more recent introductions of alien freshwater fish species (post 1970s), predominately via the aquarium and ornamental fish trade. Ornamental fish now represent the largest proportion of alien freshwater fish species in Australian freshwater ecosystems (Lintermans 2004, Koehn and MacKenzie 2004).

Of the 44 species of alien freshwater fish that have been recorded in Australian waterways, eight species were introduced for recreational angling, one for aquaculture, one for biocontrol, thirty-four for ornamental purposes and two via ballast water (Table 2).

1.4 The invasion process

Understanding the invasion process and factors that lead to the successful establishment of an introduced alien species is important to prevent future invasions and mitigate the effects of recent invasions (Garcia-Berthou et al 2005). Several authors have studied the invasion process, as well as the biological traits of alien species and the attributes of their recipient environments, in an attempt to determine factors influencing the outcome of an invasion (Vermeij 1996, Moyle and Light 1996, Sakai et al 2001, Kolar and Lodge 2001, Kolar and Lodge 2002, Marchetti et al 2004, Vila-Gispert et al 2005, Colautti et al 2006a, Moyle and Marchetti 2006). These factors are discussed in the following sections.

1.4.1 Stages of invasion

The invasion process consists of a series of complex, successive events broadly divided into arrival, establishment and integration phases (Vermeij 1996).

Arrival includes the transport and release of individuals into the recipient environment. This phase involves intentional or unintentional introduction via various vectors and pathways (Griffiths 1997, Economidis et al 2000, Fuller 2003, Lintermans 2004, Gollasch and Nehring 2006). The main human-mediated vectors associated with intentional and unintentional dispersal of alien freshwater fish are outlined in Table 4.

During the establishment phase, individuals that have survived the arrival stage reproduce and form a self-sustaining population. This may be accompanied by a continued spreading of the population and their dispersal into other regions.

In the final stage of the invasion process, known as the integration phase, invading individuals respond to local environmental conditions and interact with the biota of the recipient environment.

The invasion process involves complex interactions between the symbiotic and biological traits of the alien species and the characteristics of the recipient environment (Moyle and Marchetti 2006). Various characteristics of the alien species and the recipient environment are important at different phases of the invasion process (Kolar and Lodge 2001, Kolar and Lodge 2002, Moyle and Marchetti 2006) and therefore each phase has a largely independent probability of failure (Kolar and Lodge 2002).

Successful invasion, regarded as the alien species establishing in, spreading to or becoming abundant in a new environment (Colautti et al 2006a), is achieved when the invading species survives and completes all phases of the invasion process (Moyle and Marchetti 2006). Generally, as the stages of invasion progress, management options become more constrained, costly and difficult. Once an alien species is established, successful eradication is often impossible, and control efforts are demanding, expensive and ongoing (Kolar and Lodge 2001).

Table 4. Human mediated vectors of the dispersal of alien freshwater fish with Australian examples

Intentional	Unintentional
Legal stocking releases, eg rainbow trout, brown trout, redfin perch, brook char	Contaminants of fish stocking, eg redfin perch, common carp
Illegal stocking, eg redfin perch, common carp, Mozambique tilapia	Escape from outside ponds and dams, eg redfin perch, Mozambique tilapia
Introductions for biological control, eg eastern gambusia	Transfers via water diversion
Bait bucket introductions, eg oriental weatherloach, common carp	Transfer on commercial fishing equipment, eg redfin perch
Discarding of aquarium fish, eg platy, one-spot livebearer, swordtail, oriental weatherloach	Escape from aquaculture facilities, eg brown trout, rainbow trout, Atlantic salmon
Release for cultural or religious purposes	Contaminants of ballast water, eg yellowfin goby, streaked goby

Sources: Griffiths (1997), Economidis et al (2000), Fuller (2003), Environment Canada (2004), Lintermans (2004), Kerr et al (2005), Gollasch and Nehring (2006), Shine (2007).

1.4.2 Factors influencing invasion success

The characteristics of alien species that render them desirable to humans or facilitate their introduction via human-assisted mechanisms are termed *symbiotic* characteristics (Moyle and Marchetti 2006). For freshwater fish, symbiotic characteristics include desirability as an angling or aquarium species, for use in biological control, or for use as live bait. Table 4 expands on these characteristics.

Alien species with symbiotic characteristics are expected to have enhanced propagule pressure. Propagule pressure increases linearly with the number of individuals released (*propagule size*) and/or the number of release events (*propagule number*) and positively influences successful establishment (Lonsdale 1993, Levine 2000, Mack et al 2000, Kolar and Lodge 2001, Ricciardi 2001, Lockwood et al 2005, Gherardi 2007b, Novak 2007, Leprieur et al 2008). Ruesink (2005) found that alien fish species were more likely to form established populations when humans intended them to become established (76% of attempts forming established populations) compared to when alien fish were released with no desire for naturalisation (57%). From an evolutionary perspective, Novak (2007) and in part Sakai et al (2001) discuss how greater propagule pressure may promote successful establishment by overcoming the effects of genetic bottlenecks associated with small founder population size and by creating genetic admixture.

For many years researchers have studied the biological characteristics of introduced alien species in an attempt to discern traits that assist or hinder establishment (Ehrlich 1986, Courtney and Meffe 1989, Williamson and Fritter 1996a, Lockwood 1999, Kolar and Lodge 2001, Sakai et al 2001, Ruesink 2005, Alcaraz et al 2005, Vila-Gispert et al 2005, Moyle and Marchetti 2006, Olden et al 2006, Ribeiro et al 2008). However, a defined set of biological characters is yet to be unanimously supported. Several characters that are most frequently cited as being associated with successful fish invasions (Moyle and Marchetti 2006) include:

- being abundant and widespread in the native range
- exhibiting high physiological tolerance
- *r*-selected life history strategies (high fecundity, rapid growth, early maturity)
- parental care

- long lifespan
- moderate size
- generalist habitat and dietary preferences
- rapid dispersal
- traits novel to the recipient community.

Likewise, characteristics of recipient environments that render them vulnerable to invasion have also been hypothesised. Several authors propose that environments susceptible to invasion include those with similar habitat to the native environment of the alien species (Moyle and Light 1996, Fausch et al 2001, MacIsaac et al 2001, Moyle and Marchetti 2006), those that are highly modified, disturbed or degraded by humans (Davis et al 2000, Sakai et al 2001, Shea and Chesson 2002, Kennard et al 2005, Leprieur et al 2008), and those that have low native species richness and complexity (Elton 1958, Moyle and Light 1996, Sakai et al 2001), although there is still debate over these characteristics and their relationship to invasion success.

In a recent overview of the current status of biological invasions in inland waters, Gherardi (2007b) concluded that alien species with broad environmental tolerances and whose physiological requirements closely match those of the recipient environment are most likely to become established, although this does not preclude species becoming established in other circumstances. Gherardi (2007b) also provides evidence that the vulnerability of recipient environments, including their native species richness and assumed lack of natural enemies, plays little part in explaining the establishment of alien freshwater species, and supports the theory that alien freshwater species facilitate each other's establishment or continued coexistence. Gherardi (2007b) highlighted that propagule pressure is regarded as the key factor influencing the successful establishment of alien freshwater species. But overall there appears to be no universal formula for predicting the establishment or invasion success of an introduced species.

The complexity of interactions between characteristics of the alien species and the recipient environment at any given time makes it extremely difficult to predict the likelihood of a species establishing or an environment being vulnerable to an alien species incursion. Considering these interactions and their idiosyncratic nature, it is not surprising that many alien species fail to become established (Moyle and Light 1996, Williamson and Fritter 1996b, Moyle and Marchetti 2006). Regardless of the likelihood of an alien species establishing and possibly causing environmental, social and economic harm, Mooney et al (2005) recommended that efforts should focus on preventing alien species introductions.

1.5 Impacts of alien freshwater fish

Established alien freshwater fish populations can exert various effects on recipient environments, social values and assets, and economies. These impacts are often categorised as being detrimental or beneficial, and result from direct or indirect influences. More commonly, the impacts of alien freshwater fish are assessed in a triple bottom line manner (ie accounting for environmental, social and economic performance) (Arthington and Bluhdorn 1995, Arthington and McKenzie 1997, Agtrans 2005, Corfield et al 2007, Rowe et al 2008, SKM 2008). Predicting the impact of alien species is difficult because impacts generally: vary in type, scale and duration and with time; may be subtle, cumulative, direct or indirect, or synergistic; and may cause cascading effects (Simon and Townsend 2003, Rilov et al 2004, Boggs et al 2006, Reaser et al 2007). In the following sections, environmental, social and economic impacts of established alien freshwater fish are briefly discussed.

1.5.1 Environmental impacts

Established alien fish can negatively impact native species both directly and indirectly by:

- competing for food (Arthington et al 1986, Crowl et al 1992, Bohn et al 2008)
- competing for habitat (Crowl et al 1992, Fausch 2007, Bohn et al 2008)
- direct predation (Crowl et al 1992, Belk and Lydeard 1994, Ivantsoff and Aarn 1999, Canonico et al 2005, Fausch 2007)
- spatial exclusion (Canonico et al 2005, Fausch 2007)
- aggressive behaviour, for example fin nipping and sexual harassment (Rowe 2004, Valero et al 2008)
- transmitting diseases and parasites (Langdon 1989, Geiger et al 2005, Whittingham and Chong 2007)
- altering and degrading aquatic habitat (Roberts and Tilzey 1997, Koehn et al 2000, Starling et al 2002, Geiger et al 2005)
- reducing genetic integrity (Hickley and Chare 2004, Gunnell 2008).

These impacts may influence more than one aspect of ecology simultaneously, including individuals (life history, morphology, behaviour), population dynamics (abundance, population growth, etc), genetics (eg hybridisation), communities (species richness, diversity, trophic status) and ecosystem processes (nutrient availability, primary production, etc) (Hurlbert 1972, Parker et al 1999, Mack et al 2000, Simon and Townsend 2003). Recent reviews by Corfield et al (2007), Rowe et al (2008) and SKM (2008) discuss the impacts of several alien freshwater fish species in Australia.

There are very few documented examples of alien freshwater fish having positive environmental impacts. One exception is the use of alien freshwater fish to control aquatic vegetation (Petr 2000, McIntosh et al 2003, Wells et al 2003). Other potential applications may be the control of unwanted aquatic fauna (eg snails, mosquitoes), but research and past experience shows that this has mixed success (Courtney and Meffe 1989, Slootweg 1994, Ghosh et al 2005, Childs 2006).

1.5.2 Economic impacts

Established alien freshwater fish create both economic benefits and costs. Recreational angling of alien freshwater fish species creates revenue through industries related to fishing, tourism and aquaculture. Stocked alien species can be highly valued angling species, such as salmonids and redfin perch (*Perca fluviatilis*), as well as translocated native species such as barramundi (*Lates calcarifer*). Trout fishing in inland waters of Tasmania is valued at $A35–40 million annually and is heavily promoted nationally and internationally to encourage local tourism (IFS 2004). Likewise, the recreational trout fishery in the Snowy Mountains region of southern New South Wales generates significant economic expenditure in the region, estimated at $A70 million per annum (Dominion Consulting 2001). The estimated value of recreational fishing for barramundi in Queensland is $A8–15 million per annum, and the barramundi stocking program in Lake Tinaroo generates a potential $A31 per dollar spent (Rutledge et al 1990). Clearly, recreational angling of alien freshwater fish generates significant amounts of money for Australia’s economy. Demand for recreational freshwater fishing opportunities in Australia results in regular legal stocking of alien freshwater fish by government departments. Harvesting of alien freshwater fish also benefits the general economy and may support a commercial industry, for example, K&C Fisheries and Charlie Carp.

On the other hand, alien freshwater fish can cause significant economic loss by impacting on assets and values (Colautti et al 2006b). Very few studies have estimated the economic costs of alien freshwater fish, largely because of difficulty quantifying their effects on assets and values. Estimates of economic loss through the management and impact mitigation of alien freshwater fish species alone are substantial. McLeod (2004) estimated that $A15.8 million is spent per annum on carp management ($A2 million), impact mitigation ($A11.8 million) and research ($A2 million). During 2006–07, total expenses for tilapia monitoring, management and prevention in northern Queensland were approximately $A900,000 (Greiner and Gregg 2008). Nearly a third of these expenses were associated with activities by water corporations to minimise the risk of tilapia using irrigation channels and affecting water supplies (Greiner and Gregg 2008). Prior investment by water corporations to install and maintain screen barriers to prevent tilapia movement cost $A1.5 million during 2004 and 2005 (Greiner and Gregg 2008). In the USA, the economic loss due to alien fish is conservatively valued at $US5.4 billion per annum (Pimentel et al 2005). Likewise, the introduction of largemouth bass for sport fishing in Japan has extensively damaged commercial fisheries and freshwater ecosystems (Nishizawa et al 2006). Their removal costs totalled 229 million yen during 2004 (Nishizawa et al 2006). Estimates of the cumulative impact of zebra mussels in the Great Lakes range from $US3 billion to $US7.5 billion (Environment Canada 2004). Sea Lamprey control in the Great Lakes region totals $US21 million per annum (Environment Canada 2004). Rowe et al (2008) provided several additional examples of estimates of economic costs associated with aquatic alien species in Australia and overseas.

The development of environmental policy and resource management is influenced by an understanding of the costs and benefits of alien species and the cost-effectiveness of alternative strategies and levels of investment in management to achieve a desired outcome (Choquenot et al 2004, Rowe et al 2008). Choquenot et al (2004) warned that, without a framework to assess costs and benefits and cost-effectiveness, investment in alien fish management could be influenced by opinions rather than knowledge and objective evidence.

1.5.3 Social impacts

In a 2005 report on Australia's progress on invasive species management over the previous 10 years, Agtrans (2005) noted that few studies had analysed the degree to which alien fish species affect social values, and recommended further investigation. The lack of such studies is likely because of the difficulty in quantifying the social impact (actual vs. perceived) and its intrinsic relationship to economic values and assets. Aquatic resources have inherent social values and influence human health and wellbeing, recreational activities, social infrastructure, industry, employment opportunities and income, quality of life and cultural heritage (Agtrans 2005). Wells (2007) discussed community attitudes to alien freshwater fish in the Murray–Darling Basin, particularly highlighting the importance of engaging indigenous communities and acknowledging the differing attitudes of various communities. Rowe et al (2008) developed a Social Impact Assessment (SIA) Framework for alien fish species in Australia and applied it to assess the social impacts of eastern gambusia, redfin perch, tench (*Tinca tinca*), roach, yellowfin goby (*Acanthogobius flavimanus*) and streaked goby (*Acentrogobius pflaumii*). Their SIA framework identified four key areas of possible social impacts of alien fish — way of life (access to recreational opportunities; impact on local economies, tourism, and amenity values; and the impact of tourism); health and wellbeing (focusing on impact to personal health and wellbeing); culture and environment (including impact on indigenous cultural heritage and beliefs and community values); and fears and aspirations (impacts on native species populations). A key recommendation of Rowe et al (2008) was to conduct further detailed, location and species-specific SIAs using this method. They also suggested that management plans should include monitoring of social issues and involve community members to foster ownership and understanding of alien fish management issues.

1.6 Management of alien species

In attempts to prevent the introduction and manage the spread of alien species, there are several general management goals that can be applied to all scenarios (GISP 2005), including:

- reduce the risk of alien species introduction
- minimise the ability of introduced species to establish and/or spread in new environments
- minimise adverse environmental, social and economic impacts of established alien species
- protect native biodiversity
- protect living resources and associated industries
- implement practical and effective management practices
- achieve national and international cooperation and standardisation of management practices.

The Global Invasive Species Programme (GISP) (Shine et al 2000) recognises that the fundamental objective in all cases of alien species management is to minimise their threat to biodiversity, societal health, assets and values, and economies.

Preventing species from leaving native habitat or entering new environments is agreed as the most effective approach of averting their introduction, establishment and impact (Suarez and Tsutsui 2008) because it is extremely difficult to predict which alien species will become invasive. Some alien species readily display invasive characteristics (eg reproduce and spread rapidly), but others may take a long time to establish, occur at low densities, or have inconspicuous impacts (reviewed in Crooks and Soulé 1999). Sometimes particular events may trigger invasiveness; for example, additional introductions of propagules (Wing 1943, Roman 2006), changes in habitat structure that allow expansion (Lonsdale 1993, Rilov et al 2004), or invasion of a mutualistic species (Gardner and Early 1996, Parker 2001). In aquatic systems, preventing introductions of alien species should be the highest priority because the nature of the environment renders aquatic alien species incursions extremely difficult to detect, contain and manage. Preventative actions rely on effective pre-border and border management activities and primarily focus on legislation, trade regulations, quarantine and inspection, and education.

Early detection is the second line of defence if pre-border and border preventions have failed, allowing a rapid response to reduce population establishment and spread. Early detection and rapid response are post-border activities. The GISP describes three main components of early detection and rapid response (GISP 2005). These include:

1. early detection and reporting
2. rapid assessment
3. rapid response.

Several actions are associated with each of these components (Table 5).

Table 5. Actions associated with components of early detection and rapid response

Early detection and reporting	Rapid assessment	Rapid response
Surveillance (passive and active) Reporting Taxonomic identification and verification	Field assessment Initial incursion containment Risk assessment Incident response plan developed Source of introduction identified	Lead agency identifies incident control officer and forms rapid response team Advisory task group developed Operational control centre developed Incident response plan implemented Response downsized/upsized accordingly Incident debrief and revision Cessation of introduction mode
Communication# Documentation#		

Common to all components. Source: GISP (2005).

1.6.1 Early detection

To manage alien species incursions efficiently and effectively it is important that structured procedures are implemented to enable early detection and reporting of new alien species incursions. Procedures that are fundamental to this process include surveillance, identification and reporting.

Surveillance is the process of searching for known or potential introduced alien species. It is an important task of early detection and rapid response strategies because it improves the chance of detecting incursions before the alien species establishes and disperses beyond levels that prevent cost-effective or practical management. Surveillance encompasses both active and passive surveillance methods.

Active surveillance includes general and/or targeted surveys (site or species specific) and ongoing monitoring. Active surveillance in turn gathers benchmark information on species presence and site condition. Sampling methods and the frequency and timing of surveys should be considered because, regardless of how comprehensive the survey, species that are present may be undetected (particularly when present only in low numbers or at certain times or seasons of the year).

Passive surveillance relies on stakeholder and community involvement and their reporting of suspected alien species incursions or unusual sightings (eg mass numbers of unknown species) to appropriate state or territory agencies. For passive surveillance to be effective, reporting procedures must be well publicised and simple. Improving stakeholder awareness and understanding of alien species issues, especially through public awareness programs, is important to support passive surveillance.

Active and passive surveillance can generate large amounts of data that must be accurately collated, backed up and stored. The types of information collected should be standardised and complete so that it is comparable with other data. Records should be stored in a centralised location in an easily accessible format, and be readily available to interested parties. It is important that the data includes GIS information on the location of sightings so that information can be stored in a map database and the location easily identified.

Likewise, specimens collected to confirm taxonomic identification should be properly labelled, photographed, preserved and stored. Confirming identifications of particular species may require access to taxonomic keys and expert consultation, which can be a lengthy process.

1.6.2 Rapid assessment

Once an alien species is detected and reported, the seriousness of the threat must be assessed and a decision about whether to initiate a response must be made. If the species' identification has not been confirmed, a voucher specimen must be collected. This may coincide with a field assessment of the suspected sites to characterise the incursion and gather species and habitat information to inform subsequent management decisions. A risk assessment should be completed to guide and prioritise response, including weighing the consequences against the option of 'doing nothing'. Technically, if the risk assessment indicates that the species is likely to impose significant impacts then eradication is preferred. However, the final decision will also be influenced by the availability of resources to respond, the practicality and effectiveness of available eradication methods, the anticipated duration of response, the social, economic and environmental impacts of response actions, and the results of cost–benefit analyses. Sometimes the decision to eradicate an alien species incursion may be purely because of legislative or social reasons. For example, the Queensland Department of Employment, Economic Development and Innovation (Fisheries) often eradicate fish from farm dams because possession of alien fish is illegal under the state's *Fisheries Act 1994*. The department also undertakes eradication activities if members of the public are concerned about the presence of alien fish in a pond or dam. Eradication of alien fish in such areas creates good public relationships and demonstrates that the agency cares about the public's concerns.

Eradication should be attempted if there is a good chance of success. To achieve eradication, the following criteria should be satisfied (Bomford and O'Brien 1995, UNEP 2001):

- The rate of removal must exceed the rate of increase at all population densities.
- Immigration and emigration must be zero.
- All individuals in the population must be placed at risk by the management technique/s applied.
- Monitoring of the species at low densities must be achievable.
- The socio–political environment must be supportive throughout the eradication effort.
- Cost–benefit analysis favours eradication over control.
- There must be adequate funding and commitment continuously over the eradication and subsequent monitoring period until there is no reasonable doubt of success or otherwise.

Because of the difficulty in detecting fish species when numbers are low, eradication should also incorporate subsequent longterm monitoring to determine success. Stakeholders should be informed of management decisions and actions to foster their understanding and support, and passive surveillance should be encouraged. If it is decided to eradicate the species incursion, then an incident response plan should be developed detailing all information about the incursion, the risk assessment process and outcome, and a thorough description of the response procedures, resources and permits required, and expected costs and sources of funds for the eradication.

Overall, the rapid assessment component involves *rapid field assessment* to characterise the incursion to inform subsequent management decisions, *rapid risk assessment* to determine the level and priority of response, and rapid development of an *incident action plan*.

1.6.3 Rapid response

Decisions made during the rapid assessment will guide actions undertaken during the rapid response. The level of response may vary from not taking action, or gathering more information, or suspending response until further notice (if relatively low priority), or instigating educational activities as a basic level of control, or implementing an intense eradication or control program. The focus of eradication is on the pest and the destruction or removal of every individual. Other management options, such as containment and control, aim to reduce or minimise the damage of the pest species, that is, the management focus shifts from the pest to managing the damage.

The incident action plan developed during the rapid assessment will guide the response. It should provide sufficient structure to ensure that the response is coordinated and effective, but be flexible to allow scaling up or scaling down of activities when required.

The response coordination structure should be integrated with institutional arrangements. A control officer from the lead agency should be responsible for overseeing and managing all activities relating to the incident. They should coordinate and manage a response team and establish an incident advisory task group containing key experts and stakeholders who will guide the response as needed. The response team should contain members with a range of expertise in technical, policy, finance, communication and operational roles, each having defined roles and responsibilities. Response procedures should be generic to allow the rapid involvement of other agencies when necessary. Response activities should operate from a centralised control centre fitted with ample facilities to enable effective response.

To ensure a rapid response, some operational actions can be pre-prepared, including funding arrangements, appropriate staff qualifications and training, permits, resource locations and usage agreements, and the availability of additional external experts such as taxonomists.

The response may be scaled down to ongoing monitoring if the eradication is considered successful. If rapid eradication is not achieved then the implementation of a longterm control and containment plan would be warranted.

The final stages of rapid response involve completing documentation, debriefing, and reviewing response actions and procedures. These actions may inform and benefit future early detection and rapid responses, and influence preventative measures.

1.7 Key conclusions

- Inconsistent terminology and definitions used in invasion biology may hinder the management of alien species. Standardised terminology should be adopted globally.
- Biological invasions are a key threat to freshwater ecosystems. The introduction of alien freshwater fish species is a global issue, and globalisation facilitates their spread. Many regions around the world support large numbers of alien freshwater fish species relative to the numbers of native fish species.
- Forty-four alien freshwater fish species have been recorded in natural environments in Australia. The majority of recent introductions (since the 1970s) have been ornamental species. Additionally, 76 native freshwater fish species and 5 native freshwater crustacean species have been translocated outside their native range within Australia.
- Introductions of alien species can be intentional or unintentional. Introductions may be for ornamental purposes, aquaculture or biological control, recreational angling, or may occur from the release of infested ballast water.
- The invasion process is a series of complex successive events, generally involving arrival, establishment and integration phases. An alien species needs to survive and complete all phases of invasion in order to survive.
- During the invasion process complex interactions occur between characteristics of the alien species and the recipient environment. This makes it difficult to predict the likelihood of an alien species establishing or an environment being vulnerable to an alien species incursion. Propagule pressure is an important factor in successful establishment.
- Established alien freshwater fish species may impose both beneficial and detrimental environmental, social and economic impacts. Impacts result from direct or indirect influences. Predicting the impacts of alien species is extremely difficult.
- Because it is difficult to predict the likelihood of an alien freshwater fish successfully establishing and its potential impacts, preventing the entry of alien species to new environments is the most effective management method. Preventative actions focus on legislation, trade regulations, quarantine and inspection, and education.
- Early detection and rapid response are primary post-border activities when prevention fails. They provide the best opportunity to limit spread, reduce impacts and eradicate incursions of alien species.

2. Review of international approaches to alien fish incursions

The issue of alien species is widespread, having global ramifications. Effective action against their spread requires global cooperation, but this can only be achieved when all countries are supportive and adequately equipped to participate. Recently there has been an increase in international political and legal developments and guidelines relating to alien species, evident through the progression of conventions and global programs and the implementation of national-level legislation and management programs.

This chapter gives a brief overview of conventions, programs and guidelines relevant to the management of alien freshwater fish species. International management approaches to new incursions of alien freshwater fish are reviewed to provide a valuable perspective of the current global knowledge base. Many lessons may be learnt from countries that are most advanced in developing and implementing management frameworks to address new fish incursions.

2.1 Conventions and programs

The growing recognition of threats to biodiversity has resulted in the modification of existing conventions and international programs, or the development of new ones. Over 40 legally binding international conventions directly or indirectly refer to alien species (Moore 2005) (Table 6). About a quarter of these relate to aquatic environments, although most are relevant to marine rather than freshwater ecosystems (Moore 2005). Some of these agreements are multilateral environmental agreements that mention alien species in reference to their potential impact on native species and ecosystems. Others are trade-related agreements on sanitary and phytosanitary measures and recognise alien species as potential pests and disease vectors (Moore 2005). Unfortunately there is no one agreement that covers all aspects of alien species regulation, including introduction, prevention, containment, eradication, control and mitigation of impacts.

The 1992 Convention on Biological Diversity (CBD), prepared by the Intergovernmental Negotiating Committee under the auspices of the United Nations, currently is the agreement most relevant to the management of alien species in freshwater environments. The CBD provides a legally binding framework for biodiversity conservation. The primary goals of the CBD are to conserve biological diversity, to sustainably use its components and to share equitably the benefits arising from the use of genetic resources. The contracting parties (to date over 175 countries, including Australia) are required to create and enforce national strategies and action plans to conserve, protect and enhance biological diversity. Alien species are specifically referred to in Article 8(h):

‘Each Contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.’

The CBD addresses alien species in the work program on inland water biological biodiversity (decision IV/4, annex I, paragraph 8 [c] [vi]) and, in paragraph 9 (e) (iv), invites states to:

‘Undertake assessments in such inland water ecosystems which may be regarded as important. Furthermore, states should undertake assessments of threatened species and conduct inventories and impact assessments of alien species within their inland water ecosystems.’

Table 6. Examples of global and regional conventions that refer to alien species or aquatic environments

Convention
Convention on Biological Diversity (1992)
Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, 1971)
Convention on the Law of the Non-Navigable Uses of International Watercourses (1997)
Draft International Convention for the Control and Management of Ships' Ballast Water and Sediments
Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (1979)
European Union Aquaculture and Integrated Coastal Zone Management (2003)
European Union Habitats Directive
United Nation Economic Commission for Europe Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992)
Convention on Fishing in the Waters of the Danube (1958)
North American Free Trade Agreement (NAFTA)
World Trade Organisation Sanitary and Phytosanitary Measures (WTO SPS)

Table 7. Themes of the CBD's 'Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species'

Themes of the CBD Guiding Principles on Alien Species	
1. Precautionary approach	9. Cooperation, including capacity-building
2. Three-stage hierarchical approach	10. Intentional introduction
3. Ecosystem approach	11. Unintentional introduction
4. The role of States	12. Mitigation of impacts
5. Research and monitoring	13. Eradication
6. Education and public awareness	14. Containment
7. Border control and quarantine measures	15. Control
8. Exchange of information	

The Conference of Parties adopted 15 guiding principles for the prevention, introduction and mitigation of impacts of invasive alien species for the full and effective implementation of Article 8(h) of the CBD[1]. The themes of these guiding principles are listed in Table 7.

[1] Known as 'Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species'.

Although there is a growing commitment to global and regional conventions, there are some weaknesses in the existing arrangements, including (UNEP 2001, Chambers 2008):

- Some conventions are inconsistent and overlap with others.
- There is often inadequate implementation and coordination of agreements at the national level.
- There is inadequate compliance and enforcement.
- Actions are often poorly funded.
- There is insufficient harmonisation of national reporting.
- Performance measures of their effectiveness are lacking.

An important program developed to tackle the global threat of invasive species is the Global Invasive Species Programme (GISP). GISP was established in 1996 through an international partnership between Commonwealth Agricultural Bureaux (CAB) International, the World Conservation Union (IUCN), the Nature Conservancy and the South African Biodiversity Institute (SANBI) and is affiliated with several other partner programs and organisations, such as the United Nations Environment Programme (UNEP) and the IUCN's Invasive Species Specialist Group (ISSG). GISP's goal is to conserve biodiversity and sustain livelihoods by minimising the spread and impact of invasive species. Working primarily at international and regional levels, GISP aims to build partnerships, provide guidance, develop a supportive environment and build capacity for national approaches towards the prevention and management of invasive species by pursuing three key objectives:

- facilitating information exchange
- supporting policy and governance
- promoting awareness among key public and private sector decision makers.

GISP supports the implementation of CBD's Article 8(h) and has produced a number of tools and publications to promote knowledge and awareness of alien species and guide management (Table 8).

Table 8. Examples of various publications developed through GISP to foster awareness of and assist alien species management

GISP Publications
Shine et al (2000). A guide to designing legal and institutional frameworks on alien invasive species.
McNeely et al (2001). A global strategy on invasive alien species.
Wittenberg and Cock (2001). Invasive alien species: A toolkit of best prevention and management practices.
Barnard and Waage (2004). Tackling biological invasions around the world: Regional responses to the invasive alien species threat.
Smith et al (2008). Invasive species management – what taxonomic support is needed?
Biological Invasions#
Diversity and Distributions#

[#] International journals.

2.2 International approaches to new alien freshwater fish incursions

The review of management approaches relating to alien fish incursions has involved a comprehensive literature search and contact with international agency professionals. It was difficult to identify lead agencies responsible for the management of alien freshwater fish overseas and, because there was limited literature on alien freshwater fish management or rapid response approaches to new incursions for specific countries, we were reliant on the agency professionals to provide information.

Individual countries or regions have developed strategies and plans to respond to new incursions and manage alien freshwater fish. Knowledge gained from reviewing approaches taken overseas may inform the development of Australian emergency response arrangements for freshwater fish incursions.

2.2.1 Canada

In response to ratifying the Convention on Biological Diversity (CBD) (1992), the Canadian Government developed the 'Canadian Biodiversity Strategy' (Minister of Supply and Services Canada 1995), which aims primarily to conserve biodiversity, promote the sustainable use of biological resources, and share benefits resulting from the use of genetic resources. By supporting this strategy, all governmental tiers (federal, provincial and territorial) agreed to develop and implement policies, plans, legislation and programs to prevent the introduction of alien species and reduce or eliminate their adverse impacts.

Subsequently a national strategy on invasive alien species was developed collectively by various federal, provincial and territorial government departments and agencies (Environment Canada 2004). Its key goals are to prevent harmful species introductions, focus on pre-border and border activities, respond rapidly to new incursions, and manage alien species through eradication, containment and control. This strategy aims to provide a framework to address alien species by considering the environmental, social and economic impacts of alien species when forming decisions, enhancing coordination and cooperation to rapidly respond to new incursions and pathways of invasion, strengthening programs that protect natural resources, and maximising collaboration between ad hoc and regional programs to ensure resources are applied to high priority issues. The strategy proposed the development of sector-specific actions plans, including a ‘Canadian action plan to address the threat of aquatic invasive species’.

The Federal Department of Fisheries and Oceans (DFO) led the development of the action plan (Aquatic Invasive Species Task Group 2004), together with the Aquatic Invasive Species Task Group, which included representatives from DFO, all provinces and territories, Transport Canada, Environment Canada and the Department of National Defence. The action plan focuses on managing the pathways and vectors of unauthorised introductions of aquatic alien species to prevent their introduction and establishing control via legislation, regulation and compliance, risk management, engagement and education, and science. Although this action plan mentions the need for rapid response and briefly discusses tasks involved, it is no substitute for a comprehensive rapid response plan.

Canada currently lacks official national and provincial/territorial rapid response plans for aquatic alien invasive species. Response actions are the responsibility of lead agencies in each province/territory and are conducted in an ad hoc manner. However, there is interest in developing rapid response plans for aquatic invasive species in Canada, and British Columbia has begun to develop a provincial plan. It is uncertain whether the framework will follow Canada’s Federal Emergency Response Management System, which adopts an incident command system similar to the Australasian Inter-service Incident Management System (AIIMS).

An example of a well-coordinated, cooperative and well-documented rapid response is the response to the incursion of round goby (*Neogobius melanostomus*) in Pefferlaw Brook, Ontario (Borwick and Brownson 2006, Stephens et al 2007). Further dispersal of the species threatened Ontario’s largest and most important inland fishery, Lake Simcoe. The Ontario Ministry of Natural Resources together with Ontario Federation of Anglers and Hunters, and several other organisations, planned and conducted the rapid response activities under guidance from a working group. Immediately after the incursion was confirmed, surveys and continuous monitoring commenced. Various sampling methods were applied. Public consultation and involvement was a key component of the response actions. An intensive public awareness campaign was launched and the general public assisted the Department of Fisheries and Oceans in the monitoring program. A site conditions report was prepared, including details of potential eradication options and procedures (Greenland International Consulting 2005). Multiple briefings and meetings with key agencies and stakeholders occurred to discuss response actions and concerns. Rotenone treatment was agreed upon, and a permit for its application was sought. Alternative arrangements were organised for launching boats and providing water supply. An onsite information centre was established and door-to-door information was provided to the local community. Prior to the treatment, four days were spent removing and transferring over 4,000 native and sport fish. Warning signs were erected 48 hours before treatment. Backpack sprayers were used to treat backwater areas with rotenone. Instream application involved rotenone release through perforated pipes. Post-treatment monitoring was conducted several times, spanning a period of more than a year, to analyse water quality, the natural fish community and round goby occurrence. Although round goby were detected several months after treatment, the rapid response program produced several successful outcomes, including no impact on the environment, the return of the fish community to its pre-treated state, a significant reduction in round goby numbers, exceptional stakeholder cooperation and support, and enhanced awareness of the invasive species issue. Overall, it displayed a working example of early detection and rapid response.

2.2.2 United States of America

The USA is not a signatory to the Convention on Biological Diversity. The National Invasive Species Council provides national leadership and coordination of federal agency activities relating to all invasive species (aquatic and terrestrial). The National Invasive Species Council (NISC) was established by Executive Order 13112 (1999). Its membership includes the secretaries of several federal government departments or agencies and it is cochaired by the Department of Agriculture, the Department of Commerce, and the Department of the Interior. Executive Order 13112 also established the Invasive Species Advisory Committee to provide advice and recommendations to the NISC, and required that the NISC develop a National Invasive Species Management Plan. The '2008–2012 National Invasive Species Management Plan' (NISC 2008) is the first revision of the initial plan, 'Meeting the Invasive Species Challenge: National Invasive Species Management Plan' (NISC 2001). Prevention, early detection and rapid response, control and management, restoration and organisational collaboration are key goals of the revised plan. Communication, education, research, information management and international cooperation elements are considered to be integral to these goals. NISC also developed general guidelines for the establishment and evaluation of invasive species early detection and rapid response systems, which broadly detail components of early detection, rapid assessment, and rapid response systems that experts consider essential or important to a system's success (NISC 2003).

For aquatic nuisance species (ANS) in particular, the *Nonindigenous Aquatic Nuisance Prevention and Control Act 1990* instigated the establishment of the ANS Task Force (www.anstaskforce.gov) to coordinate ANS programs throughout the USA. This Act has since been reauthorised and amended by the *National Invasive Species Act 1996* and the *National Aquatic Invasive Species Act 2005*. The ANS Program is led by the Invasive Species Branch of the Fisheries and Habitat Conservation Program conducted by US Fish and Wildlife Service (USFWS) of the Department of the Interior. The program funds ANS Coordinators and activities for each region within the USFWS, and supports the Aquatic Nuisance Species Task Force (ANSTF) and their activities. The *National Invasive Species Act 1996* furthered initial ANS activities by calling for the development of ballast water regulations, state ANS management plans, regional panels to combat the spread of ANS, and additional ANS outreach and research. The *National Aquatic Invasive Species Act 2005* strengthened and expanded the ANS Program by, for example, directing the ANSTF to: conduct pathways analysis to identify high risk pathways for ANS introductions and to implement management strategies to mitigate these introductions, expand the existing dispersal barrier program, establish rapid response funds to implement approved strategies, and develop a national system of ecological surveys for early detection of ANS. The Act authorised appropriated sums between US $154 million and US $163 million to perform tasks obligated by this Act for each fiscal year from 2006 to 2010. Unlike Executive Order 13112, which can be withdrawn by a new administration, the ANSTF is established in legislation and therefore provides longterm stability for the ANS program.

The ANSTF is an intergovernmental body currently comprised of 10 federal agencies and 12 exofficio members, and is cochaired by the USFWS and the National Oceanic and Atmospheric Administration.

The 10 federal agencies involved in the ANSTF are as follows:

- US Fish and Wildlife Service
- US Environmental Protection Agency
- US Department of Agriculture – Animal and Plant Health Inspection Service
- US Army Corps of Engineers
- National Park Service

- US Coast Guard
- US Geological Survey
- US Department of State
- US Department of Transport – Maritime Administration
- US Department of Commerce – National Oceanic and Atmospheric Administration.

Responsibilities of the ANSTF include:

- implementing the National Aquatic Invasive Species Act 2005
- preventing the introduction and spread of ANS
- detecting and monitoring ANS
- rapidly assessing and responding to new introductions
- controlling established invaders to reduce their impact
- increasing public awareness to prevent the introduction and spread of ANS.

To address their accountabilities and strategically fulfil their mission, the ANSTF produced a strategic plan detailing the task force's goals and objectives (ANSTF 2007). Six regional panels and five standing committees were formed by the ANSTF to assist in developing and implementing a coordinated federal ANS program.

Regional panels consist of representatives of state agencies, Native American groups, non-government organisations, commercial stakeholders and neighbouring countries. The roles of the panels include:

- identifying regional ANS priorities
- coordinating ANS program activities in the region
- making recommendations to the ANSTF
- providing advice to public and private interests concerning methods of ANS management/control.

The five standing committees were developed to reflect the essential aspects of the ANS Program:

- prevention
- detection and monitoring
- control
- research
- communication, education, and outreach.

These committees consist of government agency representatives and relevant experts. Committees are involved in the development of species-specific ANS management plans (Table 9), generic scientific procedures, public awareness and education programs (eg 'Stop Aquatic Hitchhikers', 'Habitattitude'), research priorities and post-border species assessments, and advising the ANSTF.

Over the past 15 years, State Invasive Species Councils and state agencies have also been developing state ANS management plans as required under legislation. ANS management plans are currently in place in 25 states (Table 9), and several other states are developing plans. ANS management plans have also been developed for particular interstate regions, such as the Lake Champlain Basin and Lake Tahoe, and the ANS Program's Control Committee has produced several species-specific ANS management plans (Table 9). Similar objectives in these management plans relate to preventing the introduction of aquatic nuisance species, strengthening and supporting early detection networks, providing rapid response capability, providing control and management of established populations, supporting or conducting research, monitoring and risk assessment, and public education.

Interest in producing ANS early detection and rapid response plans was a natural progression following the development of ANS management plans. The few ANS rapid response plans currently developed and available are regional, state or species-specific in scope. Workshops have been held to develop early detection and rapid response protocols and to identify key components of a successful rapid response program. Recently developed State ANS management plans, such as those for Idaho and Utah, incorporate ANS rapid response plans. Generally, the objectives of these ANS rapid response plans are common (Appendix 1) and several tasks are associated with each objective. The coordination and management structure of the rapid response plans is designed to comply with the National Incident Management System (NIMS). The 'Columbia River Basin Interagency Invasive Species Response Plan: zebra mussels and Other *Dreissenid* Species' (Heimowitz and Phillips 2008) provides a thorough example of a ANS response plan, incorporating response procedures, the coordination and management structure of multiple agencies, the roles and responsibilities of personnel, and examples of contingency plans, documents and forms. As many of these ANS rapid response plans are recently developed, their functionality remains to be evaluated. Any evaluation will probably involve desktop assessments, field trials and regular post-response reviews.

Data and information on the USA's biological resources can be accessed via the National Biological Information Infrastructure (NBII) webpage (www.nbii.gov). The NBII links various biological databases, information products, and analytical tools maintained by NBII or contributed by government agencies, academic institutions, non-government organisations and private industry. A component of NBII is the invasive species information node, including access to the National Early Detection, Rapid Assessment, and Rapid Response Framework prototype, which contains information or weblinks relating to the six main components:

- Identification and validation (checklists and identification guides, image galleries, species profiles).
- Reporting (community outreach programs, listservers, other people to contact, report online, telephone hotlines).
- Expert verification (exotic pest and invasive plant councils, federal and state government invasive species agencies, invasive species councils).
- Occurrence (occurrence databases).
- Rapid assessment (assessment protocols).
- Planning (Education, laws and regulations, management plans and reports).
- Rapid response (Community outreach programs, control).

Overall, the USA has a very comprehensive approach to new incursions of alien freshwater fish species, supported by legislation and governed by a federal interagency taskforce with advice from committees and councils, to foster the development and implementation of plans and programs. It remains to be proven whether the system applied by the USA works well in a real situation. Experience with Asian carp in the Great Lakes region suggests that the approach may need improvements and eradication can be extremely difficult.

Table 9. USA state and interstate aquatic nuisance species (ANS) management plans and species-specific ANS management/control plans

State ANS management plans#		
Alaska (2002)	Louisiana (Draft 2004)	Pennsylvania (2006)
California (2007)	Maine (2002)	Rhode Island (2007)
Connecticut (2006)	Massachusetts (2002)	Tennessee (2007)
Hawaii (2003)	Michigan (2002)	Utah (Draft 2008)
Idaho (2007)	Montana (2002)	Virginia (2005)
Illinios (1999)	New York State (1993)	Washington State (2001)
Indiana (2003)	North Dakota (undated)	Wisconsin (2003)
Iowa (undated)	Ohio (undated)	
Kansas (2005)	Oregon (2001)	
Interstate ANS management plans		
Lake Champlain Basin	Lake Tahoe	
Long Island Sound*	St. Croix Natural Scenic Riverway*	
Species-specific ANS management/control plans		
northern snakehead	ruffe	bighead, black, grass and silver carps
mitten crab	European green crab	water chestnut
New Zealand mudsnail	Genus Caulerpa	giant salvinia
brown tree snake	purple loosestrife	

Source: ANSTF website (www.anstaskforce.gov)

Several other states not listed are currently developing ANS management plans

* Under development

2.2.3 The Great Lakes

The Great Lakes are a chain of freshwater lakes located in eastern North America on the Canada–US border. Management of the Great Lakes Basin and the Saint Lawrence River is the responsibility of the Great Lakes Commission (www.glc.org). The Great Lakes Commission was established in 1955 as a result of the Great Lakes Basin Compact legislative agreement between the eight US states bordering the Great Lakes — Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin. Members of the Commission include three to five representatives from each of the eight states, as well as the Canadian provinces of Québec and Ontario, comprising senior agency officials, legislators, or appointees of the governor or premier. The Commission prides itself on being the only binational organisation of its kind in the world. Its purpose is to promote the orderly, integrated, and comprehensive development, use, and conservation of the water resources of the Great Lakes Basin, as documented in the terms and requirements of the Great Lakes Basin Compact.

Preventing the introduction and spread of aquatic alien species is a priority of the Great Lakes Commission. In 1991, in response to the US *Nonindigenous Aquatic Nuisance Prevention and Control Act 1990*, the Great Lakes Commission established the Great Lakes Panel on Aquatic Nuisance Species, containing representatives from US and Canadian federal agencies, the eight US states, the two Canadian provinces, regional agencies, user groups, local communities, tribal authorities, commercial interests, and the university and research community. As the Great Lakes region is an area highly impacted by aquatic alien species, US Congress realised that expert advice gained from the establishment of the panel would also benefit their National Aquatic Nuisance Species Task Force. Furthermore, effective prevention and management of aquatic alien species in the Great Lakes would minimise or stop the spread of alien aquatic species into other regions of either country.

The Great Lakes Panel on Aquatic Nuisance Species undertakes the following tasks:

- Identify Great Lakes priorities.
- Assist or make recommendations to the National Aquatic Nuisance Species Task Force.
- Coordinate exotic species program activities in the region.
- Advise public and private interests on control efforts.
- Annually report on prevention, research and control activities in the Great Lakes Basin.

Since 2001 the Great Lakes Commission, with support from a Rapid Response Project Advisory Team and the Great Lakes Panel on Aquatic Nuisance Species, has been preparing a 'Model Rapid Response Plan for Great Lakes Aquatic Invasions' (Great Lakes Commission 2006). Its' primary goal is to enhance the capacity to anticipate, prevent and respond to new invasions of non-indigenous aquatic invasive species in the Great Lakes – Saint Lawrence region. The plan focuses on capitalising management activities during the period of introduction and establishment of a new invasive species, when prevention has failed and management shifts to eradication or control. The plan provides general guidance to help agencies initiate planning and implementation efforts, and allows for the addition of specific information by states. The plan is expected to complement state aquatic nuisance species management plans.

There are several components to the draft 'Model Rapid Response Plan for Great Lakes Aquatic Invasions' (Great Lakes Commission 2006), including:

1. Organisational structure and communication
2. Outreach
3. Early detection and monitoring
4. Decision support and rapid scientific assessment
5. Management options for control or eradication
6. Implementation
7. Adaptive management
8. Funding.

Each of these components has multiple objectives. The plan provides a detailed account of tasks involved in rapid response and their order of implementation, but it does not describe the technicalities of tasks. For example, although the plan mentions that authority and leadership roles need to be well defined, it does not provide information on specific roles and their responsibilities. Likewise, it recommends that management efforts should be thoroughly and carefully documented, but does not provide examples of what information should be collected throughout the response process. Its' appendices include three examples of previous successful or unsuccessful rapid response attempts that highlight tasks necessary in a rapid response.

This draft model rapid response plan was tested by the Hydrilla Task Force in Michigan by applying it as a framework to develop a species-specific rapid response plan for *Hydrilla*

(*Hydrilla verticillata*). Subsequently a desktop workshop was conducted to overview the species-specific rapid response plan for *Hydrilla* and examine how rapid response planning would be modified in different jurisdictional scenarios (incursions in a private lake with multiple owners, in a Great Lakes harbour, in a private pond, in waters managed by a state, in waters managed jointly by federal and state governments, and in waters managed by Indigenous people). The outcomes of the workshop are not yet available. This process of developing a generic plan, using it as a framework to develop a species-specific plan and conducting a desktop workshop to critique the plan under various scenarios is valuable because it allows feedback from experts involved in rapid responses and identifies inadequacies in the plan before large sums of money and resources are invested in field trials or an actual incursion response.

To complement the Model Rapid Response Plan, the Great Lakes Regional Collaboration has developed a rapid response communication protocol (Great Lakes Regional Collaboration 2007) to ensure there is early and consistent communication between agencies during rapid response assessment and implementation. Additionally, numerous educational publications on Great Lakes invasive aquatic species have been produced to foster community awareness and understanding of aquatic invasive species issues, and are available through the Great Lakes Commission website (www.glc.org).

2.2.4 South America

All countries in South America are signatories to the Convention on Biological Diversity. Limited information was found on alien freshwater fish and their management in countries within South America. Ziller et al (2005a) collated primary information on known alien species and their management strategies in countries within South America. Unfortunately most of the information was presented in Spanish and was not translated. In conclusions of a workshop titled 'Prevention and management of invasive alien species: forging cooperation throughout South America', it was noted that most attention is paid to preventing and controlling invasive alien species threatening agricultural systems, with little consideration to those impacting natural ecosystems (Ziller et al 2005b). Generally, lack of public awareness, inadequate financial and technical support, limited information exchange and poor coordination and cooperation between national sectors were recognised as issues hindering alien species management in South America.

Several recent publications were obtained that discuss alien freshwater fish introductions in South America (Pompeu and Alves 2003, Latini and Petrere 2004, Vitule et al 2006, Alves et al 2007, Rocha and Schiavetti 2007, Smith et al 2007, Ortega et al 2007 Aigo et al 2008). Insight into alien freshwater fish management in South America was gathered largely from Alves et al (2007) and Ortega et al (2007) which list and discuss the impact of introduced alien freshwater fish species in Brazil and Peru respectively and suggest aspects where relevant management approaches could be improved. No information was found relating to rapid response approaches to new alien freshwater fish incursions, and it appears as though management of alien freshwater fish is at early developmental stages.

No information was able to be accessed regarding management of alien freshwater fish in Central America or Mexico.

2.2.5 Great Britain

The United Kingdom of Great Britain and Northern Ireland ratified the Convention on Biological Diversity in 2004. In addition to CBD commitments, the United Kingdom is also obligated under European Union (EU) targets to prevent and reduce biodiversity loss as outlined in the EU's Action Plan (Commission of the European Communities 2006).

In 2003 the Department for Environment, Food and Rural Affairs (DEFRA) published a review of non-native species policy and legislation throughout Great Britain (DEFRA 2003). This review highlighted that the greatest constraint with the management of non-native species in Great Britain was that the responsibility of non-native species management is spread across several government departments and agencies, resulting in uncoordinated, ineffective, incoherent policies and strategies to address non-native species issues. A key recommendation was the establishment of a single lead coordinating organisation for non-native species management across Great Britain. Other key recommendations included developing a comprehensive risk assessment process to determine the risk posed by non-native species and to prioritise preventative actions, creating targeted education and awareness strategies, revising and updating legislation relating to non-native species and establishing adequate monitoring programs.

In response to this review, a single lead body, known as the Great Britain Non-Native Species Mechanism, was created to oversee and guide the management of all non-native terrestrial and aquatic flora and fauna in Great Britain. It consists of a Programme Board and its Secretariat, a Risk Assessment Panel, a Stakeholder Sounding Board, a Stakeholder Forum and several working groups, together containing membership from several government agencies across England, Scotland, and Wales, as well as experts and various key stakeholders. 'The Invasive Non-Native Species Framework Strategy for Great Britain' (2008) provides a comprehensive national policy structure detailing actions required to address the problem of non-native invasive species in Great Britain and outlines the roles and responsibilities of the groups forming the Mechanism. Key components to the strategy include:

- prevention
- early detection, surveillance, monitoring and rapid response
- mitigation, control and eradication
- fostering awareness and understanding
- legislation
- research
- information exchange and integration.

As part of the Mechanism, a Rapid Response Working Group was established in February 2008 to develop a clear plan for implementing a rapid response against invasive non-native species in Great Britain, with consideration of the existing responsibilities and competencies of partner agencies. This plan will be applicable for all taxa in terrestrial and aquatic ecosystems. The Working Group will clarify the roles and responsibilities of different government agencies and establish principles for identifying lead agencies to implement rapid response under different circumstances. Procedures for implementing rapid response will be described with consideration to gaps in accountabilities and decision-making, cross border issues, legislation and associated obstacles, lines of communication, interaction with other stakeholders and the public, and access issues. An inventory of existing available resources required for a rapid response will be generated, and the current capacity of government agencies and non-government organisations will be explored. Deficiencies in resources and capacity will be identified. Funding opportunities for rapid response actions will be considered.

In Great Britain, the management of freshwater fish is currently shared between several government agencies including DEFRA, the Welsh Assembly, the Scottish Executive and the Environment Agency. DEFRA is responsible for policy on salmon and freshwater fisheries in the United Kingdom and is the overall custodian for marine and freshwater aquatic environments. However, the daily management and regulatory responsibility of salmon and freshwater fisheries lies with the Environment Agency. Several legislative acts administered by these agencies relate to the management of non-native fish species. Until the rapid response plan is completed and approved, present rapid response procedures to new incursions of alien freshwater fish species in Great Britain are ad hoc. Most previous eradication attempts have been conducted in closed systems where the chance of success was high, using a variety of methods including electrofishing, chemical treatment, water drawdown and netting. Basic management structures need to be established, such as comprehensive surveillance and ongoing monitoring programs for alien freshwater fish, as well as a centralised location for the collation and storage of data.

A risk identification and assessment tool called FISK (Freshwater Fish Invasiveness Scoring Kit) is currently applied to assess the risk of a newly detected fish species becoming invasive and to determine the level of response required (Copp et al 2005). The FISK program consists of a series of questions with response options of 'yes', 'no' or 'don't know' that are selected on the basis of expert evaluation of published literature on the species under consideration. Each question is scored, generally on a scale of –1 to +1, to produce a total numerical score that is positively correlated with invasiveness. FISK is freely downloadable from www.cefas.co.uk/projects/risks-and-impacts-of-non-native-species/decision-support-tools.aspx.

2.2.6 European Union

Both the 1992 Convention on Biological Diversity and the 1979 Bern Convention are relevant to the management of alien species in countries belonging to the European Union. In 2002 the European Environment Council acknowledged the scale of the alien species problem in Europe. Miller et al (2006) scoped options for European Union action on invasive alien species, including a review of the existing legal and policy framework for invasive alien species at the international, European Union and member state level, identifying gaps in the existing framework and providing recommendations and prioritising future actions required to fill these gaps. It was suggested that the management of alien species could be improved and strengthened by adopting a coordinated and cooperative, united approach among all European countries. Subsequently, the 'European Strategy on Invasive Alien Species' (Genovesi and Shine 2003) was created to facilitate the development and implementation of coordinated and cooperative efforts throughout the European Union to prevent or minimise the environmental, economic and social impacts of alien species.

The Strategy applies to all species in all environments (terrestrial, marine and freshwater). This strategy was formally approved in 2003 by countries party to the European Union (commonly known as European states). European states agreed to implement this strategy by 2008 through national strategies and action plans. The Strategy helps European states achieve the Bern Convention targets and tightly aligns with the CBD's guiding principles. There are eight specific aims of the Strategy, with a number of objectives within each aim, including:

1. Building awareness and support
2. Collecting, managing and sharing information
    - species inventories, research and monitoring, regional exchange of information
3. Strengthening national policy, legal and institutional arrangements
    - leadership and coordination, policy and legal review and development, strategies and action plans, key approaches and tools, ancient introductions, compliance and enforcement
4. Regional cooperation and responsibility
    - cooperation between Bern convention parties, role of the Bern convention, subregional cooperation

5. Prevention
    - prevention at the source and on arrival: border control and quarantine measures, intentional introductions, unintentional introductions, in-country prevention, special measures for isolated ecosystems, prediction and prevention of spontaneous spread
6. Early detection and rapid response
    - surveillance, rapid response and contingency planning
7. Management of impacts
    - policy and legal aspects, eradication, containment, control
8. Restoration of native biodiversity.

In relation to rapid response and contingency planning, the 'European strategy on invasive alien species' aims to ensure rapid response through the clear allocation of roles and powers and the development of contingency plans for eradicating newly detected alien species, except those recognised as low risk. General contingency plans are to be developed for eradicating groups of species with similar characteristics, such as plants, freshwater fishes or reptiles. All relevant authorities are to have sufficient powers to remove alien species in accordance with national law and policy. Adequate funding and equipment for rapid response will be provided for new incursions and to train staff in rapid response. However, discrepancies between the legislative requirements of European countries may affect the rapid response implementation.

The European Union is now devising contingency plans. Current procedures for rapid response are ad hoc.

In Europe, databases on invasive alien species have been developed to facilitate the transfer of information on alien species, including NOBANIS for Nordic countries (www.nobanis.org) and DAISIE for all European states (www.europe-aliens.org). These databases currently provide basic information on the biology, impacts and distribution of alien species in Europe, list relevant regulations, provide literature references, and provide a registry of experts for different taxonomic groups and areas. It has been noted that these databases need to be integrated with other international instruments, such as the Global Invasive Species Database (www.issg.org/database).

2.2.7 Africa

All African countries, except Somalia, are party to the Convention on Biological Diversity. Until recently there has been little attention paid to managing the adverse impacts of alien species outside the forestry and agriculture sectors. Most monitoring and management efforts on alien species have been aimed at terrestrial invertebrates and terrestrial and aquatic plants that threaten agricultural production, fisheries production, and water quality and supply. Progression of aquatic biosecurity has received some consideration. In 2008, FAO held a workshop on the development of an aquatic biosecurity framework for Southern Africa during which several key capacity building activities and actions to address aquatic biosecurity in the region were identified (FAO 2009).

The majority of introductions of alien freshwater fish into Africa are quite recent, with a peak timeframe from the 1950s to 1989 reflecting a search for suitable species for aquaculture development, fish stocking of artificial lakes and control of disease vectors and weeds (Satia and Bartley 1998). The collapse of Africa's natural fisheries is likely to have resulted from human overpopulation and the overexploitation of these resources, leading to the introduction of alien freshwater fish species to promote fish production or create fisheries in new areas (Ogutu-Ohwayo and Balirwa 2006). Africans rely on fisheries to alleviate poverty and hunger, create employment and control disease vectors and weeds. Therefore, the main emphasis on alien freshwater fish management in many African countries relates to enhancing productivity to increase food availability and nutritional standards.

The management of fisheries resources in Lake Victoria provides an example of the complexity of fisheries management issues in African freshwaters (Twong'o and Sikoyo 2003, Ogutu-Ohwayo and Balirwa 2006). Nile perch and tilapiine species were introduced into Lake Victoria to improve fisheries degraded by overfishing. The introduction of these species contributed to the localised extinction of over 300 species of native fish and changed the primarily small-scale artisanal fishery on the lake to a multimillion dollar commercial fishery. Current management of Lake Victoria fisheries involves maintaining this commercial fishery, while restoring and conserving native fish species impacted by the fishery (Ogutu-Ohwayo and Balirwa 2006).

Lyons and Miller (2000) and Macdonald et al (2003a, 2003b) provided an overview of the management of invasive alien species, including aquatic species, in Africa. The vast majority of African countries lack an inventory of alien freshwater fish species because there has been limited surveillance and collection of basic ecosystem data. In ecosystems where the distribution of alien freshwater fish is known, such as South Africa, Mauritius and Uganda, there are few management and awareness programs being implemented. Provinces in South Africa, particularly Western Cape Province, are taking a lead role in the management of alien freshwater fish. Surveillance programs have identified 58 alien aquatic species (mainly fish) with established populations in South African waterways, and 37 of these species are considered detrimental. The current management of alien freshwater fish species in the Western Cape Province focuses on closed systems such as dams and lakes, and involves the application of rotenone, following the USA's Rotenone User's manual, to eliminate alien freshwater fish species (Finlayson et al 2000). Ogutu-Ohwayo and Balirwa (2006) outline the major challenges of effective alien species management in Africa, including limited accessibility and application of scientific information, poor dissemination of management information, inappropriate and unharmonized fishery laws and regulations, inadequate enforcement of existing laws and regulations, weak institutions and institutional processes, and inadequate funds for implementing fishery programs. These challenges were also identified by Macdonald et al (2003a). There is no proposal to develop a rapid response plan for new incursions of alien freshwater fish in Africa because monitoring and management of alien freshwater fish species in Africa is not advanced enough to support such a plan.

2.2.8 Asia

Asian countries are in a similar situation to those in Africa. Nearly all Asian countries are signatories to the Convention on Biological Diversity. Current management of alien species focuses on enforcing quarantine and legislative regulations (Pallewatta et al 2003a, Pallewatta et al 2003b). Because of limited surveys, many Asian countries lack detailed information on their freshwater biodiversity (Kottelat and Whitten 1996). Despite this, many Asian countries are aware of the presence of alien freshwater fish species and the related issues (De Silva 1989, Pallewatta et al 2003a, Pallewatta et al 2003b). Human overpopulation has increased demand on fish resources, particularly as a protein source, leading to the introduction of alien fish species for aquaculture because they produce a higher biomass more quickly than native species (De Silva et al 2004, 2009). Although the impacts of several alien fish species on native ecosystems are acknowledged, management of alien freshwater fish rarely extends to enforcing legislation and conducting basic community education. This is because fisheries resources are a highly valued commodity and there is a lack of willingness, financial and technical support, human resources, research, and interagency coordination and cooperation to address alien species issues.

2.2.9 New Zealand

New Zealand's Ministry of Agriculture and Forestry Biosecurity (MAFBNZ) is the lead government agency for the exclusion, eradication or effective management of risks posed by pests and diseases to the economy, environment, society and human health in aquatic and terrestrial environments throughout New Zealand. MAFBNZ is accountable for conducting pre-border and border activities, surveillance, incursion responses and eradication, and the grey zone of transition to alien species management for all vertebrate, invertebrate, viral/disease, flora and fauna incursions. MAFBNZ primarily administers the *Biosecurity Act 1993* and implements the 'Biosecurity Strategy for New Zealand' (MAFBNZ 2003). The Strategy outlines three key goals:

- Prevention and exclusion — preventing the entry and establishment of pests and unwanted organisms capable of causing unacceptable harm to the economy, environment and people's health.
- Surveillance and response — early detection, identification and assessment of pests and unwanted organisms capable of causing unacceptable harm and, where appropriate, deployment of a rapid and effective incursion response that maximises the likelihood of eradication.
- Pest management — effective management (including eradication, containment and control) of established pests and unwanted organisms capable of causing harm to the economy, environment and people's health.

New Zealand's biosecurity response system is led by MAFBNZ, operating in collaboration with many other stakeholders including other government sectors (such as the Ministry for the Environment, Ministry of Tourism, Tourism New Zealand, Ministry for Economic Development, Ministry of Foreign Affairs and Trade, Ministry of Health, Land Information New Zealand, Ministry of Fisheries, the Department of Conservation, Environmental Risk Management Authority, NZ Customs, Crown Research Institutes, National Institute of Water and Atmospheric Research, New Zealand Food Safety Authority), primary production organisations, industry sectors (such as importers, exporters, transport and travel, marine and tourism operators), regional councils and local governments, the public health sector and environmental groups.

MAFBNZ follow a single system to respond to all organisms or goods that pose a biosecurity risk to the values of New Zealand (economic, environmental, human health and socio-cultural). This single system is used for responses from all sectors, of all sizes, and resulting from an incursion or pest management.

Key principles of the system are that the biosecurity response approach involves:

1. Risk based decision making
    - The Biosecurity Decisions Framework is embedded into the system. Management of risk to values is the basis of deciding how to respond through the business casing process.
2. Activity based approach
    - Response personnel are assigned to activities (not roles) based on their competency. The response is organised by workstreams, which are structured according to the activities required.
3. Consistency and scalability
    - The system applies to all sectors (animal, plants and insects and marine) and to all sizes (3 to 3,000 person response).

4. MAFBNZ Coordinated Incident Management System (CIMS)
    - CIMS has been adapted and incorporated into the system. This aligns the system with other government departments and emergency services. CIMS is similar to the Australasian Inter-Service Incident Management System (AIIMS). The CIMS structure has several prinicples, four functions (incident control, operations, planning/intelligence, and logistics) and four phases of action (investigation, planning, operation, and stand-down).
5. Project management discipline
    - All response work is planned and work is completed in accordance with the approved plan.

It is anticipated that following the system will result in:

- clear, risk based decision making
- consistency across responses
- efficient allocation of resources and realistic workload management
- good transition into longterm management.
- successful response with the best possible result for New Zealand.

MAFBNZ maintains the ability to respond to suspected incursions 24 hours a day, every day of the year. It conducts active surveillance for species commonly detected through quarantine, mainly ant species. Passive surveillance and monitoring conducted by other agencies and institutional organisations is relied upon heavily to detect freshwater incursions. Once a suspected incursion is reported, either via a hotline or other reporting channels, the report is compared to a database to determine whether it is a new record. If uncertainty surrounds the report, MAFBNZ forms a response team and conducts a field investigation to confirm the report. Specimens are collected to validate taxonomic identification.

Once the report is confirmed, a technical advisory group of five international experts is established to provide advice on the response approach. A response brief is prepared, including information characterising the incursion, available biological information of the alien species detected, and its potential social, environmental, and economic impacts. Using MAFBNZ's response prioritisation tool, the priority of response to the incursion is decided after consideration of several aspects including the scale of the incursion, the species' economic, environmental and social impact, and the political and public support to respond (Table 10). Incursions graded high or medium priority for response require immediate action, whereas those deemed low priority for response are suspended or transferred to the stand-down phase.

MAFBNZ then prepares an incident action plan including response options, the required tools and human resources, and a cost–benefit analysis. The final decision for response is made by the government, which funds response actions in conjunction with MAFBNZ. If a response is approved, MAFBNZ generally seeks tenders for the operational phase of the response, and the successful applicant follows the incident action plan under MAFBNZ supervision. After the response is put into operation, ongoing monitoring is undertaken to assess its success. If it is unsuccessful, the response approach and its feasibility are re-evaluated. If ongoing management actions are considered more appropriate, the program is transferred to the government department within the relevant sector; for the management of established alien freshwater fish, this is the Department of Conservation (DOC). Once response is scaled down or transferred, a response debrief occurs and response actions and procedures are reviewed. MAFBNZ highlight that stakeholder consultation and support is vital throughout all phases of response and may influence the effectiveness of incursion management.

Processes, standards and other resources for leading and managing biosecurity responses are readily available on MAFBNZ's Biosecurity Response Knowledge Base (http://brkb.biosecurity.govt.nz) and are intended for use by MAFBNZ employees, subcontractors and partner agencies. The Biosecurity Response Knowledge Base includes an overview of the response system, associated policy, and how response workstreams and activities fit together; processes, procedures and tools for biosecurity responses; material for developing people to lead and manage biosecurity responses and complex projects; and training resources for operations staff. Updated or new additions to the Biosecurity Response Knowledge Base are also noted, as well as a guide on using the knowledge base.

Table 10. Factors considered in MAFBNZ's Response Prioritisation Tool

Factors considered in MAFBNZ's Response Prioritisation Tool		
existing regulatory status	current distribution in NZ	tool requirement/availability
invasive potential	surveillance efficacy	cost benefit of response
economic impact	movement control efficacy	stakeholder support
environmental impact	organism management efficacy	public support
public health impact	human resource requirement/availability	political support
socio-cultural impact		

Source: S. Bissmire, pers comm. (2008).

DOC is responsible for the conservation and management of New Zealand freshwater ecosystems, including:

- protecting freshwater natural heritage
- protecting nationally important freshwater ecosystems and sites
- safeguarding the natural ecological character of freshwater ecosystems and habitats
- protecting freshwater species and stocks
- managing established alien invasive species
- providing for the recreational use of freshwater ecosystems and species
- providing access and recreational facilities, subject to the protection of freshwater values
- managing harvest and stock.

DOC primarily manages established populations of alien freshwater species and focuses on controlling or eradicating established alien freshwater fish populations and managing selected alien fish species as sport fish. They may be requested to assist MAFBNZ to respond to alien freshwater incursions. DOC has a comprehensive, ongoing western gambusia, koi carp (*Cyprinus carpio*) and rudd (*Scardinius erythrophthalmus*) surveillance and eradication program in both North and South Islands. This involves annual monitoring and eradication of these species at selected sites using rotenone treatment and physical removal. Monitoring covers new locations as well as sites that were previously treated, to detect potential reinvasions or survival. DOC is currently devising a comprehensive management plan for established alien freshwater fish.

2.3 Common challenges of alien species management

During the literature review and discussions with international agencies, common challenges to the management of alien species that are relevant to all countries were identified. Table 11 highlights some of these challenges and broadly categorises them as capacity, policy, awareness, information, resources, or institutional issues. Countries advanced in alien freshwater fish species management were aware of many of these issues and had addressed them, noting areas for improvement. Other countries or regions with limited alien freshwater fish management arrangements, such as Asia and Africa, currently face a majority of these issues. For effective and coordinated management of alien species, these challenges need to be prioritised and addressed.

Table 11. Challenges of alien species management

Challenges of alien species management

Capacity issues

- inadequate capacity at all levels of alien species management (eg surveillance, identification, eradication)
- inadequate training at all levels of alien species management
- limited expertise
- ease of introduction and movement, inadequate inspection and quarantine
- problems with taxonomic identification

Policy issues

- fragmented legislation and policy
- outdated or inadequate legislation
- political definition of alien species
- conflict of interest
- absence of clear and agreed priorities for action

Awareness issues

- poor public awareness and education
- poor awareness of policy makers
- opposition to government intervention

Resources issues

- funding for surveillance, response, control and research
- limited human and material resources
- few trained and skilled staff

Information issues

- shortage of scientific information (eg for species identification, risk analysis, detection and management techniques)
- limited inventory of alien species
- poor information accessibility and exchange
- language barriers

Institutional issues

- need for institutional arrangements, cost sharing arrangements, resource sharing arrangements
- poor coordination between government agencies, states and other stakeholders
- lack of strategic management plans
- lack of effective emergency response measures
- need for communication and reporting methods
- need for supporting advisory committees
- need for harmonisation of procedures
- need for good participatory management
- sharing national competencies
- lag time between invasion and action
- government bureaucracy

2.4 Key conclusions

- Over 40 multilateral environmental agreements relate directly or indirectly to alien species, including approximately 10 that address aquatic environments. No single agreement covers all aspects of alien species management. The Convention on Biological Diversity is the most relevant to the management of alien species in freshwater ecosystems.
- The Global Invasive Species Program (GISP) is a key international initiative established to guide, support and build capacity for national approaches towards the prevention and management of invasive species. Publications produced through the GISP foster awareness of alien species issues and provide useful advice in developing alien species management practices.
- New Zealand, followed by the USA, have the most advanced management approaches to new incursions of alien freshwater fish. A single government agency or coordinated group has the lead responsibility for responding to all vertebrate, invertebrate, disease, flora and fauna incursions in terrestrial and aquatic systems. Specific incident response plans to alien freshwater fish incursions are based on a generic response plan. Particular response actions are developed considering advice from an expert committee. Response operations are often conducted in collaboration with other government agencies and are coordinated and managed according to a structure similar to Australia's AIIMS.
- Great Britain, Canada and the European Union are currently developing generic emergency response plans applicable for incursions of alien freshwater fish.
- Many developing countries lack basic information on the occurrence and distribution of alien freshwater fish species. Alien freshwater fish production is encouraged in these countries to alleviate poverty and hunger, create employment and control disease vectors and weeds.
- The common challenges to alien species management faced by countries can be broadly categorised as capacity, policy, awareness, resource, information, or institutional issues.
- An understanding of the issues, challenges and approaches to alien fish management of countries across the globe is important for Australia. This enables learning from experiences in countries with advanced approaches, as well as understanding potential risks of entry of alien species to Australia from other countries.
- Australian agencies should actively participate in key international forums such as the International Conference on Aquatic Invasive Species and international agency exchange programs, to build relationships and learn about the latest scientific knowledge, research, technological developments, education and outreach programs, and legislative, policy and management approaches to aquatic invasive species.

3. Existing prevention, detection and management programs and tools in Australia

The appropriate management of alien freshwater fish incursions has several components. These range from preventative mechanisms to prevent their initial entry to effective approaches to manage incursions once they have been detected and identified. Programs and tools can be broadly separated into:

- legislation
- management plans and strategies
- surveillance and reporting systems
- community education
- management methods (for containment, eradication and control).

This chapter discusses the programs and tools currently in place in Australia.

There have been a number of recent relevant reviews concerning various aspects of alien fish management in Australia, in particular Koehn and Mackenzie (2004), Corfield et al (2007), Rowe et al (2008), West et al (2007) and Ansell and Jackson (2007). Therefore only a brief discussion is provided here and the other reviews should be referred to for further detail.

Because containment methods for alien fish management are lacking a comprehensive review in Australia, they are discussed in detail in Chapter 4.

3.1 Legislation

Various legislation influences the management of alien fish species in Australia, both in relation to preventing their entry and spread, and protecting the environment once they are present. Key national legislation includes the *Quarantine Act 1908* and the *Environment Protection and Biodiversity Conservation Act 1999*. Each state and territory also has relevant legislation relating to fisheries management, pest management, threatened species management, and aquaculture and disease management. Comprehensive reviews of legislation have been undertaken recently, in particular by:

- Higham (2007) — provided a detailed overview of legislation relating to the management of fisheries resources in states and territories within the Murray–Darling Basin.
- Rowe et al (2007) — reviewed the impacts of several alien fish species and analysed relevant national, state and territory legislation, including descriptions of the objectives and main clauses.

These reviews outlined the specific sections of acts and regulations relevant to alien species management. The fisheries legislation for most states and territories represent key legislation concerning alien fish management, including making it illegal to keep, trade, move or release live fish into a waterway if the species is declared 'noxious'. However, a thorough review of the legislation is required to determine whether it is adequate and effective.

Table 12 summarises the relevant terms and their definitions used for alien fish species in legislation. A key issue relates to the existing variation in terminology within acts and policies across Australia. Legislation uses a range of terms including ‘noxious’, ‘pest’, ‘exotic’ and ‘non-indigenous’, and there is potential overlap between some legislation and for confusion and inconsistencies regarding the management of species across borders. The definition of a ‘noxious’ fish varies across states and territories, and the species listed as ‘noxious’ also vary. The jurisdictions with more recent legislation consider non-indigenous fish species, that is, they do not necessarily have to be ‘noxious’ to be of management concern.

Table 12. Terms applied in state and territory fisheries legislation to describe alien fish

Term	State or Territory	Definition	Source
Noxious fish	WA	Any fish of a species prescribed under section 103 to be noxious fish	Fish Resources Management Act 1994
Non-endemic fish	WA	A fish species not endemic to the state or that area of the state	Fish Resources Management Regulations 1995
Prohibited organism	WA	An organism for which a declaration is in force under section 12. [Organism means — (a) a living thing, except a human being or part of a human being; or (b) a prion or other prescribed organic agent that can cause disease; or (c) a disease]	Biosecurity and Agriculture Management Act 2007
Controlled fish	Tas	A fish declared as such under section 149	Inland Fisheries Act 1995
Noxious fish	NT	A fish that is declared by the regulations to be a noxious fish	Fisheries Act 2005
Noxious aquatic life	NT	Aquatic life that is declared by the regulations to be noxious aquatic life	Fisheries Act 2005
Exotic	NT	Fish or aquatic life that is not indigenous to the Northern Territory	Fisheries Regulations 2008
Aquatic pest	NT	Fish or aquatic life specified in schedule 4 of the regulations	Fisheries Regulations 2008
Exotic aquatic organism	SA	Fish or an aquatic plant of a species that is not endemic to the waters to which the Fisheries Management Act 2007 applies and exotic fish and exotic aquatic plant have corresponding meanings	Fisheries Management Act 2007
Noxious fisheries resources	Qld	Fisheries resources prescribed under a regulation or management plan to be noxious fisheries resources. A noxious fisheries resource is fish identified in schedule 6, part 1 and hybrids of fish identified in schedule 6 part 1 of the Fisheries Regulation (2008)	Fisheries Act 1994 Fisheries Regulation 2008
Nonindigenous fisheries resources	Qld	Fisheries resources that in relation to a particular area or without reference to a particular area, does not fall in the category mentioned in this schedule definition indigenous fisheries resources. The prescribed nonindigenous fisheries resources are the fish identified in schedule 6, part 2 of the Fisheries Regulation (2008)	Fisheries Act 1994 Fisheries Regulation 2008
Noxious aquatic species	Vic	A noxious aquatic species declared under section 75	Fisheries Act 1995
Noxious fish	ACT	A species of fish declared to be noxious under section 14	Fisheries Act 2000

Term	State or Territory	Definition	Source
Pest animal	ACT	An animal declared to be a pest animal under section 16	Pest Plants and Animals Act 2005
Noxious fish	NSW	Fish declared under Division 6 of Part 7 to be noxious fish	Fisheries Management Act 1994

Source: modified from Higham (2007).

As noted by Rowe et al (2007), Tasmania operates slightly differently, declaring pest fish as 'controlled' rather than noxious. Western Australia has a 'prohibited organisms' list under its *Biosecurity and Agriculture Management Act 2007*, which places alien fish management under biosecurity rather than fisheries.

It is well recognised that the terminology for alien fish is inconsistent and poorly defined, and that uniform classification and legislation should be adopted (Higham 2007). A national noxious fish species list developed by the Natural Resource Management Standing Committee (www.feral.org.au) is to be incorporated into state and territory fisheries legislation in the near future (Appendix 2). Legislation should have the capacity to rapidly declare a species noxious to allow for the rapid implementation of emergency response actions to new incursions. While it may be initially uncertain whether a species will become noxious, a precautionary approach is most appropriate. There is also a need to ensure that legislation can restrict public access into areas, including rapidly declaring quarantine areas.

In addition to fisheries legislation, other state and territory legislation is relevant when planning responses to alien freshwater fish incursions (Appendix 3), viz.:

- animal welfare
- animal health
- biological control
- chemical control
- protection of flora and fauna, and management of threatening processes
- development of management plans
- management of alien species
- access to, control, management and protection of land, parks, reserves
- emergency management procedures
- water pollution prevention.

Emergency response arrangements for freshwater fish incursions must be adequately supported by relevant legislation in each jurisdiction. If an incursion is reported within a state or territory and options for management are being considered, managers must be aware of relevant legislation and understand how regulations influence management options.

Numerous agencies are involved in managing alien freshwater fish across Australia. Within states and territories, the roles and responsibilities of government organisations in all aspects of alien freshwater fish management must be clearly defined to provide an effective and efficient whole-of-government approach. Importantly, lead agencies in each state and territory must be identified. Clear governance arrangements within states and territories will facilitate rapid responses to new incursions, as well as orderly and timely communication between jurisdictions regarding alien freshwater fish management issues. They are also necessary to support coordinated and effective national emergency response arrangements.

3.2 Rapid response procedures

There is no national rapid response procedure addressing alien freshwater fish incursions. Emergency responses are generally dealt with by states and territories mostly on an ad hoc basis. Although this is not the ideal scenario for a consistent, coordinated and rapid approach, there are examples of such approaches being somewhat effective. For example, Tasmania's responses to carp incursions in the 1970s and 1990s were quick, concerted and sustained.

Some states and territories have established general emergency management response plans or arrangements (eg Northern Territory, South Australia, New South Wales and Victoria) to ensure there is a coordinated response to emergencies by all agencies having responsibilities and functions in emergencies. The roles and responsibilities of agencies are outlined in these state or territory emergency response plans. For example, in the 'New South Wales State Disaster Plan' (NSW State Emergency Management Committee 2009), the Department of Primary Industries is the designated combat agency for animal, pest and plant disease emergencies. In the 'Victorian Emergency Management Manual' (Office of the Emergency Services Commissioner 2009), the Department of Primary Industries is identified as the control agency for vertebrate pests, with the Department of Sustainability and Environment noted as a key support agency. In addition, some states and territories, including the Northern Territory and New South Wales, have generic response plans specifically for emergency responses to any introduced species. These plans are followed in response to new alien freshwater fish incursions or another biosecurity threat, such as a marine pest or animal disease. Agency staff within these jurisdictions are trained in aspects of emergency response; for example, they receive Australasian Inter-service Incident Management System (AIIMS) training and are involved in scenario testing for particular biosecurity threats (eg aquatic diseases). Queensland has recently produced a noxious fish rapid response manual (DPIF 2008), and staff emergency response training includes scenario testing workshops. Likewise, South Australia is currently developing a reponse manual for alien freshwater fish. In the absence of established plans to guide emergency response to freshwater fish incursions, other States and Territories currently apply an ad hoc approach.

National emergency response plans have been developed for other biosecurity threats, including animal diseases, marine pests and plant pest incursions (Table 13). These arrangements provide consistent, coordinated national responses to biosecurity threats of national significance. Emergency response arrangements for animal diseases have been established for many years and have guided the development of national arrangements for other biosecurity threats. While these plans relate to the management of other introduced species and environments, there is much that can be learnt from these approaches. Concurrently, a national project is underway to harmonise Australia's biosecurity emergency response arrangements. It has been recognised that differences between the existing animal and plant health arrangements could be reduced by implementing a single generic response planning framework. The Harmonisation Working Group was established in 2007 to document the differences in generic response arrangements across sectors, identify concepts and principles that underpin biosecurity emergency management, and recommend opportunities for improving response arrangements for biosecurity emergencies to the Australian Biosecurity System for Primary Production and the Environment (AusBIOSEC) Steering Group. Subsequently, the Biosecurity Emergency Preparedness Working Group (BEPWG) was established to assess these recommendations, decide upon their appropriate implementation and undertake the appropriate activities. The development of national emergency response arrangements for freshwater fish incursions should align with the progress and outcomes of BEPWG to ensure there is appropriate national support and consistency in biosecurity approach.

There are still numerous potential issues to be resolved during the development of national emergency response arrangements for freshwater fish incursions, including resource and cost sharing arrangements and agreements, staff training (eg for emergency response procedures, job roles, fish identification), and development of protocols and procedures. Once national emergency response arrangements for freshwater fish incursions have been developed, desktop trials and field trials should be undertaken to identify outstanding issues requiring attention.

Table 13. Examples of national emergency response plans for alien species in Australia

National plans	Purpose	Custodian
Australian Veterinary Emergency Plan (AUSVETPLAN)	Provides generic emergency preparedness and response guidelines for animal disease emergencies	Animal Health Australia
Australian Emergency Plant Pest Response Plan (PLANTPLAN)	Provides generic emergency preparedness and response guidelines for emergency plant pest incursions	Plant Health Australia
Australian Aquatic Veterinary Emergency Plan (AQUAVETPLAN)	Series of manuals outlining approach, response and control strategies to be activated in an aquatic animal disease emergency	Animal Health Australia (previous custodian: Aquatic Animal Health)
Australian Emergency Marine Pest Plan (EMPPlan)	Provides generic emergency preparedness and response guidelines for marine pest emergencies.	Consultative Committee on Introduced Marine Pest Emergencies

3.3 Management plans and strategies

There are a number of national policies and strategies that relate to the management of alien freshwater fish to varying degrees (Table 14). These include broad general pest animal policy frameworks such as the ‘Australian Pest Animal Strategy’ (Natural Resource Management Ministerial Council 2007), which focuses on pest spread pathways, the protection of natural assets of national importance, and the identification of a list of pest animals of national importance. ‘A Strategic Approach to the Management of Ornamental Fish in Australia’ (Natural Resource Management Ministerial Council 2006) addresses various issues relevant to ornamental species including inconsistencies in legislation and policy, and effectiveness of border controls to prevent illegal entry. The ‘National Policy for the Translocation of Live Aquatic Organisms’ (Ministerial Council Forestry, Fisheries and Aquaculture 1999) provides a policy framework and risk assessment process to assess translocation proposals. The ‘National Management Strategy for Carp Control 2000–2005’ (Carp Control Working Group 2000) provided specific focus on carp. The Bureau of Rural Science developed the ‘Managing Vertebrate Pest Series’ (a series of pest animal guidelines), as well as PESTPLAN, a guide to assist managers to identify their pest management issues and how to plan and implement an effective management strategy. The ‘National Recreational Fishing Policy’ (National Steering Committee on Recreational Fishing 2004) has less direct relevance since it does not distinguish between native and non-indigenous fish species, although it refers to the need to maintain or enhance fish stocks and encourages community awareness.

Several states and territories have pest management strategies relevant to alien freshwater fish; for example, 'The Biosecurity Strategy for Victoria' (Department of Primary Industries 2009), 'Tasmanian Biosecurity Strategy' (Tasmanian Biosecurity Committee 2006), and the 'NSW Invasive Species Plan 2008–2015' (NSW Department of Primary Industries 2008). Within the Murray–Darling Basin (MDB), the 'MDB Native Fish Strategy' (Murray–Darling Basin Ministerial Council 2004) covers alien fish management, and a specific 'MDB Alien Fish Plan' is being developed. There are also various state and territory protocols regarding fish translocations, aquaculture and recreational fishing management, as well as various biosecurity policies and strategies.

3.4 Surveillance programs

There is a need to focus on preventative measures, such as legislation, regulation, and community education, to avoid the entry of alien fish species into Australia. Once an incursion occurs, however, surveillance programs enable detection of a species. The only active surveillance programs which specifically target alien fish species are the Queensland Vulnerable Catchments Program and the Tasmanian Lakes Crescent and Sorell Carp Management Program (Inland Fisheries Service 2004). While there are no extensive and comprehensive national surveillance programs targeting alien freshwater fish incursions, there are various programs across and within states and territories that provide valuable information on fish species occurrence (Table 14). The value of such programs in detecting an alien freshwater fish incursion is clearly influenced by their frequency and intensity, the techniques used, staff awareness and reporting systems.

In comparison to some states and territories, the management of the Murray–Darling Basin has had more attention. The 'Sustainable Rivers Audit' for the Basin is a large-scale program that gathers and interprets survey data on fish, macroinvertebrate and hydrology indicators, to determine the current status of the Basin's rivers and potential trends. These surveys have been expanded into areas outside the Basin in some states (eg coastal New South Wales — 'NSW Monitoring, Evaluating, Reporting Surveys', and coastal Victoria — 'Southern Basins Program'). Sites within the Murray–Darling Basin that are recognised as significant and of high ecological value are subject to a greater survey, rehabilitation and monitoring effort (eg icon sites within the 'Living Murray Program', and 'demonstration reaches'). Various freshwater fish research projects and numerous smaller surveys are also undertaken in each state and territory, focusing on specific issues, species or sites. These projects may inadvertently detect new alien freshwater fish incursions. Generally, however, all states and territories are heavily reliant on passive surveillance approaches (ie via general public reporting) to detect new alien freshwater fish incursions.

The development of a national onground surveillance program could assist in the rapid detection of alien fish incursions. Given the potentially significant financial cost of such a proposal, particular focus could be given to priority catchments, high-risk areas, and alien fish species of greatest potential concern. The frequency and intensity of surveillance, as well as the survey techniques employed, would need to be considered to maximise detection of alien species.

3.5 Community education

Although passive surveillance has common importance in all states and territories, there is no national community education program targeting alien freshwater fish species. As a result the level of public awareness of the risk of alien freshwater fish incursions is not high. Community education should consider cultural groups and cater for their communication needs, for example by providing multilingual resources. Education products and key messages could target particular community groups, such as recreational anglers, ornamental fish traders and school students. States and territories have community education programs about alien fish to varying extents (Table 14), and some have specific online information notes and publications about particular alien freshwater fish and the need to prevent the dumping of ornamental fish. Queensland in particular has a suite of educational publications focusing on alien freshwater fish, including specific products for carp and tilapia, resources in ethnic languages such as Mandarin and Vietnamese, and an education module for schools. National programs such as Waterwatch (a community water quality network) aim to help communities understand, monitor, protect, and restore waterway and catchment health. As fish species are occasionally collected and observed during water quality monitoring activities, there is increasing interest about freshwater fish, which creates an educational opportunity to highlight alien fish species.

Various fisheries-focused educational programs such as Fishcare educate anglers and the public about, for example, sustainable fishing practices and acting responsibly and legally. Angler participation programs (eg Victoria's 'Diary Angler' program, Queensland's 'Keen Angler' program, Western Australia's 'Research Angler' program) provide potentially valuable methods to educate anglers and obtain information concerning alien freshwater fish incursions and fish species distributions.

There is a need to develop a national education program targeting alien freshwater fish that engages various stakeholders and disseminates key messages. Important messages range from preventing the release and spread of alien fish (eg 'don't dump fish', 'clean your boat', 'don't use live bait'), to methods of reporting suspicious or alien fish species and fish identification. A national education program on alien freshwater fish to enhance community awareness of the related issues may prevent new incursions of alien freshwater fish species and assist in the early detection of new incursions. The general community could also be educated about the predicted influence of climate change on the occurrence of alien freshwater fish, and the opportunities that drought conditions present in terms of localised management of alien species.

3.6 Reporting systems

There is no national reporting system for alien freshwater fish incursions, and the procedures for reporting an alien freshwater fish incursion vary between states and territories (Table 14). Suspected alien freshwater fish incursions can be reported via telephone hotlines or online forms. However, sometimes these provisions are not clearly advertised to the public; for example, in Victoria suspected alien freshwater fish incursions can be reported via the illegal fishing hotline, and in New South Wales they can be reported using the aquatic pest species and disease reporting hotline. Reporting systems need to be well advertised, easily accessible and simple to use to facilitate suspected incursion reporting, early detection and rapid response. Advertisements for the reporting provisions should include instructions about what information the general public should collect (accurate location information, description of site, specimen sample or photograph, etc) to maximise the value of reporting systems.

There is also no protocol regarding how information on incursions can be transferred between agencies and between states and territories. A national centralised database would be valuable as a central repository of alien fish distributional information. This could assist in disseminating information to a wide range of stakeholders and improving linkages between agencies. A centralised database could assist in highlighting new incursions and range expansions, and improve planning by drawing attention to catchments at risk of invasions. In NSW, animal distribution records from the Australian Museum, NSW DII and NSW DECC are regularly deposited and updated on the Bionet website (www.bionet.nsw.gov.au).

Investigation is required to determine whether similar databases exist in other states and territories and whether they can be linked to a centralised national system.

3.7 Risk assessment/decision support procedure

There is no universal risk assessment or decision support procedure in Australia for alien freshwater fish incursions. Risk assessment models have been developed for importing and keeping exotic freshwater and estuarine finfish (Bomford and Glover 2004, Bomford 2008). NSW DII implements an aquatic biosecurity risk analysis protocol, which analyses environmental, social and economic risks, to determine the response priority for alien freshwater fish incursions, however the response is largely influenced by the feasibility of actions, the results of risk analysis and the availability of human resources and equipment. Also, the listing of the species as a noxious fish can be important in obtaining external resources or funding for subsequent management action. In the Queensland noxious fish rapid response manual (DPIF 2008), a series of questions must be completed to determine the level of priority for response to an alien freshwater fish report, such as 'Is there risk of further dispersal?' and 'Would the cost of response greatly increase in time?' Subsequently, appropriate response actions are assessed by a rapid response team, and the best course of action is determined and implemented, as documented in a prepared management strategy. Other states and territories appear to have an ad hoc approach to determining the level and priority of response to new incursions of alien freshwater fish.

There is a need to develop a consistent national risk assessment procedure to help managers determine whether to respond to an alien freshwater fish incursion and the urgency of response (ie prioritisation). The assessment should consider the species' current distribution, its spread and establishment potential, its potential environmental, social, and economic impacts, its existing regulatory status, the human resources and equipment required for response, the costs and benefits of a response, and public, stakeholder and political support for a response. Many of these considerations will weigh heavily on the final decision to conduct a response.

Table 14. State and territory emergency response and management approaches to incursions of alien freshwater fish

Management plans and strategies	Active surveillance initiatives1	Community education and engagement	Reporting system	Risk assessment procedure[2]	Emergency response procedure	Staff emergency response training[3]
NATIONAL						
Australian Pest Animal Strategy A Strategic Approach to the Management of Ornamental Fish in Australia National Recreational Fishing Policy The National Management Strategy for Carp Control 2000-2005 PestPlan and PestPlan Toolkit The National Policy for the Translocation of Live Aquatic Organisms	natural resource management programs state of the environment reporting	Publications relating to plans and strategies (eg Ornamental fish trade 'Don't Dump that Fish' brochure)	No universal system	No universal standard procedure	None	None
VICTORIA						
Emergency Management Manual Victoria Biosecurity Strategy for Victoria Protocols for the Translocation of Fish in Victorian Inland Public Waters Guidelines for Assessing Translocations of Live Aquatic Organisms in Victoria 2003 Victorian Aquaculture Strategy and Action Plan Murray-Darling Basin Native Fish Strategy Murray-Darling Basin Alien Fish Plan (in development)	Sustainable River Audit Southern Basins program The Living Murray program Demonstration Reaches	'Get Hooked…It's Fun to Fish' program Fisheries notes on pest fish, available online (www.dpi.vic.gov.au) Fishcare Volunteer program The Diary Angler program Murray-Darling Basin Native Fish Strategy coordinators and their education activities Waterwatch Victoria	Illegal Fishing hotline 13FISH (13 3474)	Ad hoc[4]	Ad hoc[4]	None

Table 14 (continued)

Management plans and strategies	Active surveillance initiatives[1]	Community education and engagement	Reporting system	Risk assessment procedure[2]	Emergency response procedure	Staff emergency response training[3]
AUSTRALIAN CAPITAL TERRITORY ACT Vertebrate Pest Management Strategy ACT Aquatic Species and Riparian Zone Conservation Strategy Murray-Darling Basin Native Fish Strategy Murray-Darling Basin Alien Fish Plan (in development)	Sustainable Rivers Audit	Introduced Fish information sheets, available online via www.tams.act.gov.au/live/environment Murray-Darling Basin Native Fish Strategy coordinators and their education activities ACT Waterwatch	Phone Environment and Recreation 13 22 81	Ad hoc[4]	Ad hoc[4]	None
NEW SOUTH WALES NSW State Disaster Plan (DISPLAN) New South Wales Invasive Species Plan 2008–2015 Predation by the *Gambusia holbrooki* : A Threat Abatement Plan Murray-Darling Basin Native Fish Strategy Murray-Darling Basin Alien Fish Plan (in development) NSW Draft control Plan for the Noxious Fish Carp (*Cyprinus carpio*) 2009	Sustainable Rivers Audit NSW Monitoring, Evaluating, Reporting (MER) Surveys Integrated Monitoring of Environmental Flows The Living Murray Program Demonstration Reaches Survey and Control of New Pest Fish (delimiting survey program to confirm and determine extent of incursion)	Fishcare volunteer program Fish Friendly Farms program Online information on freshwater pests via www.dpi.nsw.gov.au Murray-Darling Basin Native Fish Strategy coordinators and their education activities Waterwatch NSW Get Hooked, it's Fun to Fish program in NSW primary schools	Phone Aquatic Pest Species and Disease Reporting hotline (24 h): (02) 4916 3877 Email: aquatic.pests@dpi.nsw.gov.au Completion of online Aquatic pest sightings form via www.dpi.nsw.gov.au	NSW DII Aquatic Biosecurity Risk Analysis Protocol	Generic approach followed	Chemical handling course for rotenone use NSW DII Emergency management training

Table 14 (continued)

Management plans and strategies	Active surveillance initiatives[1]	Community education and engagement	Reporting system	Risk assessment procedure[2]	Emergency response procedure	Staff emergency response training[3]
QUEENSLAND Queensland Pest Animal Strategy 2002-2006 Control of Exotic Pest Fishes - An operational strategy for Queensland freshwaters 2000-2005 Noxious Fish Rapid Response Manual 2008 Murray-Darling Basin Native Fish Strategy Murray-Darling Basin Alien Fish Plan (in development)	Vulnerable Catchments Program Sustainable Rivers Audit Demonstration Reaches Fisheries Long-term Monitoring Program Ecosystem Health Monitoring Program (via www.ehmp.org)	Aquatic Invaders website (via www2.dpi.qld.gov.au) Exotic pest fish publications, available online via www2.dpi.qld.gov.au or by phoning DPIF Business Information Centre hotline 13 25 23 Keen Angler program Fishcare Volunteer program Murray-Darling Basin Native Fish Strategy coordinators and their education activities Waterwatch Queensland Stop the Spread program	Phone DPIF hotline 13 25 23 Online via www.dpi.qld.gov.au or by post or fax to DPIF.	As in Qld Noxious Fish Response Plan - priority rating of the incident (Appendix 2)	Qld Noxious Fish Response Plan	Scenario testing workshops
NORTHERN TERRITORY Northern Territory Strategic Plan for Fisheries Research and Development 2007-2011 DPIFM Biosecurity Emergency Management Response Plan Northern Territory All Hazards Emergency Response Arrangements	No routine alien freshwater fish surveillance	River Watch program Publications (eg Protect NT Waterways from Tilapia; Fish Notes for species such as carp, mosquitofish, oscar, tilapia) Waterwatch Northern Territory Aquarium brochures Media releases Communicationwith commercial suppliers	Phone (BH) (08) 8999 2126 or mobile (AH) 0413 381 094 Email: aquaticbiosecurity@nt.gov.au Fax: (08) 8999 2065 (photograph or specimen encouraged)	Ad hoc[4]	Generic approach followed	

Table 14 (continued)

Management plans and strategies	Active surveillance initiatives[1]	Community education and engagement	Reporting system	Risk assessment procedure[2]	Emergency response procedure	Staff emergency response training[3]
WESTERN AUSTRALIA						
The Aquaculture and Recreational Fishing Stock Enhancement of Non-endemic Species in Western Australia 1997 Management Directions for Western Australia's Recreational Fisheries 2000 WESTPLAN Animal and Plant Biosecurity 2008	No routine alien freshwater fish surveillance	Fisheries Volunteer program Research Angler program Publications (eg Aquatic Invaders - Introduced species are a threat to our inland waterways) Waterwatch WA	Phone FISHWATCH hotline **1800 815 507**	Ad hoc[4]	Ad hoc[4]	None
SOUTH AUSTRALIA						
Draft Action Plan for South Australian Freshwater Fishes 2007-2012 State NRM Management Plan 2005 South Australia Arid Land NRM Pest Management Strategy 2005-2010 A Biosecurity Strategy for South Australia PIRSA Emergency Management Response Arrangement State Emergency Management Plan Murray-Darling Basin Native Fish Strategy Murray-Darling Basin Alien Fish Plan (in development)	Sustainable Rivers Audit The Living Murray program Demonstration Reaches River Murray Wetlands Baseline Surveys	'Get Hooked' Educational kit Publications (eg 'Don't Dump your Aquarium Fish') Waterwatch SA	Phone 24 h FISHWATCH hotline 1800 065 522	Ad hoc[4]	Ad hoc[4]	None

Table 14 (continued)

Management plans and strategies	Active surveillance initiatives[1]	Community education and engagement	Reporting system	Risk assessment procedure[2]	Emergency response procedure	Staff emergency response training[3]
TASMANIA						
Tasmanian Inland Recreational Fishery Management Plan 2007–2017 Tasmanian Biosecurity Strategy Tasmanian Biosecurity Policy	Lakes Crescent and Sorell Carp Management Program	Fishcare Volunteers Anglers Alliance Tasmania Publications Online information on pest fish via www.ifs.tas.gov.au Waterwatch Tasmania	Phone 1300 INFISH (BH) or mobile 0408 145 768 Email: infish@ifs.tas.gov.au	Ad hoc[4]	Ad hoc[4]	None

[1] Information on fish species occurrence is also gathered through specific research projects requiring fisheries permits from relevant states and territories.

[2] Undertake risk assessment to determine whether to respond/urgency of response.

[3] Specific training on emergency response procedures for freshwater fish incursions, Note: states and territories participate in national training relating to aquatic animal disease.

[4] No formal procedure; treated on case by case basis.

3.8 Management options

To provide the best opportunity for success and a clear measure of success, alien freshwater fish management programs must be well planned and coordinated, they must include transparent goals and timelines, and they must consider ecological, economic and social consequences. There are few techniques available for alien freshwater fish management, particularly for eradication, and research into new methods is urgently needed. If eradication of an incursion is unfeasible or unsuccessful, the management focus shifts to mitigating its impacts generally by reducing abundances (ie control). Monitoring programs operating concurrently with eradication or control programs can help set objectives and measure success.

Before undertaking an eradication exercise, it is important to understand the original pathway of invasion. If there is a high risk of re-invasion and little opportunity for prevention, then an eradication attempt might be inappropriate. There are several examples where an eradication attempt was initially thought successful, particularly when small lakes were dried, but the alien freshwater fish reappeared soon after the system refilled. There are various possible reasons for this, for instance (1) not all fish were eradicated, (2) re-invasion occurred during the natural inundation of the dried lake, or (3) human-assisted dispersal caused the re-invasion. Education programs should be integral components of an alien freshwater fish eradication program to reduce the likelihood of re-invasion.

Techniques for the eradication and control of alien freshwater fish have recently been reviewed (West et al 2007, Rowe et al 2008, Corfield et al 2007). The available methods can be broadly classified as: physical removal, chemical treatment, habitat manipulations and biological control. Table 15 presents the methods currently available for alien freshwater fish management. Each method has limitations and their application should be considered on a case-by-case basis, with regard to, for example, characteristics of the target species and the incursion location, required resources and costs, presence of non-target species, and overall objectives of the program. More than one method may be applied in a particular case.

It is important that easily accessible and detailed information is available on the various eradication and control techniques, their advantages and disadvantages, and application issues to consider. Such information is needed to educate and guide the various agencies throughout Australia that potentially play a role in freshwater fish incursion management programs, especially because staff expertise and the options available vary. This information could be incorporated into a decision support program to help agency staff determine the most appropriate eradication or control technique. Documentation from past alien freshwater fish management attempts could be stored and made available through the decision support program to facilitate learning from others' experience. Research results on newly established techniques might also be incorporated to encourage field trials.

Table 15. Techniques for alien freshwater fish management

Technique	Advantages	Limitations
PHYSICAL REMOVAL METHODS eg Electrofishing, netting	Generally publicly acceptable Can target specific species or size classes Applicable in all waterbodies	May impact non-target species May cause biomass and size-class shifts Economically unsustainable (expensive) Labour intensive Time consuming Potential escapement of fish Population may recover once control efforts cease – that is, short-term control Outcome affected by several variables, for example, population dynamics Disposal of large quantities of alien freshwater fish Unlikely to provide eradication Multiple treatments required
eg Traps and cages, such as Williams' carp separation cage, carp pushing trap	Can be an automated removal method Can be deployed in some remote locations Generally publicly acceptable Potential minimal impacts on non-target species Can target specific species or size classes	Require constricted area (fishway, culvert or regulator) Can be expensive (>$A 25K) Require monitoring and maintenance Disposal of large quantities of alien freshwater fish Unlikely to provide eradication Multiple or continuous treatments required
eg Containment (physical and behavioural barriers)	Suitable for various waterbodies Can be preventative Selected barriers are mobile Some barriers can be rapidly deployed Generally socially acceptable	Need for more experimentation before deployment Often not 100% effective at containing target species Will impact on native fish and aquatic fauna May be costly to construct, install and maintain Require regular monitoring and maintenance Can compromise watercraft navigation Will not provide eradication Continuous or semipermanent application
eg Angling	**Suitable for all waterbodies** **Raised community awareness and education** **Potential for slight short term population reduction**	May impact non-target species Need to manage stakeholder expectations Difficulty organising events and managing large groups of people Will not provide eradication Is not a viable method for effective alien freshwater fish control

Table 15 (continued)

Technique	Advantages	Limitations
CHEMICAL TREATMENTS		
eg Lime, chlorine and other chemicals	Low cost Readily available Potential for eradication	Unsuitable for in large water bodies and flowing water. More suited to shallow closed systems, such as ponds, small lakes, wetlands. Use of chemicals creates public concern Chemical must be registered for use in Australia Permit required for chemical use Temporary loss of public water supply and recreational activities Impacts on aquatic habitats and non-target species Does not always effect all individuals Needs to be thoroughly mixed, hence is difficult to apply effectively in deep habitats One or multiple treatments required Moderate costs
eg Piscicide – Rotenone	Potential for eradication Controls all post-embryonic lifestages Rapid results Non-target species can be revived if quickly collected Various application methods, for example, tank/hose, backpack sprayer, helicopter Available in powdered or liquid formulations Degrades quickly and can be neutralised No residual effects after breakdown (very short effective life) USA Rotenone User's Manual available Rotenone registered for use in Australia	Extremely difficult to apply in large water bodies and flowing water. More suited to closed systems, such as ponds, small lakes, wetlands. Toxic to all fish with some variation by species Potential non-target mortality on fish, amphibians and so on. Use of chemicals creates public concern Permit required for use. Rotenone application dictated by permit regulations (Rotenone use prohibited in Victoria) Temporary loss of public water supply and recreational activities Temporary impacts on aquatic habitats and non-target species, for example, amphibians, macroinvertebrates Does not kill fish eggs until the shell raptures at hatching Can be repellent which may enable escape Application weather dependent Difficult to apply in large or flowing waters Difficult to apply in complex habitat Larger applications are expensive One or multiple treatments required

Table 15 (continued)

Technique	Advantages	Limitations
eg Piscicide – Antimycin	Potential for eradication Rapid breakdown Rapid results No residual effects after breakdown Limited impact on aquatic fauna other than fish Greater toxicity than rotenone, thus can use smaller quantities	Extremely difficult to apply in large water bodies and flowing water. More suited to closed systems, such as ponds, small lakes, wetlands. Toxic to all fish with some variation by species Use of chemicals creates public concern Not registered for use throughout Australia Limited history of use overseas Decreasing toxicity with increasing pH— not effective at high pHs (>8.5) Decreasing toxicity with decreasing temperature Toxicity reduced by turbidity, organic matter and alkalinity Temporary loss of public water supply and recreational activities Possible temporary impacts on aquatic habitats and non-target species Does not kill fish eggs until the shell raptures at hatching More expensive compared to rotenone One or multiple treatments required
eg Explosives	Localised impact Relatively inexpensive	Suitable only in isolated waterbodies Harmful to non-target species and humans May cause damage to adjacent properties/structures Unlikely to provide eradication Multiple treatments required
HABITAT MANIPULATION eg Water level management → dewatering → drawdown	Only known method of complete population eradication without the use of toxins Relatively inexpensive Regular annual drawdown regimes may be implemented to affect specific habitats of targeted species Potential for eradication	Can impact on non-target species and important habitats Suitable only in small, isolated waterbodies or those with mechanisms for water level control Limited by level of hydrological control Can have social impacts (eg drying of the town lake), create public concern Very few areas can be completely drained to achieve eradication — pools may remain where fish can survive One or multiple treatments required

Table 15 (continued)

Technique	Advantages	Limitations
BIOLOGICAL CONTROL		
eg Predators	Stocking of predatory native fish is generally publicly acceptable Potential for eradication	May impact non-target species Unpredictable results May alter ecosystem dynamics Translocation issues Variable success maintaining predator populations Introduction of new pathogens or animals has inherent risk Multiple releases of biological control species may be required
eg Genetic techniques	Can potentially impact at broad scales Potential for eradication No impact on non-target species (the genetic method will require *no* evidence of impacts on non-target species to be approved)	Still experimental Expensive technology, ongoing costs unknown Genetically modified organisms require public perception management Risk management process required Multiple treatments may be required

3.8.1 The drought: a unique opportunity for alien freshwater fish management?

The present drought has impacted both native and alien freshwater fish and there are numerous cases where carp recruitment has failed and populations have been reduced to only large adult fish. As water bodies dry, water quality declines and may result in mass fish mortality. In some cases the complete drying of ornamental ponds, lakes and reservoirs has resulted in the destruction of large numbers of alien freshwater fish, most noticeably carp. Some examples are:

- Lake Boga (Victoria) dried out in January 2008 with destruction of approximately 10,000 carp and redfin perch. Some native fish were also destroyed.
- Shepparton Town Lake (Victoria).
- Lake Wendouree near Ballarat (Victoria) dried in early 2007, and all carp were destroyed.
- Lake Colac (Victoria); thousands of carp destroyed when the lake dried in early 2008.
- Lake Brewster, Lake Peery, Macquarie Marshes and Great Cumbung swamp and various other inland lakes and wetlands of NSW dried out since 2001 with destruction or retraction of tens of tonnes of carp and redfin perch.
- Lake Victoria, Maryborough (Victoria), dried out and all carp and redfin perch were destroyed. However, alien freshwater fish re-invaded as the lake filled in 2008.
- Lake Bonney (SA) in 2008 suffered from water quality issues with carp and redfin perch deaths reported; commercial fishers licensed to harvest carp accumulations trying to leave the lake.
- Various rivers, creeks, impoundments or parts thereof (eg Avoca and Glenelg rivers, Victoria) have dried, resulting in carp destruction.
- Various urban wetlands and lakes throughout Melbourne have dried resulting in the destruction of eastern gambusia.

Because many lakes and rivers, or systems are dry or have very low water levels, there is an opportunity to assess each on a case-by-case basis for the potential to eradicate all remaining alien freshwater fish and to limit or stop future re-invasion. The methods for limiting re-invasion of alien freshwater fish or their impacts may include:

- installing screening systems
- stocking native fish (increase species abundance) to compete with alien fish
- enhancing native fish habitats (snags) while water levels are low
- installing lake drainage or carp harvest systems while water levels are low
- public education.

The drought also provides unique opportunities to harvest carp from freshwater refuges and remaining riverine areas while also collecting basic population data on biomass, age structure, sex ratio, recruitment and mortality. These data would be useful for understanding the population dynamics and planning future control efforts.

3.8.2 The problems of alien freshwater fish disposal

With the closure of the native fish commercial fishery in Victoria, NSW and South Australia, fishers switched to common carp and common yabby. However, because of the low market value of carp (eg A$0.80/kg) and because the drought reduced the supply, the fishery soon contracted. There are now few active fishers in Victoria and NSW, although several are still active in South Australia. The lack of commercial fishers and their gear has resulted in few opportunities to harvest and utilise carp in drying lake beds. For isolated river systems or periods when only low abundances (< 10 tonnes) of carp are available there is little financial incentive for a commercial fishing exercise.

On-ground initiatives to control carp have also been affected by the carp disposal problem. In northern Victoria, the disposal of carp from Williams' carp separation cages has been successful because they have been processed at the nearby Charlie Carp fertiliser factory at Deniliquin. However, the rollout of Williams' carp separation cages along the Murray River has been hampered by the disposal of small quantities of carp in isolated reaches downstream of Wentworth. In Queensland, legislation precludes the transport of carp and thus the application of some control technologies. In these areas a specific carp disposal plan is required before any control effort can be applied. The Queensland Department of Employment, Economic Development and Innovation (Primary Industries and Fisheries) is developing a policy principle in collaboration with all stakeholders (eg Natural Resource Management groups, MDBA etc) to ensure there can be effective and useful disposal (utilisation) of carp in a non-commercial way.

In South Australia a partnership between commercial fishers and SA Water, licensed by PIRSA Fisheries, enabled the removal of 70 tonnes of carp from a Williams' carp separation cage at Lock 1 on the Murray River in 2007–2008 and 2008–2009 (Conallin et al 2008). These fish were frozen on site and then removed for commercial sale.

Alien freshwater fish control and appropriate disposal therefore requires:

- a detailed plan identifying who is responsible for fish disposal
- prioritisation of sites for alien freshwater fish control.

3.9 Past eradication and control programs in Australia

Table 16 provides a summary of existing known eradication and control exercises for alien freshwater fish in Australia. Some of these documented examples are general broad overviews, for example, 'carp eradicated in 1,300 dams in Victoria in the 1960s using chemical treatment, while others relate to specific management attempts. The majority of information was collated from government agency annual reports, newsletters, and personal communications. Very few descriptions of management attempts have been published in peer-reviewed journals or government reports. Some attempts were discovered only because they were cited in other reports, and obtaining further information was often challenging.

The difficulty in gathering and interpreting information on past eradication or control programs for alien freshwater fish in Australia highlights that there has been no consistent or formal approach to undertaking or documenting the processes used and the outcomes of such exercises. This may reflect the varied approaches to alien freshwater fish management between states and territories, as well as the different agencies or staff members leading or conducting the program. Within states and territories, a number of longserving agency staff could recall basic information on past eradication or control attempts. The fact that a great deal of information on past attempts has been lost because of poor documentation or staff turnover, reinforces the importance of keeping detailed, accurate documentation to enable learning from past experience. A lack of accurate documentation may also lead to incorrect information being cited, interpreted and perpetuated.

Documentation of past eradication and control attempts lacked detail and generally only stated the location, species targeted and method, and sometimes their success or otherwise. Hence it is extremely difficult to learn from past experience. Clear detailed objectives, descriptions of site characteristics (including the physical structure and native and alien species composition), specifics of methods for the exercise including the post-monitoring phase, resourcing requirements (eg number of staff, person–hours required, equipment), costs (overall total plus breakdown of staff costs, equipment costs, etc), permits required, other government agency support, community engagement and involvement, and so on, should be documented so future readers can understand the rationale for choosing the approach taken and its requirements, repeat the actions or methods, and decipher factors that contributed to the success or failure of the attempt.

State/territory

While eradication and control exercises have been undertaken in all states and territories, the greatest numbers documented have been in Tasmania, followed by New South Wales, Western Australia, Victoria and Queensland. It is uncertain however, whether the number of documented exercises reflects the number of exercises undertaken in each jurisdiction. It is possible that many more eradication or control exercises have been undertaken and not recorded.

Species

Almost 20 alien freshwater fish species have been the target of Australian eradication and control exercises, as well as the common yabby. This represents nearly 45% of the 44 alien freshwater fish species that have been recorded in Australia to date. The majority of alien freshwater fish species that have received attention were originally ornamental species, the remainder being species introduced for recreational angling or biocontrol (eastern gambusia). Five of the species (brown trout, rainbow trout, common carp, eastern gambusia and Mozambique tilapia) are among eight freshwater fish species listed in the top '100 of the World's worst alien invasive species' (Lowe et al 2000). Significant efforts have been made to eradicate localised populations of species of concern, such as tilapias in Queensland and gambusias in Tasmania, while control efforts have focused on widespread, high-profile species such as common carp. No information was found on the management of translocated native species, with the exception of the common yabby and Australian smelt in Tasmania.

Purpose

In many cases the detailed aims were not specified, and often could be gleaned only from references. Eradication appears to have been the intention in most cases, while control has been the aim in other instances, presumably where eradication is considered unfeasible, such as for carp management.

Date

The dates of some attempts are unknown, although approximately half have been made since the early 2000s. Overall, the majority have occurred since the 1970s, with a particular focus since the early 2000s. There were, however, concerted efforts in the 1960s in Victoria to eradicate carp in 1300 farm dams. The increasing number of documented eradication or control exercises may reflect an increasing awareness and scale of the problem, greater focus of management effort, higher expectations of managers, and recognition of the importance of reporting.

Location

Past attempts have been undertaken in various types of water bodies, including small-scale and large-scale closed systems such as lakes, wetlands and ponds, and open systems such as creeks, rivers and drainage channels. The ease with which a management strategy can be implemented will be influenced by the type of water body: closed systems are much easier to deal with than open systems, and they have a greater chance of successful eradication. Characteristics of the location, such as water depth, aquatic vegetation density and substrate, should also be noted, as these will influence the type of management strategy and how easy it is to implement. Apart from the general location name, generally in all cases no information was provided about the site characteristics of eradication or control attempts.

Methods

The level of detail provided about the methods varies. In many instances a combination of methods has been used. The majority of eradication and control attempts can be divided into physical removal and chemical techniques.

Almost half of the attempts include the use of rotenone, or more generally the use of a piscicide or fish poison. There are several examples of the use of endosulphan, an agricultural pesticide, to control common yabbies in dams in Tasmania, although this technique is considered experimental in Australia (Corfield et al 2007). Liming with calcium hydroxide has been used in a few situations for eastern gambusia in dams in Tasmania, and historically for common carp in dams in Victoria. This method can be used in small closed water bodies such as ponds, although there are associated non-target risks (Corfield et al 2007).

Electrofishing and a variety of netting techniques (gill, seine, pound, fyke) have been used for various species, although these techniques are generally considered control techniques. There are examples of line fishing by anglers in programs such as CarpBusters, although these are components of control programs and provide only short-term reduction in abundances. Explosives have been used to a very limited extent, for Jack Dempsey cichlid in a disused quarry in NSW and for various species at Waroona Dam in Western Australia. While these exercises did not eliminate the species, the method is potentially useful in small waterbodies if the blast field can affect the entire waterbody (Corfield et al 2007). Screens have been used on water outlet channels and lakes for tilapia, carp and eastern gambusia.

There are a small number of examples of habitat manipulations where water levels have been varied; this included complete drainage for eradication and drainage to remove access to spawning habitats or to influence spawning movements for control. Drainage may be relatively feasible for small ponds where water can be easily manipulated. Drainage can enhance the effectiveness of subsequent chemical treatments by reducing the scale of chemical application required; including the size of the waterbody to be treated and water depth which influences the difficulty and effectiveness of chemical treatment. Other habitat manipulations relate to habitat restoration to theoretically change the balance between natives and alien freshwater fish to benefit native species. Corfield et al (2007) noted that there may be potentially unforseen ecological impacts of such an approach on other species.

Biological control, including the addition of predators and restocking of native species, also represents an option for control. Restocking with native species has been trialled following poisoning in a drainage channel in the Northern Territory to eradicate jewel cichlids, and the addition of trout species has been trialled to eradicate eastern gambusia in farm dams in Tasmania.

Outcome

Clear aims of an eradication or control attempt should be established at the beginning of the program, because the outcomes can then be compared against the aims to evaluate the overall success of the program. In many instances it is impossible to know whether the program was successful because either the aims or the outcomes were not adequately documented. If eradication is the aim then success can only be the complete removal of all individuals. Failing to set timeframes to aims may also make it difficult to assess the outcome of attempts. For example, in the short term an eradication attempt may have been considered successful, but in the long term reinvasion may occur (eg via contaminated waterflow during flooding), so the outcome would be deemed unsuccessful if it were assessed on a longer time scale.

Despite these difficulties in interpretation, it is clear that many eradication attempts were unsuccessful. But because of the lack of documentation it is unclear why some failed.

Post-response monitoring

Post-response monitoring is important to assess the effectiveness of a response and to monitor the recovery of the ecosystem. Most cases mention post-response monitoring, although usually with little detail about what this monitoring entailed. Records of post-response monitoring should include the monitoring method, frequency and intensity of monitoring events, and duration (ie weeks, months or years following the eradication or control effort).

Table 16. Summary of previous eradication and control actions for alien freshwater fish in Australia

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
AUSTRALIAN CAPITAL TERRITORY						
Cyprinus carpio (common carp), ***Carassius auratus*** (goldfish) and *Gambusia holbrooki* (eastern gambusia)	Eradication	Australian National Botanical Gardens, Canberra. 4 ponds 1990	Rotenone	3 ponds successful, 1 pond unsuccessful due to dense vegetation		Lintermans and Rutzou (1990) Lintermans (2004) Rayner and Creese (2006)
Oncorhynchus mykiss (rainbow trout)	Eradication	Lees Creek, Canberra 23-24 March 1992	Rotenone in small stream, above barrier	Successful	Yes (over 4 years)	Lintermans (2000) Lintermans and Raadik (2003)
NEW SOUTH WALES						
Cyprinus carpio (common carp)	Eradication	Farm dams in NSW		Successful		Lintermans (2004)
Cyprinus carpio (common carp)	Control	Botany Bay Wetlands, Sydney 1996-2004	Electrofishing, gill netting	Successful, ~4,000 carp removed between 1996-2004, impacts of carp reduced	Yes	Pinto et al (1995)
Cyprinus carpio (common carp)	Eradication	Kurrajong, Sheepwash and Bulgari Lagoons, Narrandera, NSW	Bait pellets containing rotenone	Unsuccessful, only 12 carp killed. ~3000 non-target Australian smelt died. Pellets had low palatability and poor floatation.		Gehrke (2003)
Cyprinus carpio (common carp)	Control	Lachlan River demonstration reach site at Euabalong 2007-2008	Electrofishing, Line-fishing — community carp musters	Successful, reduction in carp		Gehrke (2008)
Cyprinus carpio (common carp)	Control — commercial harvesting by K&C Fisheries	Various locations ongoing	Electrofishing, seining, specialised traps	Successful		Bell (2003)
Gambusia holbrooki (eastern gambusia)	Control — to benefit the green and golden bell frog population	Narawang Wetland, Sydney Olympic Park Aug-Oct 2003-2005	Water draw down of three groups of wetlands. Wetlands left to dry for four weeks	Successful removal for on average 3 months; recolonisation during inundation from infected ponds. Increased indices of bell frog breeding	Yes — in conjunction with green and golden bell frog monitoring	O'Meara and Darcovich (2008)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Gambusia holbrooki (eastern gambusia)	Eradication	12 pools at a landfill site near Kurnell, NSW 2000	Powdered rotenone	Successful		Rayner and Creese (2006)
Carassius auratus (goldfish)	Eradication	Storm water retention basin draining into Manly Dam	Rotenone			ASFB (2007)
Carassius auratus (goldfish)	Control	Whites creek wetland June 2004	Draining, wetland remained drained for one week			Sydney Coastal Member Councils (2004)
Cichlasoma octofasciatum (Jack Dempsey cichlid)	Eradication	A disused quarry at Angourie 2004–2005	Water drawdown, explosives applied on three separate occasions over 12 months, complemented by post stocking of native fish predators	99% reduction in numbers, but species still present suggesting new stocking or some survival	Yes	ASFB (2006a) Corfield et al (2007)
Phalloceros caudimaculatus (one-spot livebearer)	Eradication	Long Reef Golf Course, North Sydney 2002	Rotenone — 10 infested ponds treated 3 times over 2 weeks	Unsuccessful	Yes	ASFB (2007) Rayner and Creese (2006)
Phalloceros caudimaculatus (one-spot livebearer)	Eradication	Long Reef Golf Course, North Sydney June 2006	Removal native species, water draining, rotenone — 10 infested ponds treated 3 times over 2 weeks	Successful	Yes, in January 2007, December 2007, April 2008. No One-spot livebearer detected. Used electrofishing, trapping, spotlighting	ASFB (2007) ASFB (2008) Rayner and Creese (2006) Frances, J. pers comm. (2008)
Misgurnus anguillicaudatus (oriental weatherloach)	Eradication	Wingecarribee dam to water treatment works ~8 km	Rotenone		No	Burchmore et al (1990)
Perca fluviatilis (redfin perch)	Eradication	Lake Canobolas near Orange late 1970s	Method unknown — attempt undertaken by Orange Trout Acclimatisation Society	Unsuccessful		Orange City Council
Perca fluviatilis (redfin perch)	Control	Lake Canobolas near Orange	Removal of willows, restore native trees, restocking of native fish including Murray cod, silver perch, golden perch			NSW Department of Primary Industries (2009)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Perca fluviatilis (redfin perch) (continued)	Prevention/ Control via community education and awareness	Upper Lachlan and upper Wollondilly River catchments 2006	Community education and awareness (Initial surveys and analysis of available eradication or control options rendered no options feasible)			Frances, J. pers comm. (2008)
Xiphophorus maculates (platy)	Eradication	Campvale drainage system, Medowie Jan 2009	Rotenone treatment after delimiting length of drain and lowering water levels.	Post-eradication surveys found platy in reduced numbers. Further management under consideration (as at April 2009).	Yes, March 2009.	Walker, M. pers comm. (2009)
NORTHERN TERRITORY						
Gambusia holbrooki (eastern gambusia)	Eradication	Ilparpa Swamp at Alice Springs Discovered May 2000, eradicated by Jan 2001	Swamp was dried via pumping and evaporation	Successful		ASFB (2002) DBIRD (2004)
Gambusia holbrooki (eastern gambusia)	Eradication	Backyard ponds, Alice Springs 2001	Draining ponds; rotenone	Successful		ASFB (2002) www.nt.gov.au
Gambusia holbrooki (eastern gambusia)	Eradication	Todd Mall Church Pond, Alice Springs 2001	Draining ponds; rotenone	Successful		ASFB (2002) Corfield et al (2007) www.nt.gov.au
Hemichromis bimaculatus (jewel cichlid)	Eradication	Drainage channel of the Royal Darwin Turf Club, ('Racecourse Creek') 2002	Treatment then restocking with native fish	Successful	Yes	Lintermans (2004) DPIFM (2005) DPIFM (2007)
Xiphophorus maculatus (platy)	Eradication	Charles Darwin University Chinese garden pond and storm water drain adjacent to Charles Darwin University, the drain feeds directly into the Rapid Creek system 2005	Drainage and chemical treatment of the pond; modification of the pond's overflow to prevent re-introduction to the drain. Chlorine treatment of the grate and stormwater drain.	Unsuccessful in the pond. Successful in the storm water drain.	Yes	ASFB (2005b) DPIFM (2006)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Poecilia reticulata (guppy)	Eradication	Drainage gully known as Racecourse creek, Fanny Bay. Racecourse Creek runs adjacent to Darwin Turf Club and enters natural waterway at Ludmilla Creek. 2006	Rotenone	Successful (temporarily) Re-introduced via suspected backyard pond overflow in surrounding suburbs	Yes	Northern Territory DRDPFI (2008)
Poecilia reticulata (guppy)	Eradication	Storm water drain in Leanyer, flows into Buffalo Creek during the Wet Season 2007	Rotenone	Successful	Yes	H Cribb, personal communication, 2009
Poecilia reticulata (guppy) and ***Xiphophorus maculatus*** (platy)	Eradication	Drainage gully known as Racecourse Creek, Fanny bay. Racecourse Creek runs adjacent to Darwin Turf Club and enters natural waterway at Ludmilla Creek. 2007	Rotenone	Successful (temporarily) Reintroduced via suspected backyard pond overflow in surrounding suburbs	Yes	Northern Territory DRDPFI (2008)
QUEENSLAND						
Tilapia mariae (black mangrove cichlid)	Eradication	5km stretch of Eureka Creek (N Qld) 2008	Electrofishing initial short-term control. Eradication: containment — stopping water flow from Solanum Weir and installing temporary sand dams immediately upstream and downstream of the Chillagoe Road Crossing. Electrofishing removal of native species. Treatment of contained area with rotenone.	Pending (initial post survey showed no tilapia in the treated area)	Yes, planned for a period of 12 months	Z Sarac, personal communication, 2009 DPIF (2008)
Oreochromis mossambicus (Mozambique tilapia)	Control	Tinaroo Falls Dam in the Barron River catchment	Mesh screens onto outlet channels	Successful, no tilapia have been observed since the inclusion of screens	Long term survey	ASFB (2003a) Greiner and Gregg (2008)
Oreochromis mossambicus (Mozambique tilapia)	Control	Boondooma dam pipeline	Mesh screens	Successful	Yes, ongoing	ASFB (2003a)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Large ponds in Townsville Botanical Gardens June 1980	Rotenone	Unsuccessful	Yes, in September 1981	Arthington et al (1984)
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Southern Townsville, drainage canal above the tidal gates opening into Ross Creek June 1980	Rotenone	Unsuccessful	Yes	Arthington et al (1984)
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Yeppoon and Port Douglas	Rotenone			Tuma (1990)
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Port Douglas golf course @ Mirage Resort 1988	Rotenone	12–16 tonnes removed		Invasive Species Council (2002) Andersen (2008)
Oreochromis mossambicus (Mozambique tilapia)		North Pine River Brisbane, d/s from North Pine Dam c. 1988	Physical removal (many tonnes)			Bluhdorn et al (1990)
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Small dam in Rockhampton		Unsuccessful		Arthington et al (1999)
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Bullyard properties near Bundaberg. 16 privately owned dams on two properties. Aug 2009	Rotenone	> 5,500 Tilapia destroyed. Successful eradication TBC	Yes, occurring three months and 12 months after treatment.	Willett, D. pers comm. (2009)
Misgurnus anguillicaudatus (oriental weatherloach)	Eradication	Drain adjacent to the Bay Fish farm located approx 200m from Burpengary Creek, Brisbane. The weatherloach were found in a small table drain rather than the creek itself.	Rotenone	Successful		Challen, S. pers comm. (2009) Brooks, S. pers comm. (2009) Lintermans (2004)
Tanichthys albonubes (white cloud minnow)	Eradication	Small waterhole on a suburban creek in Brisbane	Rotenone			ASFB (2003b)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
SOUTH AUSTRALIA						
Aquarium species	Eradication	Victoria House pond 70 m^2, Adelaide Botanical Gardens	Piscicide; signage (education)			Balla et al (1985) Lintermans (2004)
Aquarium species	Eradication	Victoria House pond 70 m^2, Adelaide Botanical Gardens	Piscicide	Removed 3 Cichlidae sp., 2 Anabantidae sp., 1 Cyprinidae sp., 1 Poeciliidae sp., 1 Ariidae sp.		Pierce (1991) Lintermans (2004)
Cyprinus carpio (common carp)	Control	Banrock Station June 2008	Removal (carp finger pushing trap)	Successful , c. 4,700 carp captured		B Smith, personal communication, 2008 Fredberg et al (2009)
Cyprinus carpio (common carp)	Eradication	Cooper Creek drainage	Chemical	Successful		Hall (1988)
Cyprinus carpio (common carp) and ***Carassius auratus*** (goldfish)	Eradication	Leigh Creek retention dam Apr 1988	Rotenone powder	Successful, 200,000 carp 2-3 million goldfish killed		Hall (1988) Lintermans (2004)
Phalloceros caudimaculatus (speckled livebearer)	Eradication	4km stretch of Willunga Creek	Rotenone undertaken Apr to May 2010	Pending (initial post survey suggests the treatment was 100% effective)		D McNeil, personal communication, 2009 J Gilliland, personal communication, 2009
Perca fluviatilis (redfin perch)	Eradication	Farm dam c. 1999	Rotenone			http://services.apvma.gov.au/permits/response.jsp
TASMANIA						
Retropinna semoni (Australian smelt)	Eradication	Farm dam near New Norfolk Mar 1982	Rotenone			Inland Fisheries Commission (1982) Diggle, J. pers comm. (2008) Fulton, W. pers comm. (2008)
Carassius auratus (goldfish)	Eradication	Dams across the state 1986				Inland Fisheries Commission (1986)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Carassius auratus (goldfish)	Eradication	Farm dams at Huonville and Brighton 1987	Rotenone			Inland Fisheries Commission (1987)
Carassius auratus (goldfish)	Eradication	Farm dams in Meander River Catchment (N Tas) 1976	Rotenone			Diggle, J. pers comm. (2008)
Cyprinus carpio (common carp)	Eradication	Farm dams and lakes in NW Tasmania 1975	Rotenone	c. 10,000 carp removed Successful	Some surveys undertaken	Rayner and Creese (2006) Diggle, J. pers comm. (2008) Fulton, W. pers comm. (2008)
Cyprinus carpio (common carp)	Eradication	Chasm Creek Catchment near Stowport 1980	Rotenone	Successful	Some surveys undertaken	Diggle, J. pers comm. (2008) Fulton, W. pers comm. (2008)
Cyprinus carpio (common carp)	Eradication	Lakes Crescent and Sorell since 1995 (continuing)	Various: Public closure, electrofishing, mesh screens, barrier nets, fyke, seine, and gill nets, pheromone generators, traps, radio tracking males, community education and awareness.	Successful containment and control (decline in numbers). Not yet eradicated.		Diggle, Day and Bax (2004) Inland Fisheries Service (2004)
Cherax destructor (common yabby)	Eradication	Various dams in Mole Creek area (NW Tas) 1989	Endosulphan	Unsuccessful		Diggle, J. pers comm. (2008)
Cherax destructor (common yabby)	Eradication	Various dams in Cremorne area (SE Tas) 1979	Endosulphan	Unsuccessful		Fulton, W. pers comm. (2008) Diggle, J. pers comm. (2008)
Gambusia holbrooki (eastern gambusia)	Eradication	Farm dam in Northern Tasmania 1993				Keane and Neira (2004)
Gambusia holbrooki (eastern gambusia)	Eradication	Farm dam #1 in Legana (N Tas)	Poison	Unsuccessful	Yes	Inland Fisheries Service (2005)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Gambusia holbrooki (eastern gambusia)	Eradication	Farm dam #1 in Legana (N Tas) June 2005	Water level pumped down to residual level and treated with rotenone			Inland Fisheries Service (2005)
Gambusia holbrooki (eastern gambusia)	Eradication	Farm dam #2 in Legana (N Tas) June 2005	Water level pumped down to residual level and treated with rotenone			Inland Fisheries Service (2005)
Gambusia holbrooki (eastern gambusia)	Eradication	Dam at Kingston (S Tas) 2003	Limil (Calcium hydroxide)	Successful		ASFB (2003b) ASFB (2005a) Diggle, J. pers comm. (2008)
Gambusia holbrooki (eastern gambusia)	Eradication/ Control	Tamar Catchment	Various: Lime, rotenone, screens, raising levees, heat/light attractants	Unsuccessful		Scurr, G. pers comm. (2008) Milner (2006)
Gambusia holbrooki (eastern gambusia)	Eradication	Dam at Snug (S Tas) 2003	Calcium hydroxide (lime)	Unsuccessful	Yes	ASFB (2005a)
Gambusia holbrooki (eastern gambusia)	Eradication	Dam at Snug (S Tas) 2004	Pumped down, added liquid rotenone	Successful	Yes	ASFB (2005a) Diggle, J. pers comm. (2008)
Oncorhynchus mykiss (rainbow trout)	Eradication	Johnsons Lagoon (Central Tasmania World Heritage Area) 2006–2008	Physical removal using gill netting	Successful	Yes, using netting	Diggle, J. pers comm. (2008) ASFB (2007) Inland Fisheries Service (2009)
Perca fluviatilis (redfin perch)	Eradication	Clarence River Catchment (two small dams near the Lyell Highway in close proximity to the Clarence River) Feb 2008	Liquid rotenone, dams already at low levels	Successful	Yes, electrofishing	Inland Fisheries Service (2006) Inland Fisheries Service (2008) ASFB (2007)
Perca fluviatilis (redfin perch)	Eradication	Farm dam at Gawler in Leven River Catchment (NW Tas) 1975	Rotenone			Diggle, J. pers comm. (2008)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Perca fluviatilis (redfin perch)	Eradication	Farm dams in Upper Macquarie River Catchment 1989	Rotenone			Diggle, J. pers comm. (2008)
Perca fluviatilis (redfin perch)	Eradication	Lodge Dam, Great Lake Catchment Feb 1996	Rotenone			Diggle, J. pers comm. (2008)
Perca fluviatilis (redfin perch)	Eradication	Brushy Lagoon 1998	Rotenone	Unsuccessful — reinvasion		Diggle, J. pers comm. (2008) Fulton, W. pers comm. (2008)
Perca fluviatilis (redfin perch)	Eradication	McPartlan's Canal below the outflow gate from Lake Pedder 2007	Rotenone, velocity barrier to prevent redfin movement into Lake Pedder	Successful		Inland Fisheries Service (2008)
Perca fluviatilis (redfin perch)	Eradication	Small borrow pits in upper Derwent catchment 2007	Rotenone	Successful		Diggle, J. pers comm. (2008)
Perca fluviatilis (redfin perch)	Eradication	Great Lake catchment 1996	Chemical			Sanger and Koehn (1997)
Salmo trutta (brown trout)	Control	Blue Tier Creek, Macquuarie River catchment c. 1990	Migration barrier — enhanced waterfall to prevent brown trout migration into Swan galaxias (*G. fontanus*) habitat			Fulton, W. pers comm. (2008)
Tinca tinca (tench)	Eradication	Mining dam at Adamsfield (W Tas) 1974	Rotenone			Diggle, J. pers comm. (2008)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
VICTORIA						
Cyprinus carpio (common carp)	Eradication/ Control	Rocklands Reservoir, Glenelg River Catchment ongoing	Boat electrofishing, screens, netting	Unsuccessful		Bishop, K. pers comm. (2008) Stuart and Jones (2002)
Cyprinus carpio (common carp)	Control — commercial harvesting by K&C Fisheries	Various locations ongoing	Electrofishing, seining, specialised traps	Successful		Bell (2003)
Cyprinus carpio (common carp)	Eradication	1,300 dams in Victoria May 1962	Limil, santabrite or rotenone	Successful	Yes, conducted following year	Sanger and Koehn (1997) Hume et al (1985)
Cyprinus carpio (common carp)	Eradication	Yallourn storage dam in the La Trobe river system May 1962	Limil, santabrite or rotenone	Unsuccessful, carp detected in 1965	Yes	Sanger and Koehn (1997)
Cyprinus carpio (common carp)	Eradication	Main lake in Sale 1970s	Rotenone			McKenzie, J. pers comm. (2008)
Cyprinus carpio (common carp)	Eradication	Main lake in Shepparton 1970s	Rotenone			McKenzie, J. pers comm. (2008)
Cyprinus carpio (common carp)	Control	Various fishways ongoing	Williams' carp separation cage	Successful — removal of tonnes carp		Stuart and Jones (2002) Stuart et al (2003)
Cyprinus carpio (common carp)	Control to benefit local Macquarie Perch population	Hughes Creek Dec 2009	Back pack electrofishing	Successful reduction in numbers, ~ 500 carp removed	Yes, as by-product of Macquarie perch monitoring	Kearns, J. pers comm. (2009)
Gambusia holbrooki (eastern gambusia)	Eradication	Tirhatuan Wetlands c. 1989	Draining; rotenone			Breen et al (1989)
Gambusia holbrooki (eastern gambusia)	Eradication	Hallam Valley wetlands 2008	Water draw down, drying	Successful	Yes, bait traps	Colemann, R. pers comm. (2009)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Gambusia holbrooki (eastern gambusia)	Eradication	Gresswell Grange Lakes, corner of Grange Boulevard and Main Drive, Bundoora Feb 2007	Water level pumped down, added liquid lime	Unsuccessful		ASFB (2005a)
Salmo trutta (brown trout) and *Oncorhynchus mykiss* (rainbow trout)	Eradication	Morning Star Creek, Pheasant Creek, Perkins Creek, Raspberry Creek, Godfrey Creek near Woods Point; Taggerty River, Keppel Hut Creek and Cameron Creek near Marysville pilot 1994; eradication attempt 1995	Rotenone, fine mesh stop-nets, downstream barriers	Successful, but reintroduction by anglers at Raspberry Creek and Morning Star Creek	Yes, 5+ yrs	Lintermans and Raadik (2003)
Cyprinus carpio (common carp), *Perca fluviatilis* (redfin perch) and ***Carassius auratus*** (goldfish)	Control — to benefit local catfish population	Lake Victoria, Maryborough Nov 2008	Electrofishing	Successful reduction in numbers, removal of ~250 individuals	Yes as by-product of catfish program	Clunie, P. pers comm. (2008)
WESTERN AUSTRALIA ***Carassius auratus*** (goldfish)	Survey distribution	Vasse River Dec 2003, Mar 2004	Back pack electrofishing, gill nets, seine nets	91 goldfish captured. goldfish concentrated in lower Vasse River	Yes	Morgan et al (2005) Morgan and Beatty (2006a)
Carassius auratus (goldfish)	Control	Vasse River Mar 2005	Boat electrofishing and gill nets	105 goldfish removed over 2 days	Yes	Morgan et al (2005) Morgan and Beatty (2006a)
Carassius auratus (goldfish)	Control	Vasse River May 2006	Boat electrofishing and gill nets	55 goldfish removed over 2 days	Yes	Morgan and Beatty (2006a)
Carassius auratus (goldfish)	Control	Vasse River Sep 2006	Boat electrofishing and gill nets	No goldfish captured in main channel, 4 goldfish captured in adjacent wetland — New River Wetland		Morgan and Beatty (2006a)
Oreochromis mossambicus (Mozambique tilapia)	Eradication	Ornamental ponds in Geraldton		Successful		Arthington et al (1984)

Table 16 (continued)

Species (common name)	Purpose	Location and date	Method	Outcome	Post monitoring	Reference or Cited in
Phalloceros caudimaculatus (one-spot livebearer)	Control	Bull Creek Apr 2006	Backpack Electrofishing, fyke nets to remove One-spot Livebearer (April 2006) and reintroduced native Western Pygmy Perch and Western Minnows (April 2006)		Yes, summer 2006–2007	Morgan and Beatty (2006b)
Geophagus brasiliensis (pearl cichlid)	Eradication	Bennet Brook at Lockridge and Kiara, Perth 2005–2006, 2006–2007, 2007–2008	Electrofishing, netting, rotenone			Department of Fisheries (2006, 2007, 2008) C Astbury, personal communication, 2008 Wells et al (2009)
Tilapia zillii (redbelly tilapia)	Eradication	Swan River				Arthington et al (1999) Lintermans (2004)
Perca fluviatilis (redfin perch)	Control	Phillips Creek Reservoir Nov 2003 (draining, destocking), Jan 2004 (draining, destocking), Mar 2005 (Marron restocking)	Draining of dam, crayfish traps, commercial crab traps, gill nets, seine nets and via manual scooping. Restocking with native marron	925 redfin removed from Phillips Creek Reservoir		Beatty and Morgan (2005)
Perca fluviatilis (redfin perch) and *Gambusia holbrooki* (eastern gambusia)	Eradication	Waroona Dam (Lake Navarino) 2003	Seining, explosives and draining	Unsuccessful		ASFB (2003a) Molony et al (2005)
Puntius conchonius (rosy barb)	Eradication	Jingarmup Brook near Eagle Bay				ASFB (2007b)
Cherax destructor (common yabby), *Gambusia holbrooki* (eastern gambusia), *Perca fluviatilis* (redfin perch), *Salmo trutta* (brown trout), ***Oncorhynchus mykiss*** (rainbow trout)	Eradication	Water storages including Phillips Creek Reservoir, Pinwernying Dam, Bottle Creek Reservoir, Churchman Brook Dam and Waroona Dam (Lake Navarino) 2003–2004	Draining of dams	Successful		ASFB (2005a)
Cherax destructor (common yabby) and ***Carassius auratus*** (goldfish)	Control	Housing estate wetland that flows into a tributary of the Margaret River	Fyke netting			ASFB (2007b)
Most states and territories Various species, mainly carp	Control	Various locations and dates	Line-fishing, for example, carp busters community days	Short term reduction in numbers, fosters community awareness		

3.10 Key conclusions

Legislation and agency roles

- Legislation and terminology directly relating to alien freshwater fish management needs to be consistent across Australia.
- The intended incorporation of the National Noxious Fish Species List into fisheries regulations across Australia is an important step in addressing inconsistency across jurisdictions.
- Clarification is required nationally and within each state and territory regarding specific roles and responsibilities of agencies in the event of alien fish incursions.

Rapid response procedures

- Emergency responses for alien freshwater fish incursions are generally managed by individual state and territories on an ad hoc basis. Exceptions include Queensland, where the Queensland Noxious Fish Response Plan is implemented, and the Northern Territory and New South Wales, which follow generic response procedures established for species incursions.
- The development of emergency response arrangements for freshwater fish incursions should align with current national initiatives where possible, including the national project underway to harmonise Australia's biosecurity emergency response arrangements and approaches in other biosecurity sectors, for example, disease, plant pests, marine pests.
- Once emergency response arrangements for freshwater fish incursions are developed, scenario testing using desktop and field based trials should be undertaken to identify outstanding issues and any required modifications.

Management plans and strategies

- There are various national, state and territory strategies and policies which deal with pest animals, ornamental fish, fish translocation, recreational fishing and biosecurity.
- A number of states and territories have pest management strategies that encompass pest fish. The Murray–Darling Basin Authority is currently developing a 'MDB Alien Fish Plan' to guide management of alien freshwater fish in states and territories within the MDB.

Surveillance

- The only active surveillance programs specifically targeting alien fish species are Queensland's Vulnerable Catchments Program and Tasmania's Lakes Crescent and Sorell Carp Management Program.
- There are fish survey and monitoring programs throughout Australia, ranging from broad-scale programs (eg Sustainable Rivers Audit) to programs focusing on specific issues, species and sites. There is varying potential for these programs to provide ad hoc information on new fish incursions.

- The development of a national onground surveillance program could assist in rapid detection of alien fish incursions and provide valuable baseline information on alien species distributions.

Community education

- There is no national community education program targeting alien fish species. Most states and territories have specific online information and other publications regarding particular pest fish and related issues, such as prevention of dumping of ornamental fish.
- The development of a national education program specifically for alien fish would be a valuable tool in reducing the risk of new alien freshwater fish incursions and the spread of established alien freshwater fish. Key messages would include the need to prevent, identify and report alien fish incursions.

Reporting systems for alien fish incursions

- There is no national reporting system for alien fish incursions. State and territory provisions vary but generally it is via a phone hotline. Reporting systems need to be well advertised, accessible and user-friendly.
- A centralised database to incorporate data on alien fish incursions could assist in highlighting new incursions, range expansions and improve planning by drawing attention to catchments at risk from invasion.

Risk assessment

- There is no universal national risk assessment procedure for determining whether to respond to an alien freshwater fish incursion and the priority of response.
- A standardised national risk assessment procedure is required that considers the social, economic and environmental impacts of the alien freshwater fish, as well as other factors such as; community and political support for response, availability of human resources and equipment, and cost/benefit of response. This risk assessment procedure would be applied to identify high risk alien freshwater fish species of national significance.

Management methods

- There are options available for eradication and control. Examples include physical removal, chemical methods, habitat manipulations and biological control. Each option has advantages and disadvantages.
- Research on new eradication and control techniques should be undertaken to add to the options already available.
- The focus and scale of management effort to eradicate and control alien fish species varies between states and territories.
- Well known and widespread species, and those of greatest concern, have received the greatest attention.

- Eradication is the initial intention of many exercises.
- Eradication has been achieved in few situations, highlighting the difficulty of eliminating alien freshwater fish species once they are introduced and the importance of prevention.
- The majority of previous eradication exercises have involved rotenone application.
- The majority of control exercises have used a combination of techniques such as electrofishing, netting, screening and water manipulation.
- Documentation of eradication and control programs is increasing, although the extent of documentation is very variable in most aspects, including methodology, results and long-term monitoring.
- Consistent documentation is needed for all eradication and control programs.
- A centralised database would enable the collation, analysis and interpretation of eradication and control programs, as well as facilitating dissemination of information for educational purposes.
- A centralised decision support program would provide easily accessible information to responsible agencies concerning options for eradication and control of alien fish, advantages and disadvantages of various options, and issues that should be considered.
- Suitable monitoring programs are an essential component of any eradication and control program to assess their effectiveness and the recovery of native fish communities.

4. Review of international alien freshwater fish containment methods

An important aspect of alien freshwater fish management is limiting their spread to a defined geographical area (containment) or preventing their entry into a defined geographical area (exclusion). Containment and exclusion are critical actions in a rapid response to new incursions of alien freshwater fish and in the ongoing management of established alien freshwater fish populations. Effective containment and exclusion reduces the geographical area requiring subsequent management, thus reducing associated management costs and resources and limiting the scale of potential adverse environmental, social and economic impact. Often containment and exclusion methods are integrated with eradication and control programs.

The application of a barrier is required to contain or exclude alien freshwater fish. Natural biogeographic barriers, including waterfalls and cascades, catchment divides, major mountain ranges and oceans, restrict the movement of freshwater fish (Rahel 2007). Artificial structures such as dams, weirs, floodgates and waterway crossings (eg culverts, causeways, roads and bridges) may also disrupt fish movement. These types of barriers have been extensively reported in Europe, North America and Australia (Thorncraft and Harris 2000, Rivinoja et al 2001, Quinn and Kwak 2003, Barrett et al 2008). Barriers may be purposely designed and installed to contain or exclude freshwater fish. They are commonly categorised into physical or behavioural barriers. Physical barriers physically obstruct fish passage. Examples include rotating drum screens, travelling screens, vertical drops and barrier nets. Behavioural barriers involve the application of an external stimulus to elicit fish movement in a desired direction. Light barriers, sound deterrents, electrical barriers, air bubble curtains, hydrodynamic louvre screens and combinations of these systems are examples of behavioural barriers.

In all scenarios, successful fish containment and exclusion relies on:

- the fish detecting the barrier and responding to it as intended
- the ability of individual fish to overcome the water velocity and change their orientation
- the absence of escape routes (Turnpenny et al 1998).

One challenge for alien freshwater fish management is that a key aspect of native fish management focuses on overcoming barriers to fish migration. Barriers impeding native fish passage are a key threat to native fish populations because many native fish species require migration to complete their life history, gain access to spawning, feeding and refuge habitat, and maximise their relative fitness and adaptability to change (Barrett et al 2008). Impeded native fish dispersal creates fragmented fish populations and communities and may result in local extinctions above barriers and reduced populations downstream (Barrett et al 2008). Consequently many developed countries have legislation to protect and provide fish passage, and undertake programs to remove or modify existing artificial barriers to facilitate native fish passage and protect fish passage around water diversion structures.

Removing or modifying existing artificial barriers creates a dilemma because the dispersal of alien fish as well as native fish is facilitated. In the USA and Europe there has been extensive research and development on different barriers to prevent fish entering water abstraction intakes. These barriers may be suitable for containing or excluding alien freshwater fish.

Various physical and behavioural barriers designed to protect fish at water abstraction intakes have been reviewed by several authors (Turnpenny et al 1998, DWA 2006, Jamieson et al 2007). Coutant (2001) provides examples of their application. There are no extensive reviews on the use of barriers in Australia or guidelines for their application. Knight (2008) provides some background on barriers applied previously in Australia for alien freshwater fish exclusion when reviewing suitable barriers for redfin perch exclusion within the Hawkesbury–Nepean catchment.

The following section briefly describes a selection of barriers that have potential for use in alien freshwater fish containment and exclusion. Characteristics of each barrier option are summarised, and examples of their application are provided. Finally, considerations for fish containment or exclusion are discussed, such as knowledge of species biology and fish barrier design.

4.1 Physical barriers

4.1.1 Barrier screens

Flat panel screens

Flat panel screens consist of one or more mesh screen panels inserted vertically into a slot attached to a solid supporting structure such as a culvert (Turnpenny et al 1998, O'Keefe and Turnpenny 2005, DWA 2006). The mesh screens can be made of various materials, including stainless steel and plastic, and are available in a variety of mesh aperture sizes. Flat panel screens operate under all flow conditions. They are prone to debris loading and therefore require frequent maintenance to remove debris and uphold fittings and seals. Debris loading may be reduced by placing a coarser trash rack in front of the mesh screen. Alternatively, the screen may be constructed to allow it to pivot so debris can be backwashed off, or angled so trash accumulates on one side, or a mechanical screen cleaner may be applied, with a consequent increase in capital and operating costs.

Wedge-wire screens

Wedge-wire screens consist of wedge-shaped stainless steel bars set side by side to form a screen. The broad side of the bars form the screen surface facing the flow and presents a smooth surface which significantly reduces the risk of injuries to fish. Because of the wedge shape of the bar, the spacing between bars widens and allows debris to more readily pass through than mesh screening materials. The ability to space bars closely together creates a fine screen capable of stopping smaller fish (DWA 2006), but this increases costs and debris loads. Like flat panel screens, wedge-wire screens are fixed to a support structure. Regular maintenance is required to clean the screen and repair seals.

4.1.2 Rotating drum screens

Rotating drum screens consist of a cylindrical shaped frame covered in a mesh screen (O'Keefe and Turnpenny 2005, DWA 2006, Jamieson et al 2007). The frame is fixed to a structure and set perpendicular to the flow, with the axis of the drum orientated horizontally. A single drum or a series of drums placed end to end may be set. The drums rotate continuously in the direction of downstream flow. Debris passes over the top of the drum and is washed downstream. For effective screening and debris handling, it is recommended that the drum screens operate at depths that are 65–85% of their diameter (Washington Department of Fish and Wildlife 2000). Maintenance is required to ensure that all moving parts are functional and that seals at the bottom and sides of the drum are intact. The support structure design may allow the drum to be lifted out of the water for easy maintenance.

Drum screens are considered effective for smaller applications at locations where the water level is stable. Their self-cleaning and excellent debris handling ability is a great advantage, but to achieve this, a continuous rotation of the drum is required. Drum screens are expensive to construct and install, but have low maintenance costs and are relatively economical to operate.

4.1.3 Rotating travelling screens

Travelling screens consist of a mesh screen belt made from flexible plastic perforated plates, wire or grid materials, which rotates vertically between two drums or rollers (O'Keefe and Turnpenny 2005, DWA 2006, Jamieson et al 2007). One drum is located above the water surface, while an opposing drum is submerged slightly above the sediment surface. A drive mechanism turns the top drum thus rotating the screen. The screen is fixed vertically or on a slight incline within a solid supporting structure that spans the water channel.

Like drum screens, travelling screens have low debris loading because debris is lifted over the top of the screen and washed away by flow. Maintenance is required to ensure that all moving parts are functional and that seals at the bottom and sides of the screen are intact. Sediment accumulation near the submerged drum may increase maintenance. Unlike drum screens, travelling screens can operate effectively at various water depths.

4.1.4 Barrier nets or fences

Barrier nets are mesh nets deployed to exclude fish from a selected area (O'Keefe and Turnpenny 2005, DWA 2006). For example, they can be deployed across the channel width to prevent upstream or downstream movement of fish, or deployed in a manner that excludes access to selected habitat. The net mesh size must be selected to block the passage of the target species (of all sizes and life stages) but not trap them, as this would likely damage the net.

It is important to study the physical conditions of the selected location for the barrier net prior to its deployment, to minimise maintenance while maximising effectiveness (Dixon 2006). The bottom substrate should be assessed to ensure that the base of the net will be flush with the substrate surface to prevent opportunities for fish escape, that is, check for rocks, logs, sand, clay, and so on. The water depth should be generally uniform. Flow direction, magnitude and turbulence should be observed, and where possible the historical water level data should be evaluated to gain an idea of its potential fluctuation. Debris loading conditions should also be considered as this will influence the frequency of debris removal and net repair.

Barrier nets are relatively cheap to construct and easy to deploy, but cost and ease increases with the size of the barrier. Regular maintenance is required to remove debris and repair the net, although the maintenance frequency varies and more maintenance is likely after periods of high flow. If the net is lifted from the water for maintenance, another net may have to be positioned to prevent fish passage.

The length of barrier nets can be quite variable and depends on site conditions and exclusion objectives. Stober et al (1983) reported on the use of a 1 km long barrier net to prevent the kokanee (*Oncorhynchus nerka*) entering the main irrigation canal intake of Banks Lake in Washington, USA. Using this method, fish entrapment was reduced from 64% to 10%.

In Australia, barrier nets have been successfully applied in Lake Crescent and Lake Sorell in Tasmania to control common carp recruitment by preventing access to spawning habitat. A modified version of a barrier net (shade-cloth fencing) was installed to prevent common carp movement in the Lachlan River demonstration reach, but this was foiled by an unexpected increase in water level (Gehrke 2008). In a similar case reported by Stuart and Jones (2002), high flows inundated a wire mesh barrier for carp in Barmah Lake, Victoria. In New Zealand stacked sand bags have been employed to create a barrier fence during efforts to eradicate western gambusia (*Gambusia affinis*) (Elkington and Maley 2005).

4.1.5 Floating curtains

Floating curtains consist of nylon strips or metal chains suspended side by side from bridges or pontoons set perpendicular to the water flow (Therrien and Bourgeois 2000, DWA 2006). It is uncertain whether floating curtains deter fish by the noise generated by the strips or chains, or by the physical effect of the curtain, or both. Floating curtains are more effective in slower flow conditions because excessive movement of the curtain creates opportunities for fish passage. The effectiveness of floating curtains is enhanced when they are illuminated, suggesting that they may also be a visual deterrent. Floating curtains require occasional maintenance, depending on levels of debris loading and repair. Taft (1986) reported that 71% of salmonids were deterred by chain curtains under laboratory conditions. Unfortunately these results could not be replicated in the field (DWA 2006). Floating curtains are not often installed, probably because of their poor efficiency and maintenance needs (DWA 2006).

4.1.6 Vertical drop barriers

Vertical drop barriers create a hydraulic drop over the structure that is higher than the jumping ability of the targeted fish species, thus preventing their upstream movement. Vertical drop barriers are generally very effective fish barriers. They can be constructed cheaply from various materials, for example, steel, rocks, wood and concrete. They should be designed so that the spatial geometry of the downstream pool below the barrier deters staging of fish prior to jumping (FishPro 2004). It is also important to ensure that water is directed over the centre of the barrier to prevent the barrier being eroded near the bank edges.

Vertical drop barriers have been applied in the USA to protect populations of native cutthroat trout from alien brook trout. (www.wildfish.montana.edu/projects/barrier/browse.asp).

In Australia, Lintermans and Raadik (2003) describe the application of vertical drop barriers to protect native *Galaxias* species from introduced rainbow trout and brown trout. Vertical drop barriers have also been used in Tasmania, Australia, to exclude salmonids from native Swan galaxias habitat (W Fulton, personal communication, 2008).

4.1.7 Traps and cages

Traps and cages are commonly applied in combination with physical barriers, and may be portable or permanent. Permanent types are generally made from steel or concrete. They are either rectangular or square and are built into a permanent barrier or fishway. Portable types are made from lighter, durable materials, in a design similar to their permanent counterparts. Portable types are often applied during the migration period of the targeted species and removed afterwards.

The cost of traps and cages varies greatly with their design and their construction materials. Their design and fit may influence whether they are selective for a targeted species or fish size, and their effectiveness. Regular maintenance is required to remove captured fish and debris and conduct repairs. Some issues surrounding the use of traps and cages include public concerns over the method of capture (animal ethics), fish disposal options, and the capture of non-target species. The Williams' carp separation cage, the carp finger pushing trap and sea lamprey traps are examples of traps and cages that are applied, or could be applied, in combination with physical barriers.

The Williams' carp separation cage

The Williams' carp separation cage is designed specifically to trap adult carp by taking advantage of their pronounced jumping behaviour (Stuart et al 2006). The cage is separated into two compartments by a jumping baffle. Fish enter the cage through a funnel into a holding compartment, and face the jumping baffle. Carp jump over the baffle into the second compartment, from which they cannot escape. Fish that do not jump the baffle are released periodically through an automatically opening false floor leading to an escape exit that passes underneath the second compartment. The cage must be raised to remove the captured carp. The cage was designed to be set into fishways, wetland entrances, irrigation channels, or other narrow channels where fish movement is bottlenecked.

Carp finger pushing trap

The carp finger pushing trap is a relatively new device that traps carp by exploiting their innate behaviour to push underneath barriers (Thwaites et al 2007). It is a modification of the Williams' carp separation cage. Fish enter the cage through a funnel into a holding compartment, then can either jump over the baffle or push through a series of hinged, downward pointing and weighted steel fingers into separate holding compartments. To remove fish from the holding compartment, as well as captured carp from the other compartments, the trap is periodically, mechanically raised. The cage is designed to be incorporated primarily into wetland inlets to capture carp migrating into wetland habitats to spawn. Initial field trials of the carp finger pushing cage applied at Banrock Station, South Australia, have proven this method to be highly successful at capturing carp. The replacement of mesh screens at wetland entrances with carp finger pushing traps during the peak migration period of carp has been suggested.

Sea lamprey traps

In the USA, sea lamprey traps are applied to capture adult sea lamprey migrating upstream to spawn (Morris and Maitland 1987, Johnson 1988, Mattes 2008). Traps are strategically placed in the stream channel where migrating adult sea lamprey densities are high, for example at waterfalls and along the face of weirs. Sea lamprey traps can be portable or permanent. Portable traps are strong wire mesh box traps with a cone-shaped net entrance. Wing extensions on either side of the trap block the channel width and guide sea lampreys to the trap entrance. Permanent sea lamprey traps are generally made from concrete and are built into dams or weir structures. Sea lampreys captured in portable or permanent traps are removed at regular intervals. Occasionally captured male sea lampreys are used for a sterile male release program. Recent research has shown that the effectiveness of the traps can be enhanced by using pheromones to attract migrating sea lampreys (Johnson et al 2005a, Wagner et al 2006).

4.2 Behavioural barriers

Behavioural barriers involve the application of an external stimulus to attract or deter fish and induce fish movement in a desired direction. Behavioural barriers take advantage of the highly advanced and adapted sensory systems of fish that function to detect and respond to various external stimuli, including sound, light, temperature, taste and odour, pressure change, touch, water flow and electrical fields. To be effective the external stimulus must be strong enough to cause the fish to react and actively move away, and the response to the stimulus must be sustained and not adaptive.

In all behavioural barriers the sensitivity of fish and their ability to respond to external stimuli differs between species and lifestages. Environmental factors, such as turbidity, water temperature, flow and depth, can also influence the transmission of stimuli and the ability of fish to detect stimuli.

Behavioural barriers are often applied when physical barriers are impractical because of, for example, excessive debris loading, location accessibility or cost considerations. Occasionally behavioural barriers are operated in tandem ('multisensory systems') or supplement physical barriers ('hybrid systems').

4.2.1 Sound barriers

The use of underwater sound to modify fish movement has been studied for about 50 years (Carlson and Popper 1997). Acoustic fish barriers can be categorised according to emission frequencies: infrasound (below 20 Hz), audible range (20–20,000 Hz), and ultrasound (above 20,000 Hz) (Turnpenny et al 1998). Sound barriers typically exploit hearing sensitivity in the 20 to 500 Hz range (Turnpenny et al 1998, FishPro 2004). Lambert et al (1997) describes several key factors influencing successful fish deflection, including that the nature of the signal should be repellent to fish, the sound should be detectable above ambient noise, and the water velocity should allow fish response and movement.

Audible frequency systems

Acoustic barriers using audible frequencies are being applied using one of two methods, a sound projector array or a Bio-Acoustic Fish Fence.

Sound projector array

A sound projector array (SPA) comprises of an electronic signal generator to create a sweeping range of low frequency audible sound, generally between 20 and 500 Hz and repeated four to five times per second (Turnpenny et al 1998, DWA 2006). The sound is amplified using one or more power amplifiers and projected underwater via several underwater sound projectors (Turnpenny et al 1998, DWA 2006). The sound projectors can be suspended at various water depths however, a maximum spacing of 3m between sound projectors is recommended (Turnpenny et al 1998). Prior to SPA installation at a known location, an acoustic model can be used to predict the resulting sound pressure to detect sound reflections which create potential passable points in the system (Turnpenny et al 1998). SPA systems require at least annual maintenance to ensure optimum performance. All components require checking, cleaning, and repair. Initial capital costs are low and running costs are generally low because power requirements are minimal (Turnpenny et al 1998).

Bio-Acoustic Fish Fence

The Bio-Acoustic Fish Fence (BAFF) uses a combination of a sound source and an air bubble curtain, causing sound to propagate within the rising air bubbles (Fish Guidance Systems Ltd, http://www.fish-guide.com/). The BAFF is deployed in the same manner as an air bubble curtain, but the sound greatly enhances its effectiveness (Turnpenny et al 1998, DWA 2006). The sound signals generated are similar to the SPA, varying between 20 and 500 Hz and using frequency or amplitude sweeps (Turnpenny et al 1998). Costs and maintenance requirements for the BAFF are similar to those mentioned for the SPA and air bubble curtains.

Infrasound frequency systems

The ability of fish to detect infrasound (sound below audible levels) was only discovered in the 1980s (Sand and Karlsen 1986, Karlsen and Sand 1991). The use of infrasound technology to create fish barriers is being studied but requires further development to reach a practical commercial stage. In laboratory trials, infrasound has produced flight or avoidance responses in juvenile Atlantic salmon (*Salmo salar*) (Knudsen et al 1992) and in juvenile chinook salmon and rainbow trout (Knudsen et al 1997). Knudsen et al (1994) demonstrated that migrating Atlantic salmon were completely deterred from an infrasound source placed in a small river. In laboratory and field trials, Sand et al (2000) reported a highly significant response of European silver eels (*Anguilla anguilla*) away from the infrasound source.

Ultrasound frequency systems

Generally fish are not sensitive to ultrasound (sound above audible levels) (Turnpenny et al 1998) and therefore ultrasound frequency systems do not receive much attention. Carlson (1995) and Taft et al (1999) reported on the application of ultrasound transmitters in the USA to repel clupeid fish (shad and herring species) around water intake structures.

4.2.2 Light barriers

Fish can see light of approximately 400–700 nm wavelength (DWA 2006). The sensitivity and response of different species to light varies because they often have different eye structures (Popper and Carlson 1998). Likewise, vision ability and response also differs with developmental stage. Fish respond to light by moving towards (positive phototaxis) or away from (negative phototaxis) light sources (DWA 2006).

Light barriers involve the use of lamps to emit light to attract or deter fish. Several lights are distributed across a length of cable submerged in the water. Underwater lighting reduces the reflective loss at the water surface and minimises surrounding light pollution (Turnpenny et al 1998). Various lamp types can be applied, such as strobe, mercury vapour, sodium, fluorescent or filament lights. Lamp types differ in maximum light intensity and emission (continuous or discontinuous (flashing) spectrum) (DWA 2006).

Generally continuous light radiation is considered more effective than discontinuous light sources (Turnpenny et al 1998, DWA 2006). However, the efficiency of light barriers is also influenced by water turbidity and ambient light conditions. Light barriers are cheap to install but have high maintenance costs because they require frequent cleaning and occasional globe renewal. The response varies with species and life stage, and fish can become acclimatised to the stimulus.

4.2.3 Electrical barriers

Electrical barriers are one of the oldest types of behavioural barriers (DWA 2006). The traditional design consists of a vertical array of electrodes submerged in the water, set 15–30 cm apart and of alternating polarity. When electrical current is applied a local electrical field is created and evokes a reaction in exposed fish. A greater voltage is needed to cause a response in smaller fish. Many applications of this traditional design have been decommissioned, largely because fish were becoming narcotised too quickly, resulting in fish death (Turnpenny et al 1998, DWA 2006).

More recently, a new electrical barrier design has been created called the Graduated Field Fish Barrier (GFFB) (Smith-Root no date, O'Keefe and Turnpenny 2005). The GFFB uses a series of pulse generators to apply short pulses of direct current through a parallel array of electrodes across the river bottom. Direct current poses low risk to fish as it is less damaging than alternating current. The most effective electrical field is produced when the potential difference runs from head to tail along the fish, which means it must be parallel to the water flow because fish swim instinctively with their heads into the flow. When the fish swims across the electric field it receives almost no electric shock depending on the field strength. The main advantage of the GFFB design is that each pulse generator is adjusted to produce increasing voltage between successive electrode pairs, thus creating a graduated electric field. As fish swim into the graduated field they feel an increasingly unpleasant sensation. Larger fish receive more head-to-tail voltage and are affected at an earlier stage than smaller fish. When the sensation is too intense, fish turn perpendicular to the field and are swept away from the increasing electric field.

Smith-Root designs and manufactures several electrical barrier models applicable for various situations, such as portable electrical arrays, culvert electrical barriers, and a louvred intake electrical barrier (Smith-Root, no date). In 2000 Smith-Root produced a new series of pulse generators for more effective use in deeper waters and in wider channels. The operating system was also updated to complement the higher power requirements and associated monitoring demands.

Passavant-Geiger, a German company, also markets an electrical fish barrier known as the Geiger Fipro-Fimat Fish Repelling Device (www.passavant-geiger.de). It utilises a random generator to produce various pulse frequencies and sequences to deflect fish and prevent their habituation. The system repels fish within 5–10 m of the main electrodes. No further information could be found on its application, effectiveness, safety or installation locations.

Overall, the efficiency of electrical barriers is influenced by the chemical and physical properties of water. Their effect on fish is species and size specific, and depends on individual fish health and swimming ability. Installation costs are expensive and frequent maintenance is required to remove accumulated debris and intermittently replace electrodes. Safety of personnel, the public and animals is of concern. The overall reliability and suitability of electrical barriers continues to be debated (Smith-Root no date, Therrien and Bourgeois 2000, DWA 2006).

4.2.4 Air bubble curtain

Air bubble curtains are one of the most basic forms of behavioural barriers. An air bubble curtain is produced by pumping compressed air through a pipe with strategically positioned ejection nozzles or perforations. The pipe is secured to the bottom of the water body. The rising curtain of air bubbles evokes an avoidance reaction in fish, believed to be caused by a combination of visual, sound, current and touch stimuli (O'Keeffe and Turnpenny 2005, DWA 2006).

Several investigations have been carried out on the efficiency of air bubble curtains, with many producing inconclusive results. Solomon (1992) cited fish deflection efficiencies for air bubble curtains in laboratory tests of 98%, but dropping to between 51% and 80% in darkness or turbid waters. Bramsaea et al (1942) found that common carp and pike (*Esox lucius*) were deflected by the air bubble curtain but rainbow trout were not deterred and passed freely. Experiments conducted on a 70 m long air bubble curtain placed across the water intake at Heysham Power Station (Lancashire UK) resulted in a significant reduction (37%) in fish entrapment (Turnpenny 1993). Hadderingh et al (1988) noted an initial deterrent response by juvenile perch to an air bubble curtain, but they soon became habituated and no longer responded.

It is recommended that air bubble curtains are constructed from non-corrosive materials such as galvanised iron or PVC (Turnpenny et al 1998). Other design considerations include the size and spacing of air ducts, the air pressure applied, the volume of air discharge, the curtain's position in relation to the bank (Turnpenny et al 1998), flow velocity, water depth (maximum 3 m), bed stability and illumination (O'Keeffe and Turnpenny 2005). Common problems include blockage of the air ducts and disruption of the air curtain by water turbulence.

Although costs associated with installation and maintenance of air bubble curtains are generally low, they increase with increasing curtain length and water depth. Overall, air bubble curtains are commonly considered unreliable because of poor efficiency.

4.2.5 Water jet curtain

A water jet curtain operates in a similar fashion to an air bubble curtain except pressurised water is pumped through the pipe instead of air. The water jets deter fish by causing strong flow or turbulence. Although water jet curtains achieve high efficiencies, extensive maintenance and operational costs because of clogging jets and their demand for water and power often renders them unsuitable (DWA 2006).

4.2.6 Hydrodynamic louvre screens

Hydrodynamic louvre screens were first developed in the 1950s (O'Keefe and Turnpenny 2005). They consist of a panel angled between 11° and 40° diagonally to flow, with slats attached perpendicular to flow and spaced 2.5–30 cm apart (Therrien and Bourgeois 2000). Although they are a physical structure, hydrodynamic louvre screens deter fish by generating flow turbulence, resulting in a behavioural response. Consistent high or medium water velocity is required to achieve efficiency. The maintenance requirements are low, with debris loading of primary concern. Capital costs depend upon the materials used to create the structure. Although they offer high deflection efficiency under favourable conditions (Turnpenny et al 1998, Therrien and Bourgeois 2000, Jamieson et al 2007), hydrodynamic louvre screens are not commonly used in the UK and Europe, unlike in North America (Turnpenny et al 1998), and are considered unviable in certain locations (FishPro 2004).

4.2.7 Pheromone barriers

Sorensen and Stacey (2004) defined a pheromone as 'an odour or mixture of odorous substances, released by an individual (the sender) and evoking in conspecifics (the receivers) adaptive, specific and species-typical response(s), the expression of which need not require prior experience or learning'. Pheromone excretions by fish broadly function as anti-predation and alarm cues, non-reproductive aggregants or reproductive aggregants and stimulants (Sorensen and Stacey 2004). The development and deployment of selective fish pheromones holds promise as a tool for preventing fish population expansion and for population control (Sorensen and Hoye 2007, Burnard et al 2008). Their application might be applied to disrupt fish movement and migration patterns, disrupt fish reproductive success, repel individuals, facilitate fish trapping and assess population size and distribution (Sorensen and Stacey 2004).

However, the use of pheromones to guide fish movement is still a relatively new concept, both in Australia and overseas, and requires further research. To manage a targeted fish species using pheromones, its various pheromones must be identified and characterised, and their function determined. This can be a long and difficult process. Laboratory and field trials would be required to test their effectiveness and persistence. The most renowned successful application of pheromones for fish control has been in the Great Lakes sea lamprey management program. Traps baited with spermiating males (as sex-pheromone attractants) have been shown to be highly effective at capturing ovulating females (Johnson et al 2005a). Likewise, in field conditions, Wagner et al (2006) demonstrated that 90% of actively migrating sea lampreys could be drawn into streams treated with a migratory pheromone. Furthermore, they found that sea lampreys were three times more likely to enter a trap applied in combination with a barrier when the trap was baited with a pheromone.

Table 17 highlights characteristics of various physical and behavioural barriers. Factors considered include their documented optimum exclusion efficiency, whether they affect all species and lifestages, whether they are navigational hazards (for fish or boats), the flow range required for their operation, construction and installation difficulties, operation and maintenance requirements, safety concerns, power needs and cost. References documenting trials or the use of specific barriers are provided, including some that focus on alien freshwater fish containment or exclusion.

Physical barriers generally provide greater optimum exclusion efficiency compared to behavioural barriers, but they affect all fish species, are more expensive and more difficult to construct and install, and have demanding operational and maintenance requirements. Electrical barriers are the most commonly applied method of restricting alien freshwater fish movement, particularly in the USA.

Table 17. Characteristics of various physical and behavioural fish barriers.

Physical barriers
Screens (eg flat-panel screens, wedge-wire screens) • About 100% optimum exclusion efficiency • Excessive debris loads cause loss in efficiency • Loss of efficiency during flooding • All fish species excluded, lifestage excluded varies with mesh size • Restricts movement of non-target species • Restricts boating navigation • Operates in all flow conditions • Requires construction of a supporting structure; proper fit important for effectiveness • Regular maintenance required to remove debris and maintain seals • Automated cleaning reduces maintenance • Low public safety concerns • No power required for operation • Medium capital costs Examples: Aitken et al (1966), Solomon (1992), Inland Fisheries Service (2004), K. Bishop, pers comm. (2008)
Rotating drum screen • About 95–100% optimum exclusion efficiency • Excessive debris loads cause loss in efficiency • All fish species excluded, lifestage excluded varies with mesh size • Restricts movement of non-target species • Operates in all flow conditions • Loss of efficiency during flooding • Requires construction of a supporting structure; proper fit important for effectiveness • Regular maintenance required especially for moving parts (eg bearings, drive chains) and seals • Continuous rotation required for debris removal and self-cleaning • Suitable in regulated and stable water surface elevations • Low public safety concerns • Restricts boating navigation • No power required for operation • High capital costs Example: Whalls et al (1957)
Rotating travel screen • About 95–100% optimum exclusion efficiency • Excessive debris loads cause loss in efficiency • All fish species excluded, lifestage excluded varies with mesh size • Restricts movement of non-target species • Operates in all flow conditions (0.7 m^3/s to 21 m^3/s) • Loss of efficiency during flooding • Requires construction of a supporting structure; proper fit important for effectiveness • Regular maintenance required especially for moving parts (eg bearings, drive chains) and seals • Continuous rotation required for debris removal and self-cleaning • Operation at variable water depths • Low public safety concerns

Table 17 (continued)

Rotating travel screen (continued)

- Restricts boating navigation
- No power required for operation
- High capital costs, especially for larger applications

Examples: Gessel et al (1991), Hartvich et al (2008)

Nets and fences

- Fish species excluded dependent on fish size, lifestage and mesh size
- May restrict movement of non-target species
- Operates in all flow conditions
- Loss of efficiency during flooding
- Nets relatively easy to construct and deploy
- May require construction of supporting structure if mechanically raising netting for cleaning/repair
- Regular maintenance required to remove biofouling and debris and repair any net damage
- Low public safety concerns
- Some impact on boating navigation
- No power required for operation
- Capital costs vary with size of application

Examples: Stober et al (1983), Inland Fisheries Service (2004)

Floating curtains (eg chains, nylon strips)

- Low optimum efficiency
- Fish tend to pass through curtains that are not illuminated
- Light, turbidity and flow influence effectiveness
- Possible exclusion of all species and lifestages, including non-target species
- Loss of efficiency during flooding
- Operates best under low flow; effectiveness declines with increasing water velocity
- Medium to high construction and installation difficulty; requires construction of supporting structure
- Low maintenance requirements, largely debris removal
- Low public safety concerns
- Some impact on boating navigation
- No power required for operation
- Capital costs vary with design

Vertical drop

- About 95–100% optimum exclusion efficiency
- Effectiveness site dependent
- Requires knowledge on the target species' jumping ability
- Most fish species and lifestages excluded
- May restrict movement of non-target species
- Restricts boating navigation
- Operates under all flow conditions
- Loss of efficiency during flooding
- Relatively easy to construct; various materials can be used to create the vertical drop
- Low maintenance requirements
- Low public safety concerns
- No power required for operation
- Capital costs vary with design, material choice and size

Examples: Kelso et al (1998), Lintermans and Raadik (2003)

Table 17 (continued)

Traps and cages (applied in combination with a physical barrier)

- Efficiency varies with trap and cage design, and species and lifestage
- Restricts movement of all species, including non-target species
- Restricts boating navigation
- Suitable flow range varies depending upon cage/trap design (eg presence or absence of supporting structure)
- Requires construction or modification of supporting structure
- Regular maintenance to remove debris loading
- Regular removal and disposal of collected fish required
- High public concerns about animal ethics and welfare
- No power required for operation
- Capital costs vary with trap and cage design

Examples: Hunn and Young (1980), Johnson et al (2005), Stuart et al (2006), Wagner et al (2006), Thwaites et al (2007)

Behavioural barriers

Sound (SPA or BAFF)

- Effectiveness varies with ambient conditions/noise
- Optimum efficiency varies with the type of sound barrier applied (<50–90%)
- Fish exclusion efficiency varies depending on fish species, lifestage, size, swimming ability
- Exclusion is species and lifestage specific
- Effective at various flow ranges; BAFF™ air bubble screen loses efficiency in higher flow
- Easy to construct and install
- Occasional maintenance required; BAFF™ unclogging of jets and de-silting required after periods of inactivity
- Few public concerns
- Power required for operation
- Capital costs low

Examples: Nestler et al (1992), Katopodis et al (1994), Knudsen et al (1994), Ross et al (1996), Lambert et al (1997), Popper and Carlson (1998), Michaud and Taft (2000), Gibson and Myers (2002), Welton et al (2002), Maes et al (2004), Karlson et al (2004), Taylor et al (2005), Sonny et al (2006)

Light

- Effectiveness varies with natural light conditions and water turbidity
- Strobe light efficiency varies between 65–92%.
- Fish exclusion efficiency varies depending on fish species, lifestage, size, swimming ability
- Generally species and lifestage specific; minimal impact to non-target species
- Easy to construct and install
- Suitable for use in any stream independent of dimension, flow, current velocity.
- Regular cleaning of lamps required and periodical globe replacement
- Few public concerns
- Power required for operation
- Capital costs generally low, but vary with design and size

Examples: Patrick et al (1985), Nemeth and Anderson (1992), Fredricks et al (1996), Michaud and Taft (2000), Welton et al (2002), Johnson et al (2005b), Richards et al (2007), Hamel et al (2008)

Table 17 (continued)

Electrical

- Optimum exclusion efficiency about 90–99%
- Fish exclusion efficiency varies depending on fish species, lifestage, size, swimming ability
- Excludes target and non-target species
- Effective under all flow conditions
- Difficult to construct and install, for example, electrode installation in water
- May restrict boating navigation
- High operation and maintenance requirements, for example, safety, data storage, debris removal
- High public concerns, for example, potential harm to humans and local wildlife, animal ethics and staff OH&S
- Power required for operation
- High capital costs

Examples: McLain (1957), Stewart (1981), Palmisano and Burger (1988), Katopodis et al (1994), Verrill and Berry (1995), Barwick and Miller (1996), Maceina et al (1999), Swink (1999), Savino et al (2001), Clarkson (2004), Dawson et al (2006), Smith-Root Inc. (no date)

Air bubble curtain

- Optimum exclusion efficiency about 50–95%
- Fish exclusion efficiency varies depending on fish species, lifestage, size, swimming ability
- Excludes target and non-target species
- Low public safety concerns
- Effective in low flow conditions; not effective in high water velocity and turbulence
- Frequent maintenance required, for example, unclogging of jets, de-silting of submerged equipment
- Low capital costs
- Power required for operation

Examples: Stewart (1981), Patrick et al (1985), Liu and He (1988), Pavlov (1989), Solomon (1992), Turnpenny (1993), Michaud and Taft (2000)

Water jet curtain

- Optimum exclusion efficiency low
- Fish exclusion efficiency varies depending on fish species, lifestage, size, swimming ability
- Excludes target and non-target species
- Effective in low flow conditions; not effective in high water velocity and turbulence
- Frequent maintenance required, for example, unclogging of jets, de-silting of submerged equipment
- Low capital costs
- Power required for operation
- Low public safety concerns

Example: Taft (1986)

Hydrodynamic louvre screens

- Optimum exclusion efficiency about 86–97%
- Fish exclusion efficiency varies depending on fish species, lifestage, size, swimming ability
- Most suited to exclude larger, stronger swimming fish
- Excludes target and non-target species
- Flow range medium to high (7 m^3/s to 255 m^3/s)
- Moderate construction and installation difficulty
- Some public safety concerns
- May restrict boating navigation
- Large openings between slats allow passage of small debris and sediment, thus reducing cleaning frequency. Mechanical equipment required for cleaning

Table 17 (continued)

Hydrodynamic louvre screens (continued)

- Debris intertwined or embedded in louvres is difficult to remove and clean
- Louvres must be removed occasionally and scraped clean
- No power required for operation
- Capital cost varies depending on size of structure and materials used

Examples: Katopodis et al (1994), Karp et al (1995), Kynard and Buerkett (1997), Goosney (1997)

Pheromones

- Technology in development
- Optimum exclusion efficiency unknown
- May be species and lifestage specific; minimal impact on non-target species
- Often used in combination with traps and cages
- May be applicable in all flow conditions, however flow will influence extent of pheromone dispersal
- Pheromones difficult to develop; requires knowledge on pheromone characteristics and function
- Regular maintenance required to replenish pheromone supply
- When applied in conjunction with a trap, regular removal and disposal of captured fish is required
- No power required for operation
- Public safety concerns unknown; chemical use in water may be a concern, animal ethics
- Capital costs unknown; pheromones may be expensive to synthesise but only a small amount is needed

Examples: Johnson et al (2005a), Wagner et al (2006)

Sources: Turnpenny et al (1998), FishPro (2004), DWA (2006), Jamieson et al (2007).

4.3 Considerations for fish containment

4.3.1 A strategic approach to fish barrier technology in Australia

Despite the considerable number of studies on fish barrier design, their laboratory and field testing and their field application in the USA, parts of Europe and the UK, and New Zealand, there is little similar knowledge in Australia. So far there has been limited documentation of experiences applying barriers to contain alien species except in the USA, and most relates to electrical barriers.

Nonetheless, information learnt from international research and application of barriers to protect fish species at water intakes provides valuable fundamental knowledge on species response and barrier effectiveness which is relevant to alien freshwater fish containment.

The Australian experience of installing barriers is limited to screens and cages, primarily for common carp in South Australia, Victoria and Tasmania (Inland Fisheries Service 2004, Stuart et al 2006) and tilapia in Queensland (Greiner and Gregg 2008). Barrier nets have also been applied to restrict common carp movement in Tasmanian lakes (Inland Fisheries Service 2004). There has also been long term use of barriers in salmonid management in Tasmania, starting c. 1870 (W Fulton, personal communication, 2008), with more recent applications in Victoria and the ACT (Lintermans and Raadik 2003). The lack of other applications of barriers in alien fish management in Australia highlights that this is an area requiring further research to inform their potential use.

Controlled laboratory testing of various barrier technologies against alien fish species present in Australia is a priority. After setting the primary objectives, data can be collected concerning the potential impact of each barrier technology on non-target or native fish species, followed by subsequent field trials.

4.3.2 Knowledge of targeted fish species biology

Having a thorough understanding of the biology and behaviour of the targeted fish species to be contained is vital to ensure that the most suitable containment method is applied. A primary consideration when designing a fish barrier is an understanding of the species' sensitivity to ambient conditions and its swimming ability (Jamieson et al 2007).

Fish have highly developed sensory organs that are adapted to the different environments they occupy. Consequently, the senses of fish vary greatly between species. Sensory organs contain receptors that detect and receive stimuli from the ambient environment and convert them into biological signals, which are transmitted to the central nervous system, evoking a physical response (Helfman et al 1997). There are several types of fish sensory systems, including the photoreception system (visual), auditory system (hearing), olfactory system (smell), gustation system (taste), electrosensory system (detection of environmental electricity), and lateral line system (physical contact). Barriers take advantage of sensory systems by creating a change in ambient stimuli that is strong enough to be detected and reacted to by fish, resulting in their movement away from the barrier.

The swimming ability of fish will influence their ability to respond to ambient stimuli and will influence the effectiveness of a barrier (DWA 2006). Fish must be able to endure and move through the water perpendicularly to the barrier (approach velocity) and the water sweeping across the barrier (sweep velocity) to avoid being impinged or entrained on the barrier or swept downstream of the containment area. Fish swimming ability is influenced by several factors related to fish biology, physiology and environmental conditions, such as fish size, developmental stage, health, water temperature and dissolved oxygen.

4.3.3 **Barrier** design

To implement the most effective barrier option, the following factors should be considered.

Barrier location

To provide the best protection for native fish, the location of natural barriers should be identified and primarily utilised in the containment of alien freshwater fish species. Examples of such natural barriers include waterfalls and natural dry reaches that form during drought. However, these types of barriers have inherent limitations. For example, fish jumping performance and climbing ability largely influences the effectiveness of waterfalls as natural barriers. Also because of the transience of drought conditions and waterway connectivity, the longer term containment of alien freshwater fish by dry reaches is unpredictable but could be used opportunistically.

The use of existing artificial barriers such as weirs and road bridges may also be investigated as barrier options for alien freshwater fish incursions. If these barriers prove to be effective fish containment options, then utilising them would save resources spent on constructing and installing fish-specific barriers.

If is it decided to apply a fish barrier, the location of the barrier should reflect the occurrence of the alien freshwater fish species and also the objective of the application. For example, drum screens that inhibit the passage of all species could be prioritised for irrigation networks, which act as fish sinks. On the other hand, a species-specific barrier could be used in the main river channel and still allow passage of non-target organisms. Site-specific characteristics should also be considered, such as hydrology, habitat complexity, debris loading and the availability of electrical power. The remoteness of a site may make monitoring and maintenance difficult, but may also reduce deliberate or accidental human interference. Overall, the application of barrier technology should be reviewed on a case-by-case basis.

Barrier materials

Fish barriers may be constructed from various types of screening materials. Physical barriers are often made from woven wire mesh, perforated plates or profile bars. The aperture dimensions of the screens, such as mesh size and spacing between bars, will influence the size of fish being excluded and thus, the successful operation of the barrier. The smaller the target fish species or lifestage to be excluded, the smaller the mesh size and spacing that is required to ensure barrier effectiveness. Knowing the body dimensions of the smallest fish to be excluded (ie fish length, height, depth and maximum body width) is important for calculating the appropriate screen aperture dimensions (DWA 2006, Jamieson et al 2007). Differences in the weight, quality and cost of screening materials should also be considered in relation to the barrier application, durability and potential maintenance needs. DWA (2006) and Jamieson et al (2007) reviewed the minimum mesh sizes for screening materials for a number of fish species.

Likewise, for some behavioural barriers a consideration of the materials used is important for determining their cost, durability and maintenance needs. For example, PVC rather than metal piping is recommended for air bubble curtains and water jet curtains, to prevent corrosion problems (Turnpenny et al 1998). Also the various types of lamps used in light barriers differ in price and operational longevity, thus influencing ongoing costs and maintenance frequency.

Operation and maintenance

A key reason why only simple screen barriers have been applied previously in Australia may be the natural variability of rivers, with long droughts and occasional floods. The barrier technology not only needs to operate automatically in remote systems but must be resilient to floods. The operation and maintenance of barriers is a major consideration, particularly in remote areas. In many locations mains power supply is not available, which might limit the application of some barriers. Before selecting and constructing a barrier, an assessment of the likely debris and trash load is necessary, as well as an investigation of possible methods for mitigation. Barriers might require protection from trash by coarse debris screens, floating booms, automated self-cleaning or sweeping flows and trash pits. Regular maintenance is also an important component of barrier effectiveness, and these maintenance schedules need to identify the responsible authority and tasks. In many cases a considerable amount of effort will be required for barrier maintenance. Hence deploying a surveillance camera might be useful for remotely monitoring the barrier.

Behavioural barriers have not been studied in Australia and consequently their potential for application is largely unknown. Behavioural barriers have several advantages over physical barriers including potentially reduced maintenance, debris and water loss problems. In addition, behavioural barriers do not impede navigation. The disadvantage of behavioural barriers is that they are rarely highly effective.

Seasonal barrier application based on fish biology and hydrology

For some fish, application of barrier technology can be seasonal or even diurnal based on a thorough knowledge of fish biology. For example, large eels appear to migrate downstream at night and for their protection, barriers and spillway patterns can be altered to facilitate night passage while operating for hydro-power generation in the daytime (Carr and Whoriskey 2008).

For alien freshwater fish, such as common carp, installing barriers and modifying wetland inundation during the spring spawning season might reduce the spawning success of adult fish in wetlands. Similarly, sea lamprey traps operate during their annual migration period between April and July and are removed, where possible, at other times (Tuunainen et al 1980, Morris and Maitland 1987). Spawning of trout may be effectively controlled by installing barriers to prevent their upstream migration.

4.3.4 Permanent versus temporary fish barriers

The urgency to establish a fish barrier and the anticipated duration of a fish barrier application may influence the decision of which barrier method to employ.

Most of the physical barriers available, excluding barrier nets, cannot be rapidly deployed because extensive construction of supporting structures is required, in addition to the assembly and fitting of the barrier itself. In some instances the application of physical barriers may be quickened by modifying existing structures to support the barrier, for example, the addition of carp separation cages on modified fishways and the attachment of screen barriers or electrical barriers to existing culverts.

In contrast, behavioural barriers, such as sound barriers, light barriers and air bubble screens, may be easily and rapidly deployed if the materials are readily available because they do not have extensive installation requirements. However, the application of behavioural barriers requires prior knowledge of the response of the target species to the specific stimulus applied to ensure the barrier will be effective.

Therefore, when considering the use of fish barriers to contain new incursions of alien freshwater fish, barrier nets may be most appropriate as they can be quickly constructed, or previously constructed and stored for such occasions, and rapidly deployed in selected locations after consideration of site characteristics. It is expected that barriers applied to control new incursions of alien fish would be temporary barriers, which would be removed after successful eradication or modified into permanent barriers if ongoing management was needed. The longevity and durability of barriers should be considered in relation to the anticipated duration of the application.

When containing the spread of established populations of alien freshwater fish, consideration of their dispersal rate is important when determining the appropriate location of a barrier. In the USA, a preventative approach was taken to containing the movement of Asian carp in the Illinois River to protect Lake Michigan (Stokstad 2003). Based upon the known current occurrence of Asian carp, an electrical barrier was constructed 40 km downstream in anticipation that in several months time, Asian carp would have dispersed to that location (Stokstad 2003). The benefit of this preventative approach is that the most viable barrier may be constructed for the targeted species at a selected location.

From another perspective, the anticipated duration of a fish barrier application may be termed permanent or temporary. For example, in the US state of Maine fish barriers are considered temporary when installed for less than 7 months, and a permit is required for barriers installed for longer time periods (Maine Department of Inland Fisheries and Wildlife 2006).

4.4 Key conclusions

- Natural and artificial barriers and specific fish barriers can restrict fish movement. Various fish barriers have been developed to contain or exclude freshwater fish. Although their application has primarily been to protect fish at water intakes, these fish barriers may be suitable for alien freshwater fish containment and exclusion.
- Research, development and application of fish barriers have largely occurred in the USA, UK, Europe and New Zealand. Documented information on the use of fish barriers overseas to restrict alien freshwater fish movement is becoming more frequent. Limited research and application of fish barriers has occurred in Australia.
- Fish barriers can be categorised as physical or behavioural. Effective physical barriers provide complete exclusion of fish, whereas behavioural barriers involve the application of an external stimulus to evoke fish response, so complete exclusion is highly unlikely to be achieved.
- Fish barriers vary in design and thus also effectiveness, cost, construction and installation difficulty, operational and maintenance requirements, flow applicability and requirements, power supply needs, safety, and so on. The application of a particular barrier to contain or exclude targeted fish species at a selected location should therefore be decided on a case-by-case basis.
- Fish barriers deployed to contain new alien freshwater fish incursions must be easy and quick to deploy and be highly effective (ie ideally provide 100% containment). These considerations eliminate the application of most physical barriers because they take time to construct and install. Even though behavioural barriers may be easier and quicker to construct and install, behavioural barriers require prior knowledge of the species response to specific external stimuli and they are rarely highly effective.
- Fish barriers deployed to contain new incursions of alien freshwater fish are often temporary. For ongoing containment of established alien fish, permanent barriers are required or the seasonal application of fish barriers. Fish barriers which are difficult and timely to construct may be appropriate for preventative actions against established alien freshwater fish dispersal.
- Research and development is required to assess the effectiveness of barriers to contain alien fish species that occur in Australia. The response of non-target or native species to various fish barriers also needs investigation. Both laboratory and field trials are recommended. The procedure and result of all testing should be reported and made widely available to ensure current best practice management of alien freshwater fish in Australia.

Appendices

Appendix 1. Objectives in various Aquatic Nuisance Species Rapid Response Plans in the United States of America

A1. Table 1. Objectives of the draft Early Detection and Rapid Response Plan for Aquatic Invasive Species in Washington State

Source: Washington State Aquatic Nuisance Species Committee (2005)

Objectives
1. Ensure Early Reporting of New Invasions
1.1 Design and Implement an Integrated Monitoring Plan
1.2 Establish a Centralized Reporting System
1.3 Modify Existing Websites
1.4 Develop an Outreach and Communication Strategy
2. Ensure New Species Identification and Risk Assessment
2.1 Compile an Unwanted Invader list
2.2 Compile an On-call Expert list
2.3 Develop a Risk Assessment Methodology
3. Define Decision Making Responsibility and Response Protocol
3.1 Assign Responsibilities
3.2 Develop a Rapid Response Action Protocol
4. Establish and Maintain Capacity to Act
4.1 Establish a Rapid Response Fund
4.2 Develop a Rapid Response Checklist
4.3 Compile Eradication and Control Libraries
4.4 Identify Barriers and Constraints to Rapid Response
4.5 Remove Barriers and Constraints
4.6 Develop Model Response Plans
4.7 Develop and Conduct Training for Rapid Responders
5. Incorporate Adaptive Management in Plan Implementation
5.1 Periodically Review Plan Implementation and Associated Procedures
5.2 Amend Plan and Procedures to Reflect New Technologies and Lessons Learned

A1. Table 2. Response objectives for the Columbia River Basin Interagency Invasive Species Response Plan: Zebra Mussels and Other Dreissenid Species (Heimowitz and Phillips 2008)

Objectives
1. Make Initial Notifications
2. Activate appropriate organizational elements of the Columbia River Basin Interagency Response Plan
3. Verify Reported Introduction
4. Define Extent of Colonization
5. Establish External Communications System
6. Obtain and Organize Resources
7. Prevent Further Spread Via Quarantine and Pathway Management
8. Initiate Available/Relevant Control Actions
9. Institute Long-Term Monitoring
10. Evaluate the Response and the Plan

A1. Table 3. Ten objectives to be achieved in a rapid response plan: objectives of Idaho's Aquatic Nuisance Species Rapid Response Plan and Utah's Aquatic Invasive Species Rapid Response Plan

Note: these state plans have similar objectives The Idaho Invasive Species Council Technical Committee 2007, Utah Division of Wildlife Resources 2008

Objectives
1. Verify reported aquatic invasive species detection
2. Immediately notify relevant managers and aquatic invasive species Task Force
3. Define extent of colonization
4. Set-up an appropriate interagency response management team, if needed
5. Establish internal and external communication systems
6. Organize available resources (personnel, equipment, funds, etc)
7. Prevent further spread via quarantine and pathway management
8. Apply available or relevant control and containment actions, and seek mitigation
9. Institute long-term monitoring
10. Evaluate effectiveness and modify the Rapid Response Plan, if needed

Appendix 2. The National Noxious Fish List for Australia

A2. Table 1. The National Noxious Fish List for Australia (to be incorporated into state and territory fisheries legislation)

Source: www.feral.org.au/

Family	Species name	Common name
Acestrorhynchidae	*Acestrorhynchus microlepis*	pike characin
Alestiidae	*Hydrocynus spp.*	giant tigerfishes
Amiidae	*Amia calva*	bowfin
Anabantidae	*Anabas testudineus*	climbing perch
Bagridae	*Anaspidoglanis macrostoma*	flatnose catfish
Bagridae	*Bagrus ubangensis*	Ubangi shovelnose catfish
Centrarchidae	*all species*	banded or spotted sunfish, largemouth bass, bluegill
Centropomidae	*Centropomus (12 spp.)*	snooks
Centropomidae	*Lates microlepis*	forktail lates
Centropomidae	*Lates niloticus*	nile perch
Channidae	*Channa spp.*	snakeheads
Chacidae	*Chaca chaca*	angler, frogmouth or squarehead catfish
Characidae	*Colossoma spp.*	
Characidae	*Serrasalmus spp.*	redeye piranhas
Characidae	*Pygocentrus spp.*	red piranhas
Cichlidae	*Boulengerochromis microlepis*	giant cichlid, yellowbelly cichlid
Cichlidae	*Oreochromis spp.*	tilapia
Cichlidae	*Hemichromis fasciatus*	banded jewelfish
Cichlidae	*Sargochromis spp.*	pink or slender greenwoods, mortimers, cunean and green happy
Cichlidae	*Sarotherodon spp.*	
Cichlidae	*Sarotherodon melanotheron*	blackchin tilapia
Cichlidae	*Serranochromis spp.*	
Cichlidae	*Tilapia spp. (All except T. buttikoferi)*	redbelly tilapias
Citharinidae	*entire subfamily Ichthyborinae*	African pike-characins, tubenose poachers, fin-eaters
Clariidae	*Clarias spp.*	walking catfishes
Cobitidae	*Misgurnus anguillicaudatus*	weatherloach
Cyprinidae	*Hypophthalmichthys nobilis*	bighead carp

Family	Species name	Common name
Cyprinidae	*Neolissochilus hexagonolepis*	copper mahseer
Cyprinidae	*Gibelion catla*	catla
Cyprinidae	*Catlocarpio siamensis*	giant barb
Cyprinidae	*Cirrhinus cirrhosus*	mrigal
Cyprinidae	*Ctenopharyngodon idella*	grass carp
Cyprinidae	*Cyprinus carpio*	common carp
Cyprinidae	*Labeo calbasu and L. rohita*	orange-fin labeo, rohu
Cyprinidae	*Zacco platypus*	freshwater minnow
Cyprinidae	*Hypophthalmichthys molitrix*	silver carp
Cyprinidae	*Tor (17 spp.)*	river carp, deccan, high-backed, jungha, putitor, Thai mahseers
Cyprinidae	*Notropis spp.*	shiners
Cyprinidae	*Phoxinus erythrogaster*	southern redbelly dace
Doradidae	*Oxydoras spp.*	ripsaw catfish, black doras, black shielded catfishes
Elassomatidae	*Elassoma spp*	pygmy sunfish
Eleotridae	*Oxyeleotris marmorata*	marble goby
Erythrinidae	*Erythrinus spp.*	trahiras
Erythrinidae	*Hoplerythrinus spp.*	
Erythrinidae	*Hoplias spp.*	
Esocidae	*Esox spp.*	pikes
Gasterosteidae	*Pungitius pungitius*	ninespine stickleback
Gasterosteidae	*Apeltes quadracus*	fourspine stickleback
Gasterosteidae	*Culaea inconstans*	
Gobiidae	*Acanthogobius flavimanus*	yellowfin goby
Gobiidae	*Tridentiger trigonocephalus*	chameleon goby or striped goby
Gymnarchidae	*Gymnarchus niloticus*	aba aba
Gymnotidae	*Electrophorus electricus*	electric eel
Hepsetidae	*Hepsetus odoe*	African pike
Heteropneustidae	*Heteropneustes fossilis*	stinging catfish
Lepisosteidae	*Atractosteus (3 spp.)*	American, armoured or alligator gars
Lepisosteidae	*Lepisosteus (4 spp.)*	American, armoured or alligator gars
Malapteruridae	*Malapterurus spp.*	electric catfishes
Mormyridae	*Mormyrops anguilloides*	bottlenose, cornish jack
Poeciliidae	*Belonesox belizanus*	pike minnow, pike killifish
Poeciliidae	*Gambusia spp.*	mosquito fishes, gambusias
Polyodontidae	*Polyodon spathula*	Mississippi paddlefish

Family	Species name	Common name
Polyodontidae	*Psephurus gladius*	Chinese swordfish
Protopteridae	*Protopterus annectens*	African lungfish
Schilbeidae	*Schilbe mystus*	African butter catfish
Siluridae	*Silurus spp*	European catfish, Wels catfish
Trichomycteridae	*Paravandellia oxyptera*	parasitic catfish
Valenciidae	*Valencia hispanica*	Valencia toothcarp
Cambaridae	*Procambarus clarkii*	red swamp crayfish

Appendix 3. Legislation to be considered when devising alien freshwater fish emergency response or management plans

A3. Examples of legislation to be considered when devising alien freshwater fish emergency response or management plans

Animal welfare

Purpose: To provide for the welfare of animals, prevent cruelty to animals and for related purposes.

Animal Welfare Act 2002 (WA)

Animal Welfare Act (NT)

Animal Care and Protection Act 2001 (Qld)

Prevention of Cruelty to Animals Act 1979 (NSW)

Animal Welfare Act 1992 (ACT)

Prevention of Cruelty to Animals Act 1986 (Vic)

Animal Welfare Act 1985 (SA)

Animal Welfare Act 1993 (Tas)

Animal health

Purpose: Prohibition of the movement of diseased animals, establishment of restriction/control areas.

Exotic Disease of Animals Act 1993 (WA)

Stock Diseases Act 2005 (NT)

Fisheries Act (NT)

Exotic Diseases in Animals Act 1981 (Qld)

Animal Diseases (Emergency Outbreaks) Act 1991 (NSW)

Animal Disease Act 2005 (ACT)

Livestock Disease Control Act 1994 (Vic)

Livestock Act 1997 (SA)

Animal Health Act 1995 (Tas)

Biological control methods

Purpose: Legislation for biological control of pest species.

Biological Control Act 1986 (WA)

Biological Control Act (NT)

Biological Control Act 1987 (Qld)

Biological Control Act 1985 (NSW)

Biological Control Act 1986 (Vic)

Biological Control Act 1986 (SA)

Biological Control Act 1986 (Tas)

Chemical control methods

Purpose: To provide for permitted use, sale, storage, transportation, and so on, of chemicals

Agricultural and Veterinary Chemicals (Western Australia) Act 1995 (WA)

Agricultural and Veterinary Chemicals (Northern Territory) Act (NT)

Agricultural and Veterinary Chemicals (Control of Use) Act 2004 (NT)

Agricultural and Veterinary Chemicals (Queensland) Act 1994 (Qld)

Agricultural and Veterinary Chemicals (New South Wales) Act 1994 (NSW)

Agricultural and Veterinary Chemicals (Victoria) Act 1994 (Vic)

Agricultural and Veterinary Chemicals (Control of Use) Act 1992 (Vic)

Agricultural and Veterinary Chemicals (South Australia) Act 1994 (SA)

Agricultural and Veterinary Products (Control of Use) Act 2002 (SA)

Inland Fisheries (Destruction of Controlled Fish) Order 1996 (Tas)

Agricultural and Veterinary Chemicals (Tasmania) Act 1994 (Tas)

Agricultural and Veterinary Chemicals (Control of Use) Act 1995 (Tas)

Explosives Act 1999 (Qld)

Explosives Act 2003 (NSW)

Environmentally Hazardous Chemicals Act 1985 (NSW)

Poisons and Dangerous Drugs Act (NT)

Protection of flora and fauna, declaration of threatening processes, development of management plans, management of alien species

Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)

Biosecurity and Agriculture Management Act 2007 (WA)

Nature Conservation Act 1992 (Qld)

Fisheries Act 1994 (Qld)

Threatened Species Conservation Act 1995 (NSW)

Non-indigenous Animals Act 1987 (NSW)

Fisheries Management Act 1994 (NSW)

Nature Conservation Act 1980 (ACT)

Pest Plants and Animals Act 2005 (ACT)

Flora and Fauna Guarantee Act 1988 (Vic)

Nature Conservation Act 2002 (Tas)

Threatened Species Protection Act 1995 (Tas)

Territory Parks and Wildlife Conservation Act (NT)

Access to, control, management and protection of land, parks, reserves, and so on.

Environmental Assessment Act (NT)

Conservation and Land Management Act 1984 (WA)

Aboriginal Heritage Act 1972 (WA)

Nature Conservation Act 1980 (ACT)

Recreation Areas Management Act 2006 (Qld)

Catchment Management Authorities Act 2003 (NSW)

National Parks and Wildlife Act 1974 (NSW)

Aboriginal Land Rights Act 1983 (NSW)

Wilderness Protection Act 1992 (SA)

Natural Resources Management Act 2004 (SA)

National Parks and Wildlife Act 1972 (SA)

Catchment and Land Protection Act 1994 (Vic)

Heritage Rivers Act 1992 (Vic)

Natural Resource Management Act 2002 (Tas)

National Parks and Reserves management Act 2002 (Tas)

Emergency management procedures

Purpose: To provide for effective emergency management.

Emergencies Act 2004 (ACT)

Emergency Management Act 2004 (SA)

State Emergency and Rescue Management Act 1989 (NSW)

Emergency Management Act 1986 (Vic)

Disaster Management Act 2003 (Qld)

Emergency Management Act 2005 (WA)

Fire and Emergency Act (NT)

Water pollution prevention

Purpose: To make provisions for reducing the risks to human health and the environment by pollution prevention.

Environmental Protection Act 1994 (Qld)

Environmental Protection Act 1986 (WA)

Protection of the Environment Operations Act 1997 (NSW)

Environmental Protection Act 1997 (ACT)

Dangerous Substances Act 2004 (ACT)

Environment Protection Act 1970 (Vic)

Environmental Protection Act 1993 (SA)

Environmental Management and Pollution Control Act 1994 (Tas)

Fisheries and aquatic resources management

Purpose: Declaration of noxious fish (or equivalent), regulation of the sale, importation, transport, release, control of fish species, and so on.

Fisheries Management Act 1991 (Commonwealth)

Fisheries Act 1994 (Qld)

Fisheries Management Act 1994 (NSW)

Fisheries Management Act 2007 (SA)

Fish Resources Management Act 1994 (WA)

Fisheries Act 2000 (ACT)

Fisheries Act (NT)

Fisheries Act 1995 (Vic)

Inland Fisheries Act 1995 (Tas)

Aquaculture Act 2001 (SA)

Protection, use and management of water resources

Water Act (NT)

Wild Rivers Act 2005 (Qld)

Water Management Act 2000 (NSW)

Water Resources Act 2007 (ACT)

Water Act 1989 (Vic)

Water Resources Act 1997 (SA)

References

Agtrans Research (2005). Review of progress on invasive species. Final report to Department of Environment and Heritage. Brisbane, Queensland.

Aigo J, Cussac V, Peris S, Ortubay S, Gomez S, Lopez H, Gross M, Barriga J and Battini M (2008). Distribution of introduced and native fish Patagonia (Argentina): patterns and changes in fish assemblages. *Reviews in Fish Biology and Fisheries* 18:387–408.

Aitken PI, Dickerson LH and Menzies WJM (1966). Fish passes and screen at water power works. *Proceedings – Institution of Civil Engineers* 35:29-57.

Alcaraz C, Vila-Gispert A and Garcia-Berthou E (2005). Profiling invasive fish species: the importance of phylogeny and human use. *Diversity and Distributions* 11:289–298.

Almaca C (1995). Fish species and varieties introduced into Portuguese inland waters. Lisboa: Publicacoes Avulsas do Museu Bocage.

Alves CBM, Vieira F, Magalhaes ALB and Britto MFG (2007). Impacts of non-native fish species in Minas Gerais, Brazil: present situation and prospects. In: TM Bert (Ed), *Ecological and genetic implication of aquaculture activities*. Springer, Netherlands Pp 291–314.

Andersen J (2008). The toad with fins. In: *Townsville Bulletin*. Townsville, Queensland

ANS Task Force (2007). Aquatic nuisance species task force strategic plan (2007–2012). ANS Task Force website (www.anstaskforce.gov/plan.php).

Ansell D and Jackson P (2007). Emerging issues in alien fish management in the Murray–Darling Basin: statement, recommendations and supporting papers. In: *Proceedings of a workshop held in Brisbane Qld 30–31 May 2006*. Murray–Darling Basin Commission, Canberra.

Aquatic Invasive Species Task Group (2004). A Canadian action plan to address the threat of aquatic invasive species. Canadian Council of Fisheries and Aquaculture Ministers.

Arthington AH and Bluhdorn DR (1995). Improved management of exotic aquatic fauna; R & D for Australian Rivers. Land and Water Resources Research and Development Corporation, Canberra.

Arthington AH and McKenzie F (1997). Review of impacts of displaced/introduced fauna associated with inland waters, Australia: State of the Environment Technical Paper Series (Inland Waters). Department of the Environment, Canberra.

Arthington AH, Kailola PJ, Woodland DJ and Zalucki J M (1999). Baseline environmental data relevant to an evaluation of quarantine risk potentially associated with the importation to Australia of ornamental finfish. Griffith University and University of New England, Canberra.

Arthington AH, McKay RJ and Milton D (1986). The ecology and management of exotic and endemic freshwater fishes in Queensland. Griffith University and Queensland Museum, Brisbane.

Arthington AH, McKay RJ, Russell DJ and Milton DA (1984). Occurrence of the introduced cichlid *Oreochromis mossambicus* (Peters) in Queensland. *Marine and Freshwater Research* 35:267-272.

Bacha M (2007). Freshwater fish of Algeria. Study of the ichthyofauna of the Soummam River. *Cybium* 31:351-358.

Balla S, Lloyd L and Pierce B (1985). Unwanted aquarium fishes. *Search* 16:300–301.

Barnard P and Waage JK (2004). Tackling species invasions around the world: regional responses to the invasive alien species threat. Global Invasive Species Programme, Cape Town, South Africa.

Barrett J (Ed) (2008). The Sea to Hume Dam: Restoring Fish Passage in the Murray River. Murray–Darling Basin Commission, Canberra, ACT.

Bartley DM, Bhujel RC, Funge-Smith S, Olin PG and Phillips MJ (Eds) (2005). International mechanisms for the control and responsible use of alien species in aquatic ecosystems. Report of an ad hoc expert consultation. Xishuangbanna, People's Republic of China, 27–30 August 2003. FAO, Rome.

Barwick DH and Miller LE (1996). Effectiveness of an electrical barrier in blocking fish movement. In: *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 50:139–147.

Beatty SJ and Morgan DL (2005). Management of aquatic fauna during refurbishment of Phillips Creek Reservoir. Prepared for the Water Corporation of Western Australia. Centre for Fish and Fisheries Research, Murdoch University, Murdoch, Western Australia.

Beatty SJ (2006). The diet and trophic positions of translocated, sympatric populations of *Cherax destructor* and *Cherax cainii* in the Hutt River, Western Australia: evidence of resource overlap. *Marine and Freshwater Research* 57:825–835.

Belk MC and Lydeard C (1994). Effect of *Gambusia holbrooki* on a similar-sized, syntopic Poeciliid, *Heterandria formosa*: Competitor or Predator? *Copeia* 2:296–302.

Bell K (2003). A review of the commercial use of carp. In: KL Lapidge (Ed), *Proceedings of the National Carp Control Workshop*. March 2003, Canberra. Cooperative Research Centre for Pest Animal Control, Canberra.

Bianco PG (1998). Freshwater fish transfers in Italy: history, local changes in fish fauna and a prediction on the future of native populations. In: IG Cowx (Ed), *Stocking and introduction of fish*. Fishing News Books, Oxford, England. Pp 167–185.

Bluhdorn DR, Arthington AH and Mather PB (1990). The introduced cichlid, *Oreochromis mossambicus*, in Australia: a review of distribution, population genetics, ecology, management issues and research priorities. In: D Pollard (Ed), *Introduced and translocated fishes and their ecological effects*. Australian Government Publishing Service, Canberra. Pp 93.

Boggs CL, Holdren CE, Kulahci IG, Bonebrake TC, Inouye BD, Fay JP, Mcmillan A, Williams EH and Ehrlich PR (2006). Delayed population explosion of an introduced butterfly. *Journal of Animal Ecology* 75:466–475.

Bohn T, Amundsen PA and Sparrow A (2008). Competitive exclusion after invasion? *Biological Invasions* 10:359–368.

Bomford M (2008). Risk assessment models for establishment of exotic vertebrates in Australia and New Zealand. Invasive Animals Cooperative Research Centre, Canberra.

Bomford M and Glover J (2004). Risk assessment model for the import and keeping of exotic freshwater and estuarine finfish. Bureau of Rural Sciences, Canberra.

Bomford M and O'Brien P (1995). Eradication of Australia's vertebrate pests: a feasibility study. In: GC Grigg, PT Hale and D Lunney (Eds), *Conservation through sustainable use of wildlife*. Centre for Conservation Biology, University of Queensland, Brisbane.

Borwick J and Brownson B (2006). The Pefferlaw Brook round goby eradication project. In: *A.D. Latornell Conservation Symposium*.

Bramsaea F, Morgens J and Otterstrom CV (1942). Barriers against fishes by means of electricity or veils of air. *Reports of the Danish Biological Station* 47:39–46.

Burchmore J, Faragher R and Thorncraft G (1990). Occurrence of the introduced oriental weatherloach (*Misgurnus anguillicaudatus*) in the Wingecarribee River, New South Wales. In: DA Pollard (Ed), *Introduced and translocated fishes and their ecological effect*. Australian Government Publishing Service, Canberra. Pp 38–46.

Burnard D, Gozlan RE and Griffiths SW (2008). The role of pheromones in freshwater fishes. *Journal of Fish Biology* 73:1–16.

Canonico GC, Arthington AH, McCrary JK and Thieme ML (2005). The effects of introduced tilapias on native biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15:463–483.

Carlson TJ and Popper AN (1997). Using sound to modify fish behaviour at power-production and water control facilities: a workshop December 12–13, 1995. Portland State University, Portland Oregon. Phase II: Final report, report to Bonneville Power Administration, Contract No. 1986BP62611, Project No. 199207101. 360pp.

Carlson TJ (1995). Historical review of the use of sound to modify fish behaviour. In: TJ Carlson and AN Popper (Eds), *Using sound to modify fish behaviour at power-production and water-control facilities: A workshop December 12–13, 1995. Portland State University Portland, Oregon, Phase II: Final Report, Report to Bonneville Power Administration, Contract No. 1986BP62611, Project No. 199207101*.

Carlton JT and Geller JB (1993). Ecological roulette: the global transport of nonindigenous marine organisms. *Science* 261:78–82.

Carp Control Working Group (2000). National Management Strategy for Carp Control: 2000 – 2005. Murray–Darling Commission, Canberra.

Carr JW and Whoriskey FG (2008). Migration of silver American eels past a hydroelectric dam and through a coastal zone. *Fisheries Management and Ecology* 15:393–400.

Casal CMV (2006). Global documentation of fish introductions: the growing crisis and recommendations for action. *Biological Invasions* 8:3–11.

Chambers WB (2008). Interlinkages and the effectiveness of multilateral environmental agreements. United Nations University, Hong Kong.

Chang A, Grossman J, Spezio T, Weiskel H, Blum J, Burt J, Muir A, Piovia-Scott J, Veblen K and Grosholz E (2009). Tackling aquatic invasions: risks and opportunities for the aquarium fish industry. *Biological Invasions* 11:773–785.

Chapman FA, Fitz-Coy SA, Thunberg EM and Adams CM (1997). United States of America Trade in Ornamental Fish. *Journal of the World Aquaculture Society* 28:1–10.

Chiba K, Sakai Y and Oozeki Y (1989). Present status of aquatic organisms introduced into Japan. In: SS De Silva (Ed), *Exotic Aquatic Organisms in Asia. Proceedings of the workshop on introduction of exotic aquatic organisms in Asia*. Asian Fisheries Society, Manila, Philippines. Pp. 63–70.

Childs MR (2006). Comparison of Gila topminnow and western mosquitofish as biological control agents of mosquitoes. *Western North American Naturalist* 66:181–190.

Choquenot D, Nicol SJ and Koehn JD (2004). Bioeconomic modelling in the development of invasive fish policy. *New Zealand Journal of Marine and Freshwater Research* 38:419–428.

Clarkson RW (2004). Effectiveness of electrical fish barriers associated with the Central Arizona project. *North American Journal of Fisheries Management* 24:94–105.

Clunie P, Stuart I, Jones M, Crowther D, Schreiber S, McKay S, O'Connor J, McLaren D, Weiss J, Gunasekera L and Roberts J (2002). A risk assessment of the impacts of pest species in the riverine environment in the Murray-Darling Basin. Department of Natural Resources and Environment Arthur Rylah Institute, Heidelberg, Victoria.

Colautti RI (2006a). Propagule pressure: A null model for biological invasions. *Biological Invasions* 8:1023–1037.

Colautti RI (2006b). Characterised and projected costs of nonindigenous species in Canada. *Biological Invasions* 8:45–59.

Colautti RI and MacIsaac HJ (2004). Biodiversity research: A neutral terminology to define 'invasive' species. *Diversity and Distributions* 10:135–141.

Commission of the European Communities (2006). Halting the loss of biodiversity by 2010 and beyond — sustaining ecosystem services for human well-being. European Commission website (www.ec.europa.eu/environment/nature/biodiversity/comm2006/bap_2006.htm).

Conover G, Simmonds R and Whalen M (Eds) (2007). Management and control plan for bighead, black, grass, and silver carps in the United States. Asian Carp Working Group, Aquatic Nuisance Species Task Force, Washington, D.C

Copp GH, Bianco PG, Bogutskaya NG, Eros T, Falka I, Ferreira MT, Fox MG, Freyhof J, Gozlan RE, Grabowska J, Kovac V, Moreno-Amich R, Naseka AM, Penaz M, Povz M, Przybylski M, Robillard M, Russell IC, Stakenas S, Sumer S, Vila-Gispert A and Wiesner C (2005). To be, or not to be, a non-native freshwater fish? *Journal of Applied Ichthyology* 21:242–262.

Copp GH, Garthwaite R and Gozlan RE (2005). Risk identification and assessment of non-native freshwater fishes: concepts and perspectives on protocols for the UK. Science series technical report no. 129. Cefas, Lowestoft.

Corfield J, Diggles B, Jubb C, McDowall RM, Moore A, Richards A and Rowe DK (2007). Draft final report for the project 'Review of the impacts of introduced aquarium fish species that have established wild populations in Australia'. Prepared for the Australian Government Department of the Environment and Water Resources.

Courtenay WR (1997). Nonindigenous fishes. In: D Simberloff, DC Schmitz and TC Brown (Eds), *Strangers in Paradise*. Island Press, Washington, DC. Pp. 109–122.

Courtenay WRJ and Meffe GK (1989). Small fishes in strange places: a review of introduced poeciliids. In: GK Meffe and FF Snelson (Eds), *Ecology and Evolution of Live Bearing Fishes (Poeciliidae)*. Prentice Hall, New Jersey. Pp. 319–332.

Coutant C (Ed) (2001). Behavioural technologies for fish guidance. American Fisheries Society Symposium 26. Bethesda, Maryland.

Crooks JA and Soulé ME (1999). Lag times in population explosions of invasive species: causes and implications. In: O Sandlund, P Schei and Å Viken (Eds), *Invasive Species and Biodiversity Management (based on a selection of papers presented at the Norway/United Nations Conference on Alien Species, Trondheim, Norway, 1–5 July 1996)*. Kluwer Academic Publishers Dordrecht, Boston and London.

Crowl TA, Townsend CR and McIntosh AR (1992). The impact of introduced brown and rainbow trout on native fish: the case of Australasia. *Reviews in Fish Biology and Fisheries* 2:217–241.

Davis MA, Grime JP and Thompson K (2000). Fluctuating resources in plant communities: a general theory of invasibility. *Journal of Ecology* 88:528–534.

Dawson HA, Reinhardt UG and Savino JF (2006). Use of electric or bubble barriers to limit the movement of Eurasian Ruffe (*Gymnocephalus cernuus*). *Journal of Great Lakes Research* 32:40–49.

DBIRD (2004). Fishery Status Reports 2003, Fishery Report No. 78. Department of Business, Industry and Resource Development, Darwin.

DEFRA (2003). Review of non-native species policy: report of the working group. Department for Environment Food and Rural Affairs Publications, London.

DEFRA (2008). The invasive non-native species framework strategy for Great Britain. York: The GB Non-native species Secretariat. Department for Environment Food and Rural Affairs Publications, London.

De Silva SS (Ed) (1989). Exotic aquatic organisms in Asia. Asian Fisheries Society, Manila, Philippines.

De Silva SS, Nguyen TTT, Abery NW and Amarasinghe US (2006). An evaluation of the role and impacts of alien finfish in Asian inland aquaculture. *Aquaculture Research* 37:1–17.

De Silva SS, Nguyen TTT, Turchini GM, Amarasinghe US and Abery NW (2009). Alien species in aquaculture and biodiversity: a paradox in food production. *AMBIO: A Journal of the Human Environment* 38:24–28.

De Silva SS, Subasinghe RP, Bartley DM and Lowther A (2004). Tilapias as alien aquatics in Asia and the Pacific: A review. FAO, Rome.

Department of Fisheries (2006). Department of Fisheries Annual Report to the Parliament 2005/06. Department of Fisheries, Perth, Western Australia.

Department of Fisheries (2007). Department of Fisheries Annual Report to the Parliament 2006/07. Department of Fisheries, Perth, Western Australia.

Department of Fisheries (2008). Department of Fisheries Annual Report to the Parliament 2007/08. Department of Fisheries, Perth, Western Australia.

Department of Fisheries and Oceans (1995). Freshwater intake end-of-pipe fish screen guideline. Department of Fisheries and Oceans, Ontario.

Department of Primary Industries (2009). The biosecurity strategy for Victoria. Department of Primary Industries Biosecurity Victoria, Melbourne, Victoria.

Dextrase AJ and Mandrak NE (2006). Impacts of alien invasive species on freshwater fauna at risk in Canada. *Biological Invasions* 8:13–24.

Diggle J, Day J and Bax N (2004). Eradicating European carp from Tasmania and implications for national European carp eradication. Inland Fisheries Service, Hobart.

Dill WA and Cordone AJ (1997). History and Status of Introduced Fishes in California, 1871–1996. In: Department of Fish and Game (Ed), *Fish Bulletin*. The Resources Agency, California, USA

Dixon D (2006). Design considerations and specifications for fish barrier net deployment at cooling water intake structures. Electric Power Research Institute, California.

Dominion Consulting. (2001). An economic survey of the Snowy Mountains recreational trout fishery. Dominion Consulting Pty Ltd, Old Princes Highway, Sutherland, NSW.

Doupé RG, Morgan DL, Gill HS and Rowland SJ (2004). Introduction of redclaw crayfish *Cherax quadricarinatus* (von Martens) to Lake Kununurra, Ord River, Western Australia: prospects for a 'yabby' in the Kimberley. *Journal of the Royal Society of Western Australia* 87:187–191.

DPIF (2008a). Removal of Tilapia in Eureka Creek: application of rotenone as eradication tool in an open river system (draft report). Department of Primary Industries and Fisheries, Brisbane, Queensland. 16pp.

DPIF (2008b). Noxious fish rapid response manual 2008. Department of Primary Industries and Fisheries, Brisbane, Queensland.

DPIFM (2005). Fishery Status Reports 2004, Fishery Report No. 82. Department of Primary Industry Fisheries and Mines, Darwin, Northern Territory.

DPIFM (2007). Fishery Status Reports 2006, Fishery Report No. 87. Department of Primary Industry Fisheries and Mines, Darwin, Northern Territory.

Drake JM and Lodge DM (2004). Global hot spots of biological invasions: evaluating options for ballast-water management. *Proceedings of the Royal Society of London B*. 271:575–580.

DWA (2006). Fish protection technologies and downstream fishways: Dimension, design, effectiveness inspection. DWA German Association for Water, Wastewater and Waste, Hennef, Germany.

Economidis PS, Dimitriou E, Pagoni R, Michaloudi E and Natsis L (2000). Introduced and translocated fish species in the inland waters of Greece. *Fisheries Management and Ecology* 7:239.

Ehrlich, P. (1986). Which animal will invade? In: HA Mooney JA and Drake (Eds), *Ecology of biological invasions in North America and Hawaii*. Springer-Verlag, New York, USA. Pp 79–95.

Elkington S. and Maley R (2005). Eradication of gambusia (*Gambusia affinis*), koi carp (*Cyprinus carpio*), and rudd (*Scardinius erythrophthalmus*) from the Nelson/Marlborough Conservancy. Department of Conservation Te Papa Atewhai. Nelson, New Zealand.

Elton CS (1958). The ecology of invasions by animals and plants. Methuen, London.

Elvira B and Almodovar A (2001). Freshwater fish introductions in Spain: facts and figures at the beginning of the 21st century. *Journal of Fish Biology* 59:323–331.

Environment Canada (2004). An invasive alien species strategy for Canada.

FAO (2009). Report of the FAO Workshop on the Development of an Aquatic Biosecurity Framework for Southern Africa. Lilongwe, Malawi, 22–24 April 2008. FAO Fisheries and Aquaculture Report. No. 906. FAO, Rome. 55pp.

Fausch KD (2007). Introduction, establishment and effects of non-native salmonids: considering the risk of rainbow trout invasion in the United Kingdom. *Journal of Fish Biology* 71:1–32.

Finlayson BJ, Schnick RA, Cailteux RL, DeMong L, Horton WD, McClay W, Thompson CW and Tichacek GJ. (2000). Rotenone use in fisheries management: administrative and technical guidelines manual. American Fisheries Society, Bethesda, Maryland.

FishPro (2004). Feasibility study to limit the invasion of Asian carp into the Upper Mississippi River Basin. FishPro Consulting Engineers and Scientists, Springfield.

Fredberg J, Smith B, Thwaites L, Conallin AJ and Fleer D (2009). Monitoring temporal changes in the species composition and lateral movement patterns of small-bodied fishes within the inlet and outlet creeks to Banrock Station wetland. SARDI Publication No.

F209/000104-1, SARDI Report Series No. 337. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, South Australia. 18pp.

Fredricks KT, Swink WD and Montouri L (1996). Feasibility of using strobe lights to direct sea lamprey movement. National Biological Service, Lake Huron Biological Station, Michigan.

Fuller PL (2003). Freshwater aquatic vertebrate introductions in the United States: patterns and pathways. In: GM Ruiz and JT Carlton (Eds), *Invasive species: vectors and management strategies*. Island Press, Washington, DC.

Fureder L and Pockl M (2007). Ecological traits of aquatic non-indigenous species invading Austrian fresh water. In: F Gherardi (Ed), *Biological invaders in inland waters: Profiles, distribution and threats*. Springer, The Netherlands. Pp 233–257.

Garcia-Berthou E, Alcaraz C, Pou-Rovira Q, Zamora L, Coenders G and Feo C (2005). Introduction pathways and establishment rates of invasive aquatic species in Europe. *Canadian Journal of Fisheries and Aquatic Sciences* 62:453–463.

Gardner RO and Early JW (1996). The naturalisation of banyan figs (*Ficus* spp., Moraceae) and their pollinating wasps (Hymenoptera: Agaonidae) in New Zealand. *New Zealand Journal of Botany* 34:103–110.

Gehrke PC (2003). Preliminary assessment of oral rotenone baits for carp control in New South Wales. In: Department of Conservation (Ed), *Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10–12 May 2001, Hamilton*. DOC Science publishing, Wellington. Pp xiv + 174.

Gehrke PC (2008). Integrated Pest Management. Presentation: Murray-Darling Basin Commission Fish Forum 2008. Canberra.

Geiger W, Alcorlo P, Baltanás A and Montes C (2005). Impact of an introduced Crustacean on the trophic webs of Mediterranean wetlands. *Biological Invasions* 7:49–73.

Genovesi P and Shine C (2003). European strategy on invasive alien species. European Commission website (www.ec.europa.eu/environment/nature/invasivealien/index_en.htm).

Gessel MH, Williams JG, Brege DA, Krcma RF and Chambers DR (1991). Juvenile salmonid guidance at the Bonneville Dam Second Powerhouse, Columbia River, 1983–1989. *North American Journal of Fisheries Management* 11:400–412.

Gherardi F (2007a). Understanding the impact of invasive crayfish. In: F Gherardi (Ed), *Biological invaders in inland waters: Profiles, distribution and threats*. Springer, The Netherlands. Pp 507–542.

Gherardi, F. (2007b). Biological invasions in inland waters: an overview. In: F Gherardi (Ed), *Biological invaders in inland waters: profiles, distribution and threats*. Springer, The Netherlands. Pp 3–25.

Ghosh A, Mandal S, Bhattacharjee I and Chandra G (2005). Biological control of vector mosquitoes by some common exotic fish predators. *Turkish Journal of Biology* 29:167–171.

Gibson AJF and Myers RA (2002). Effectiveness of a high-frequency-sound fish diversion system at the Annapolis Tidal Hydroelectric Generating Station, Nova Scotia. *North American Journal of Fisheries Management* 22:770–784.

Gilligan DM, Gehrke PC and Schiller C (2005). Testing methods and ecological consequences of large-scale removal of common carp. NSW Department of Primary Industries, Cronulla, NSW.

Gilligan D, Rolls R, Merrick J, Lintermans M, Duncan P and Kohen J (2007). Scoping the knowledge requirements for Murray crayfish (*Euastacus armatus*). NSW Department of Primary Industries, Cronulla, NSW.

GISP (2005). GISP Training course on the management of invasive alien species.

Gollasch S and Nehring S (2006). National Checklist for Aquatic Alien Species in Germany. *Aquatic Invasions* 1:245–269.

Goosney R (1997). An efficient diversion/bypass system for Atlantic salmon (*Salmo salar*) smolt and kelt in power canals. In: *EPRI Fish Passage Workshop May 6-8, 1997. Milwaukee, Wisconsin*. Electric Power Research Institute, Palo Alto, USA.

Gozlan RE (2008). Introduction of non-native freshwater fish: is it all bad? *Fish and Fisheries* 9:106–115.

Great Lakes Commission (2006). Model rapid response plan for Great Lakes aquatic invasions (draft), Iteration III. 62pp.

Great Lakes Regional Collaboration (2007). GLRC Rapid response communication protocol. GLRC website (www.glrc.us/initiatives/invasives/AISRRCP.html).

Greenland International Consulting Ltd. (2005). Draft site condition report: for assessing round goby removal and eradication options for Pefferlaw Brook. Ontario, Canada.

Greiner R and Gregg D (2008). Tilapia in north Queensland waterways: risks and potential economic impacts. Report prepared for the Australian Centre for Tropical Freshwater Research. River Consulting, Townsville.

Griffiths D (1997). The status of the Irish freshwater fish fauna: a review. *Journal of Applied Ichthyology-Zeitschrift Fur Angewandte Ichthyologie* 13:9–13.

Gunnell K (2008). Geographic patterns of introgressive hybridization between native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) and introduced rainbow trout (*O. mykiss*) in the south fork of the Snake River watershed, Idaho. *Conservation Genetics* 9:49–64.

Hadderingh R H, Koops FBJ and Van der Stoep JW (1988). Research in fish protection at Dutch thermal and hydropower stations. Kema Scientific and Technical Reports. Pp 6/2:57–68.

Hall DA (1988). The eradication of European carp and goldfish from the Leigh Creek Retention Dam. In: *Safish* 1998:15–16.

Hamel MJ, Brown ML and Chipps SR (2008). Behavioral responses of rainbow smelt to in situ strobe lights. *North American Journal of Fisheries Management* 28:394–401.

Harlioğlu M and Harlioğlu A (2006). Threat of non-native crayfish introductions into Turkey: global lessons. *Reviews in Fish Biology and Fisheries* 16:171–181.

Hartvich P, Dvorak P, Tlusty P and Vrana P (2008). Rotation screen prevents fish damage in hydroelectric power stations. *Hydrobiologia* 609:163–176.

Heimowitz P and Phillips S. (2008). Columbia River Basin interagency invasive species response plan: zebra mussels and other *Dreissenid* species. Prepared for the 100th Meridian Initiative Columbia River Basin Team.

Helfman GS, Collette BB and Facey DE (1997). The diversity of fishes. Blackwell Publishing, Oxford, UK.

Hesthagen T and Sandlund OT (2007). Non-native freshwater fishes in Norway: history, consequences and perspectives. *Journal of Fish Biology* 71:173–183.

Hickley P and Chare S (2004). Fisheries for non-native species in England and Wales: angling or the environment? *Fisheries Management and Ecology* 11:203.

Higham J (2007). Summary of existing alien fish management mechanisms in Murray–Darling Basin jurisdictions. In: D Ansell and P Jackson (Eds) *Emerging issues in alien fish management in the Murray–Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Brisbane Qld 30–31 May 2006.* Murray–Darling Basin Commission, Canberra.

Hume D, Fletcher-Brumley A and Morison S (1985). Carp in Victoria. Fisheries and Wildlife Service, Melbourne. 8pp.

Hunn, J. B. and Young, W. D. (1980). Role of physical barriers in control of sea lamprey (*Petromyzon marinus*). *Canadian Journal of Fisheries* and *Aquatic Sciences* 37: 118–2122.

Hurlbert SH, Zedler J and Fairbanks D (1972). Ecosystem alteration by Mosquitofish (*Gambusia affinis*) predation. *Science* 175:639–641.

Inland Fisheries Commission (1982). Inland Fisheries Commission report for the year ended 30 June 1982. Inland Fisheries Commission, Hobart.

Inland Fisheries Commission (1986). Inland Fisheries Commission report for the year ended 30 June 1986. Inland Fisheries Commission, Hobart.

Inland Fisheries Commission (1987). Inland Fisheries Commission report for the year ended 30 June 1987. Inland Fisheries Commission, Hobart.

Inland Fisheries Service (2005). Inland Fisheries Service Annual Report 2004–05. Inland Fisheries Service, Moonah, Tasmania.

Inland Fisheries Service (2006). Inland Fisheries Service Annual Report 2005–06. Inland Fisheries Service, Moonah, Tasmania.

Inland Fisheries Service (2008). Inland Fisheries Service Annual Report 2007–08. Inland Fisheries Service, Moonah, Tasmania.

Inland Fisheries Service (2009). Inland Fisheries Service Annual Report 2008–09. Inland Fisheries Service, Moonah, Tasmania.

Inland Fisheries Service. (2004). Carp management program report Lakes Crescent and Sorell 1995–June 2004. Inland Fisheries Service, Moonah, Tasmania.

Innal D and Erk'akan F (2006). Effects of exotic and translocated fish species in the inland waters of Turkey. *Rev Fish Biol Fisheries* 16:39–50.

Invasive Species Council (2002). Tilapia in the Gulf? *Feral Herald, Newsletter of the Invasive Species Council* 1:4.

Ivantsoff W and Aarn (1999). Detection of predation on Australian native fishes by *Gambusia holbrooki*. *Marine and Freshwater Research* 50:467–468.

Jamieson D, Bonnett M, Jellyman D and Unwin M. (2007). Fish screening: good practice guidelines for Canterbury. National Institute of Water and Atmospheric Research Ltd., Christchurch.

Jang MH, Kim JG, Park SB, Jeong KS, Cho GI and Joo GJ (2002). The current status of the distribution of introduced fish in large river systems of South Korea. *International Review of Hydrobiology* 87:319–328.

Jeschke JM and Strayer DL (2005). From the cover: Invasion success of vertebrates in Europe and North America. *Proceedings of the National Academy of Sciences* 102:7198–7202.

Johnsen S, Taugbøl T, Andersen O, Museth J and Vrålstad T (2007). The first record of the non-indigenous signal crayfish *Pasifastacus leniusculus* in Norway. *Biological Invasions* 9:939–941.

Johnson HBG (1988). A comparison of the effectiveness of sea lamprey control in Georgian Bay and the north channel of Lake Huron. *Hydrobiologia* 163:215–222.

Johnson NS, Luehring MA, Siefkes MJ and Li W (2006). Mating pheromone reception and induced behavior in ovulating female sea lampreys. *North American Journal of Fisheries Management* 26:88–96.

Johnson NS, Siefkes MJ and Li W (2005). Capture of ovulating female sea lampreys in traps baited with spermiating male sea lampreys. *North American Journal of Fisheries Management* 25:67–72.

Johnson PN, Bouchard K and Goetz FA (2005). Effectiveness of strobe lights for reducing juvenile salmonid entrainment into a navigation lock. *North American Journal of Fisheries Management* 25:491–501.

Karlsen HE and Sand O (1991). Infrasound detection in fish. *Biomedical research.* 12 (suppl. 2):217–219.

Karlsen HE, Piddington RW, Enger PS and Sand A (2004). Infrasound initiates directional fast-start escape responses in juvenile roach *Rutilus rutilus*. *Journal of Experimental Biology* 207:4185–4193.

Katopodis C, Koon EM and Hanson L (1994). Sea lamprey barriers: new concepts and research needs. 1994 Project completion report. Report to the Great Lakes Fishery Commission. Great Lakes Fishery Commission. 90pp.

Keane JP and Neira FJ (2004). First record of mosquitofish, *Gambusia holbrooki*, in Tasmania, Australia: stock structure and reproductive biology. *New Zealand Journal of Marine and Freshwater Research* 38:857.

Keith P and Allardi J (1998). The introduced freshwater fish of France: status, impacts and management. In: IG Cowx (Ed) *Stocking and introduction of fish*. Fishing News Books, Oxford. Pp 153–166.

Kelso JRM, O'Connor LM and Geiling WD (1998). Fishery assessment of the Big Creek, Lake Erie, inflatable barrier and fishway project. Project complete report. Report to the Great Lakes Fishery Commission. Great Lakes Fishery Commission, Ontario. 40pp.

Kennard MJ (2005). Are alien fish a reliable indicator of river health? *Freshwater Biology* 50:174–193.

Kerr SJ, Brousseau CS and Muschett M (2005). Invasive aquatic species in Ontario. *Fisheries* 30:21–30.

Knight J (2008). The feasibility of excluding alien redfin perch from Macquarie perch habitat within the Hawkesbury–Nepean Catchment. NSW Department of Primary Industries, Port Stephens, NSW.

Knudsen FR, Enger PS and Sand O (1992). Awareness reactions and avoidance responses to sound in juvenile Atlantic salmon, *Salmo salar* L. *Journal of Fish Biology* 40:523–534.

Knudsen FR, Enger PS and Sand O (1994). Avoidance responses to low frequency sound in downstream migrating Atlantic salmon smolt, *Salmo salar*. *Journal of Fish Biology* 45:227–233.

Knudsen FR, Schreck CB, Knapp SM, Enger PS and Sand O (1997). Infrasound produces flight and avoidance responses in Pacific juvenile salmonids. *Journal of Fish Biology* 51:824–829.

Koehn JD and MacKenzie RF (2004). Priority management actions for alien freshwater fish species in Australia. *New Zealand Journal of Marine and Freshwater Research* 38:457.

Koehn JD, Brumley A and Gehrke P (2000). Managing the impacts of carp. Bureau of Rural Sciences, Kingston, ACT.

Kolar CS and Lodge DM (2001). Progress in invasion biology: predicting invaders. *Trends in Ecology* and *Evolution* 16:199–204.

Kolar CS and Lodge DM (2002). Ecological predictions and risk assessment for alien fishes in North America. *Science* 298:1233–1236.

Kottelat M and Whitten T (1996). Freshwater biodiversity in Asia with special reference to fish. The World Bank, Washington, D.C.

Kynard B and Buerkett C (1997). Passage and behavior of adult American shad in an experimental louver bypass system. *North American Journal of Fisheries Management* 17:734–742.

Lambert DR, Turnpenny AWH and Nedwell JR (1997). The use of acoustic fish deflection systems at hydro stations. *Hydropower and Dams* 1:54–56.

Langdon JS (1989). Experimental transmission and pathogenicity of epizootic haematopoietic necrosis virus (EHNV) in redfin perch, *Perca fluviatilis* L., and 11 other teleosts. *Journal of Fish Diseases* 12:295–310.

Latini AO and Petrere MJ (2004). Reduction of a native fish fauna by alien species: an example from Brazilian freshwater tropical lakes. *Fisheries Management and Ecology* 11:71–79.

Lehtonen H (2002). Alien freshwater fishes of Europe. In: E Leppäkoski, S Gollasch and S Olenin (Eds) *Invasive aquatic species of Europe*. Kluwer Academic Publisher. Pp 153–161.

Lenhardt M, Hegedis A, Cvijanovic G, Jaric I, Gacic Z and Mickovic B (2006). Non-native freshwater fishes in Serbia and their impacts to native fish species and ecosystems. *Geophysical Research Abstracts* 8.

Leprieur F, Beauchard O, Blanchet S, Oberdorff T and Brosse S (2008). Fish Invasions in the World's River Systems: When natural processes are blurred by human activities. *PLoS Biology* 6:404–410.

Leveque C (1996). Introduction of fish species in freshwaters: A major threat to aquatic biodiversity? In: F di Castri and T Younes (Eds), *Biodiversity, science and development: Towards a new partnership*. CAB International, Wallingford, Oxon. Pp 446–451.

Levine J (2000). Species diversity and biological invasions: relating local process to community pattern. *Science* 288:852–854.

Lintermans M (2000). Recolonization by the mountain galaxias *Galaxias olidus* of a montane stream after the eradication of rainbow trout *Oncorhynchus mykiss*. *Marine and Freshwater Research* 51:799–804.

Lintermans M (2004). Human-assisted dispersal of alien freshwater fish in Australia. *New Zealand Journal of Marine and Freshwater Research* 38:481.

Lintermans M and Raadik TA (2003). Local eradication of trout from streams using rotenone: The Australian experience. In: *Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10–12 May 2001*. Department of Conservation, Wellington, New Zealand.

Lintermans M and Rutzou T (1990). Removal of feral fish from artificial ponds in the Australian National Botanic Gardens. Wildlife Unit, ACT Parks and Conservation Service.

Lockwood J (1999). Using taxonomy to predict success among introduced avifauna: relative importance of transport and establishment. *Conservation Biology* 13:560–567.

Lockwood JL, Cassey P and Blackburn T (2005). The role of propagule pressure in explaining species invasions. *Trends in Ecology* and *Evolution* 20:223–228.

Lonsdale WM (1993). Rates of spread of an invading species *Mimosa pigra* in northern Australia. *The Journal of Ecology* 81:513–521.

Lowe S, Browne M and Boudjelas S (2000). 100 of the world's worst invasive alien species. The Invasive Species Specialist Group, Auckland, New Zealand.

Lui L and He D (1988). The reaction of five freshwater fishes to a movable bubble curtain. *Journal of Xiamen University* 27: 214–219.

Lynas J, Storey A and Knott B (2007). Introduction and spread of crayfish (Parastacidae) in Western Australia and their potential to displace indigenous species. In: F Gherardi (Ed), *Biological invaders in inland waters: profiles, distribution and threats*. Springer, The Netherlands. Pp. 577–596.

Lyons EE and Miller SC (2000). Invasive species in Eastern Africa: proceedings of a workshop held at ICIPE, July 5–6, 1999. ICIPE Science Press, Nairobi, Kenya.

Ma X, Bangxi X, Yindong W and Mingxue W (2003). Intentionally introduced and transferred fishes in China's inland waters. *Asian Fisheries Science* 16:279–290.

Macdonald IAW, Reaser JK, Bright C, Neville LE, Howard GW, Murphy SJ and Preston, G (Eds) (2003a). Invasive alien species in southern Africa: national reports & directory of resources. Global Invasive Species Programme, Cape Town, South Africa.

Macdonald IAW, Reaser JK, Bright C, Neville LE, Howard GW, Murphy SJ and Preston G (Eds) (2003b). Prevention and management of Invasive alien species. Proceedings of a workshop on forging cooperation throughout southern Africa. 10–12 June 2002, Lusaka, Zambia. Global Invasive Species Programme, Cape Town, South Africa.

Macdonald J and Tonkin Z (2008). A review of the impact of eastern gambusia on native fishes of the Murray-Darling Basin. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria

McDowall RM (2006). Fish, fish habitats and fisheries in New Zealand. *Aquatic Ecosystem Health and Management* 9:391–405.

Maceina MJ, Slipke JW and Grizzle JM (1999). Effectiveness of three barrier types for confining grass carp in embayments of Lake Seminole, Georgia. *North American Journal of Fisheries Management* 19:968–976.

Maciolek JA (1984). Exotic fishes in Hawaii and other islands of Oceania. In: WR Courtenay and JR Stauffer (Eds), *Distribution, biology, and management of exotic fishes*. Johns Hopkins University Press, Baltimore. Pp 131–161.

MacIsaac HJ, Grigorovich IA and Ricciardi A (2001). Reassessment of species invasion concepts: the Great Lakes basin as a model. *Biological Invasions* 3:405–416.

Mack RN, Simberloff D, Lonsdale MW, Evans H, Clout M and Bazzaz FA (2000). Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10:689–710.

Maes J, Turnpenny AWH, Lambert DR, Nedwell JR, Parmentier A. and Ollevier F (2004). Field evaluation of a sound system to reduce estuarine fish intake rates at a power plant cooling water inlet. *Journal of Fish Biology* 64:938–946.

MAFBNZ (2003). Tiakina Aotearoa, Protect New Zealand: the biosecurity strategy for New Zealand. MAFBNZ, Wellington.

Maitland PS (2004). Evaluating the ecological and conservation status of freshwater fish communities in the United Kingdom. In Commissioned Report No. 001: Scottish Natural Heritage.

Marchetti MP, Moyle PB and Levine R (2004). Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. *Freshwater Biology* 49:646–661.

Mattes WP (2008). Trapping activities and population estimates of adult sea lamprey in tributaries of Lake Superior during 2008. Great Lakes Indian Fish and Wildlife Commission, Odanah.

McDowall RM (2004). Shoot first, and then ask questions: a look at aquarium fish imports and invasiveness in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 38:503–510.

McIntosh D, King C and Fitzsimmons K (2003). Tilapia for biological control of giant salvinia. *Journal of Aquatic Plant Management* 41:28–31.

McKay RJ (1984). Introductions of exotic fishes in Australia. In: WR Courtenay JR Stauffer (Eds), *Distribution, biology and management of exotic fishes*. John Hopkins University Press, Baltimore.

McLain AL (1957). The control of the upstream movement of fish with pulsated direct current. *Transactions of the American Fisheries Society* 86:269–284.

McLeod R (2004). Counting the cost: impact of invasive animals in Australia 2004. Cooperative Research Centre for Pest Animal Control, Canberra.

McNee A (2002). A national approach to the management of exotic fish species in the aquarium trade: an inventory of exotic fish species. Report for the Fisheries Resources Research Fund, Commonwealth of Australia, Canberra.

McNeely JA, Mooney HA, Neville LE, Schei P and Waage JK (Eds) (2001). A Global Strategy on Invasive Alien Species. IUCN, Gland, Switzerland and Cambridge, UK.

Meador MR, Brown LR and Short T (2003). Relations between introduced fish and environmental conditions at large geographic scales. *Ecological Indicators* 3:81–92.

Meffe GK and Snelson FFJ (1989). An ecological overview of poeciliid fishes. In: GK Meffe and FF Snelson (Ed), *Ecology and evolution of live bearing fishes (Poeciliidae)*. Prentice Hall, New Jersey.

Michaud DT and Taft EP (2000). Recent evaluations of physical and behavioral barriers for reducing fish entrainment at hydroelectric plants in the upper Midwest. *Environmental Science and Policy* 3:499–512.

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: biodiversity synthesis. World Resources Institute, Washington, DC.

Miller C, Kettunen M and Shine C (2006). Scope options for EU action on invasive alien species (IAS). Final report for the European Commission. Institute for European Environmental Policy (IEEP), Brussels, Belgium.

Mills EL, Leach JH, Carlton JT and Secor CL (1993). Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. *Journal of Great Lakes Research* 46:1–54.

Milner R (2006). *Gambusia holbrooki*: a management guide and workbook. Natural Heritage Trust, Launceston.

Minister of Supply and Services Canada (1995). Canadian biodiversity strategy: Canada's response to the Convention on Biological Diversity.

Ministerial Council on Forestry Fisheries and Aquaculture (1999). National Policy for the Translocation of Live Aquatic Organisms — issues, principles and guidelines for implementation. Bureau of Rural Sciences, Kingston, ACT.

Molony B, Beatty SJ, Bird C and Nguyen V (2005). Mitigation of the negative impacts on biodiversity and fisheries values of the refurbishment of Waroona Dam, south-western Australia. Final report for the Water Corporation of Western Australia. Fisheries Research Contract Report No. 12. Department of Fisheries, Western Australia. 90pp.

Mooney HA, Mack R, McNeelet A, Neville L, Schei P and Waage J (2005). Invasive alien species: a new synthesis. Island Press, Washington (DC).

Moore P (2005). Overview of selected international agreements related to alien species in aquatic ecosystems. In: DM Bartley, RC Bhujel, S Funge-Smith, PG Olin and MJ Phillips (Eds), *International mechanisms for the control and responsible use of alien species in aquatic ecosystems*. Report of an Ad Hoc Expert Consultation. Xishuangbanna, People's Republic of China, 27–30 August 2003. FAO, Rome. Pp 51–68.

Morgan DA and Beatty SJ (2006a). Overview of the feral goldfish control programme in the Vasse River, Western Australia: 2004–2006. Report to the GeoCatch. Centre for Fish and Fisheries Research, Murdoch University, Murdoch, Western Australia. 16pp.

Morgan DL and Beatty SJ (2006b). Re-establishment of native freshwater fishes in Bull Creek. Report prepared for Melville City Council. Centre for Fish and Fisheries Research, Murdoch University, Murdoch, Western Australia.

Morgan DA, Beatty SJ and McLetchie H (2005). Control of feral goldfish (*Carassius auratus*) in the Vasse River. Report to the Vasse-Wonnerup LCDC. Centre for Fish and Fisheries Research, Murdoch University, Murdoch, Western Australia. 9pp.

Morris KH and Maitland PS (1987). A trap for catching adult lampreys (Petromyzonidae) in running water. *Journal of Fish Biology* 31:513–516.

Moyle PB and Light T (1996). Biological invasions of fresh water: empirical rules and assembly theory. *Biological Conservation* 78:149–161.

Moyle PB and Marchetti MP (2006). Predicting invasion success: freshwater fishes in California as a model. *Bioscience* 56:515–524.

Murray–Darling Basin Ministerial Council (2004). Native fish strategy for the Murray–Darling Basin 2003–2013. Murray–Darling Basin Commission, Canberra ACT.

National Invasive Species Council (NISC) (2001). Meeting the invasive species challenge: National Invasive Species Management Plan. Washington, DC. 80pp.

National Invasive Species Council (NISC) (2003). General guidelines for the establishment and evaluation of invasive species early detection and rapid response systems. 16pp.

National Invasive Species Council (NISC) (2008). 2008–2012 National Invasive Species Management Plan. Washington, DC. 35pp.

National Steering Committee on Recreational Fishing (2004). The National Recreational Fishing Policy. Department of Primary Industries and Energy, Canberra ACT.

Natural Resource Management Ministerial Council (2006). A strategic approach to the management of ornamental fish in Australia. Bureau of Rural Sciences, Canberra, ACT.

Natural Resource Management Ministerial Council (2007). Australian pest animal strategy — a national strategy for the management of vertebrate pest animals in Australia. Department of the Environment and Water Resources, Canberra, ACT.

Nemeth RS and Anderson JJ (1992). Response of juvenile coho and chinook salmon to strobe and mercury vapor lights. *North American Journal of Fisheries Management* 12:684–692.

Nestler JM, Ploskey GR, Pickens J, Menezes JK and Schilt C (1992). Responses of black herring to high frequency sound and implications for reducing entrainment at hydropower dams. *North American Journal of Fisheries Management* 12:667–683.

Nishizawa E, Kurokawa T and Yabe M (2006). Policies and resident's willingness to pay for restoring the ecosystem damaged by alien fish in Lake Biwa, Japan. *Environmental Science and Policy* 9:448–456.

Northern Territory Government Department of Regional Development, Primary Industry Fisheries and Resources. (2008). Fishery Status Reports 2007, Fishery Report No. 94. Northern Territory Government Department of Regional Development, Primary Industry Fisheries and Resources, Darwin.

Novak SJ (2007). The role of evolution in the invasion process. *Proceedings of the National Academy of Sciences* 104:3671–3672.

NSW Department of Primary Industries (2009). Recreational fishers make things happen! Stories about fishers improving fish habitat and making more fish naturally. NSW Department of Primary Industries, Orange, NSW.

NSW Department of Primary Industries (NSW DPI) (2008). NSW Invasive species plan 2008–2015. NSW Department of Primary Industries, Orange, NSW.

NSW State Emergency Management Committee (2009). New South Wales state disaster plan — DISPLAN 2009. State Emergency Management Committee, Sydney NSW.

O'Sullivan D, Clark E and Morison J (2008). The Australian Ornamental Fish Industry in 2006/07: Fisheries Research and Development Corporation, Department of Agriculture, Fisheries and Forestry, Dosaqua Pty Ltd and EconSearch Pty Ltd.

Office of the Emergency Services Commissioner (2009). Victorian emergency management manual. Office of the Emergency Services Commissioner, Melbourne, Victoria.

Ogutu-Ohwayo R and Balirwa JS (2006). Management challenges of freshwater fisheries in Africa. *Lakes and Reservoirs: Research and Management* 11:215–226.

O'Keefe N and Turnpenny AWH (2005). Screening for intake and outfalls: a best practice guide. Environment Agency, Bristol.

Olden JD, Kennard MJ and Pusey BJ (2008). Species invasions and the changing biogeography of Australian freshwater fishes. *Global Ecology and Biogeography* 17:25–37.

O'Meara J and Darcovich K (2008). Gambusia control through the manipulation of water levels in Narawang Wetland, Sydney Olympic Park 2003–2005. *Australian Zoologist* 34:285–290.

O'Neill CRJ and Dextrase AJ (1994). The introduction and spread of the zebra mussel in North America, Madison, Wisconsin. In: *Proceedings of the fourth international zebra mussel conference*. Pp 433–446.

Ortega H, Guerra H and Ramirez R (2007). The introduction of nonnative fish into freshwater systems in Peru. In: TM Bert (Ed), *Ecological and genetic implication of aquaculture activities* Springer, Netherlands. Pp 247–278.

Pallewatta N, Reaser JK and Gutierrez AT (Eds) (2003a). Invasive alien species in south-southeast Asia: national reports and directory of resources. Global Invasive Species Programme, Cape Town, South Africa.

Pallewatta N, Reaser JK and Gutierrez AT (Eds) (2003b). Prevention and management of invasive alien species. Proceedings of a workshop on forging cooperation throughout south and southeast Asia. 14–16 August 2002, Bangkok, Thailand. Global Invasive Species Programme, Cape Town, South Africa.

Palmisano AN and Burger CV (1988). Use of a portable electric barrier to estimate chinook salmon escapement in a turbid Alaskan River. *North American Journal of Fisheries Management* 8:475–480.

Parker IM, Simberloff D, Lonsdale WM, Goodell K, Wonham, M, Kareiva, PM, Williamson, MH, Von Holle B, Moyle PB, Byers JE and Goldwasser L (1999). Impact: toward a framework for understanding the ecological effects of invaders. *Biological Invasions* 1:3–19.

Parker MA (2001). Mutualism as a constraint on invasion success for legumes and rhizobia. *Diversity and Distributions* 7: 125–136.

Patrick PH, Christie AE, Sager D, Hocutt C and Stauffer J (1985). Responses of fish to a strobe light/ air-bubble barrier. *Fisheries Research* 3:157–172.

Pavlov DS (1989). Structures assisting the migrations of non-salmonid fish: USSR FAO Fisheries Technical Paper No. 308. Fisheries and Agriculture Organisation of the United Nations, Rome

Petr T (2000). Interactions between fish and aquatic macrophytes in inland waters. A review. Rome: FAO.

Pierce BE (1991). Aquarium fish: Unwanted aquarium fish removed again! *Safish* 1991:10–11.

Pimentel D, Zuniga R and Morrison D (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52:273–288.

Pinto L, Chandrasena N, Pera J, Hawkins P, Eccles D and Sim R (2005). Managing invasive carp (*Cyprinus carpio* L.) for habitat enhancement at Botany Wetlands, Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15:447–462.

Pompeu PS and Alves CBM (2003). Local fish extinction in a small tropical lake in Brazil. *Neotropical Ichthyology* 1:133–135.

Popper AN and Carlson TJ (1998). Application of sound and other stimuli to control fish behaviour. *Transactions of the American Fisheries Society* 127:673–707.

Povz M and Sumer S (2005). A brief review of non-native freshwater fishes in Slovenia. *Journal of Applied Ichthyology* 21:316–318.

Pyke GH (2008). Plague minnow or mosquito fish? A review of the biology and impacts of introduced *Gambusia* species. *Annual Review of Ecology, Evolution, and Systematics* 39:171–191.

Quinn JW and Kwak TJ (2003). Fish assemblage changes in an Ozark river after impoundment: a long-term perspective. *Transactions of the American Fisheries Society* 132:110–119.

ASFB (2002). Alien zone No. II. *Australian Society for Fish Biology Newsletter* 32(2): 60–68.

ASFB (2003a). Alien zone No. III. *Australian Society for Fish Biology Newsletter* 33(1):45–53.

ASFB (2003b). Alien zone No. 4. *Australian Society for Fish Biology Newsletter* 33(2):44–51.

ASFB (2005a). Alien zone No. 7. *Australian Society for Fish Biology Newsletter* 35(1): 48-58.

ASFB (2005b). Alien zone No. 8. *Australian Society for Fish Biology Newsletter* 35(2):71–87.

ASFB (2006). Alien zone No. 9. *Australian Society for Fish Biology Newsletter* 36(1):55–68.

ASFB (2007). Alien zone No. 12. *Australian Society for Fish Biology Newsletter* **37**(2), 81–100.

ASFB (2008). Alien zone No. 13. *Australian Society for Fish Biology Newsletter* **38** (1).

Rahel FJ (2007). Biogeographic barriers, connectivity and homogenization of freshwater faunas: it's a small world after all. *Freshwater Biology* 52:696–710.

Rayner TS and Creese RG (2006). A review of rotenone use for the control of non-indigenous fish in Australian fresh waters, and an attempted eradication of the noxious fish, *Phalloceros caudimaculatus*. *New Zealand Journal of Marine and Freshwater Research* 40:477–486.

Reaser JK, Meyerson LA, Cronk Q, De Poorter M, Eldrege LG, Green E, Kairo M, Latasi P, Mack RN, Mauremootoo J, O'Dowd D, Orapa W, Sastroutomo S, Saunders A, Shine C, Thrainsson S and Vaiutu L (2007). Ecological and socioeconomic impacts of invasive alien species in island ecosystems. *Environmental Conservation* 34:98–111.

Ribeiro F, Elvira B, Collares-Pereira M and Moyle P (2008). Life-history traits of non-native fishes in Iberian watersheds across several invasion stages: a first approach. *Biological Invasions* 10:89–102.

Ricciardi A (2001). Facilitative interactions among aquatic invaders: is an 'invasional meltdown' occurring in the Great Lakes? *Canadian Journal of Fisheries* and *Aquatic Sciences* 58;2513–2525.

Ricciardi A and MacIsaac HJ (2000). Recent mass invasion of the North American Great Lakes by Ponto-Caspian species. *Trends in Ecology and Evolution* 15:62–65.

Ricciardi A and Rasmussen JB (1998). Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. *Canadian Journal of Fisheries* and *Aquatic Sciences* 55:1759–1765.

Richards NS, Chipps SR and Brown ML (2007). Stress response and avoidance behavior of fishes as influenced by high-frequency strobe lights. *North American Journal of Fisheries Management* 27:1310–1315.

Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Dane Panetta F and West CJ (2000). Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* 6:93–107.

Rilov G, Benayahu Y and Gasith A (2004). Prolonged lag in population outbreak of an invasive mussel: a shifting-habitat model. *Biological Invasions* 6:347–364.

Rivinoja P, McKinnell S and Lundqvist H (2001). Hindrances to upstream passage of Atlantic salmon (*Salmo salar*) in a northern Swedish river caused by a hydroelectric powerstation. *Regulated Rivers Research and Management* 17:101–115.

Rixon CAM, Duggan IC, Bergeron NMN, Ricciardi A and MacIsaac HJ (2005). Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. *Biodiversity and Conservation* 14:1365–1381.

Roberts J and Tilzey R (Eds) (1997). Controlling carp: exploring the options for Australia. CSIRO Land and Water, Griffith NSW.

Rocha GRA and Schiavetti A (2007). Diversity of fish and fisheries from the Lake Encantada Environmental Protection Area, Ilhéus, Brazil. *Aquatic Conservation: Marine and Freshwater Ecosystems* 17:702–711.

Rodríguez CF, Bécares E, Fernández-aláez M and Fernández-aláez C (2005). Loss of diversity and degradation of wetlands as a result of introducing exotic crayfish. *Biological Invasions* 7:75–85.

Roll U, Dayan T, Simberloff D and Goren M (2007). Characteristics of the introduced fish fauna of Israel. *Biological Invasions* 9:813–824.

Roman J (2006). Diluting the founder effect: cryptic invasions expand a marine invader's range. *Proceedings of the Royal Society of London B* 273:2453–2459.

Ross QE, Dunning DJ, Menezes JK, Kenna MJ and Tiller G (1996). Reducing impingement of alewives with high-frequency sound at a power plant intake on Lake Ontario. *North American Journal of Fisheries Management* 16:548–559.

Rowe D (2004). Exotic fish: a growing problem in New Zealand fresh waters. *Water and Atmosphere*. 12(3):18–19.

Rowe DK, Moore A, Giorgetti A, Maclean C, Grace P, Wadhwa S and Cooke J (2008). Review of the impacts of gambusia, redfin perch, tench, roach, yellowfin goby and streaked goby in Australia. Prepared for the Australian Government Department of the Environment, Water, Heritage and the Arts.

Ruesink JL (2005). Global analysis of factors affecting the outcome of freshwater fish introductions. *Conservation Biology* 19:1883–1893.

Rutledge W, Rimmer M, Russell J, Garrett R and Barlow C (2008). Cost benefit of hatchery-reared barramundi, *Lates calcarifer* (Bloch), in Queensland. *Aquaculture Research* 21:443–448.

Sakai AK, Allendorf FW, Holt JS, Lodge DM, Molofsky J, With KA, Baughman S, Cabin RJ, Cohen JE, Ellstrand NC, McCauley DE, O'Neil P, Parker IM, Thompson JN and Weller SG (2001). The population biology of invasive species. *Annual Review of Ecology and Systematics* 32:305–332.

Sala OE, Iii FSC, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M and Wall DH (2000). Global biodiversity scenarios for the year 2100. *Science* 287:1770.

Sand A, Enger PS, Karlsen HE, Knudsen FR and Kvernstuen T (2000). Avoidance responses to infrasound in downstream migrating European silver eels, *Anguilla anguilla*. *Environmental Biology of Fishes* 57:327–336.

Sand O and Karlsen HE (1986). Detection of infrasound by the Atlantic cod. *Journal of Experimental Biology* 125:197–204.

Sanger AC and Koehn JD (1997). Use of chemicals for carp control. In: J Roberts and R Tilzey (Eds), *Controlling carp: exploring the options for Australia*. CSIRO Land and Water, Griffith NSW.

Satia BP and Bartley DM (1998). The paradox of international introductions of aquatic organisms in Africa. In: JF Agnese (Ed), *Genetics and aquaculture in Africa*. ORSTOM Editions, Paris, France. Pp 115–124.

Savino JF, Jude DJ and Kostich MJ (2001). Use of electrical barriers to deter movement of Round Goby. In: C Coutant (Ed), *Behavioural technologies for fish guidance*. American Fisheries Society Symposium 26, Bethesda, Maryland. Pp 171–182.

Shea K and Chesson P (2002). Community ecology as a framework for biological invasions. *Trends in Ecology* and *Evolution* 17:170–176.

Shine C (2007). Invasive species in an international context: IPPC, CBD, European Strategy on Invasive Alien Species and other legal instruments*. *EPPO Bulletin* 37:103–113.

Shine C, Williams N and Gündling L (2000). A guide to designing legal and institutional frameworks on alien invasive species. IUCN, Gland, Switzerland: Cambridge and Bonn.

Simon KS and Townsend CR. (2003). Impacts of freshwater invaders at different levels of ecological organisation, with emphasis on salmonids and ecosystem consequences. *Freshwater Biology* 48:982–994.

Singh AK and Lakra WS (2006). Alien fish species in India: Impact and emerging scenario. *Journal of Ecophysiology and Occupational Health* 6:165–174.

SKM (2008). An overview of the impacts of translocated native fish species in Australia. Prepared for the Australian Government Department of the Environment and Water Resources.

Slootweg R, Malek EA and McCullough FS (1994). The biological control of snail intermediate hosts of schistosomiasis by fish. *Reviews in Fish Biology and Fisheries* 4:67–90.

Smith RD, Aradottir GI, Taylor A and Lyal C (2008). Invasive species management – what taxonomic support is needed? Global Invasive Species Programme, Nairobi, Kenya

Smith WS, Petrere MJ and Barrella V (2007). Fish, Sorocaba river sub-basin, state of Sao Paulo, Brazil. *Check List* 3:282–286.

Smith-Root Inc. (2009). Fish barriers and guidance. Smith-Root website (www.smith-root.com)

Solomon DJ (1992). Diversion and entrapment of fish at water intakes and outfalls. R&D report no. 1. National Rivers Authority, Bristol. 51pp.

Sonny D, Knudsen FR, Enger PS, Kvernstuen T and Sand O (2006). Reactions of cyprinids to infrasound in a lake and at the cooling water inlet of a nuclear power plant. *Journal of Fish Biology* 69:735–748.

Sorensen PW and Hoye TR (2007). A critical review of the discovery and application of a migratory pheromone in an invasive fish, the sea lamprey *Petromyzon marinus* L. *Journal of Fish Biology* 71:100–114.

Sorensen PW and Stacey, NE (2004) Brief review of fish pheromones and discussion of their possible uses in the control of non-indigenous teleost fishes. *New Zealand Journal of Marine and Freshwater Researc*h 38:399–417.

Starling F, Lazzaro X, Cavalcanti C and Moreira R (2002). Contribution of omnivorous tilapia to eutrophication of a shallow tropical reservoir: evidence from a fish kill. *Freshwater Biology* 47:2443–2452.

Stephens BE, Borwick J and Brownson B (2007). Use of rotenone to eradicate the round goby (*Neogobius melanostomus*) in Pefferlaw Brook. In: *15th International conference on aquatic invasive species*. Nijmegen, The Netherlands.

Stewart PAM. (1981). An investigation into the reactions of fish to electrified barriers and bubble curtains. *Fisheries Research* 1:3–22.

Stober QJ, Tyler RW and Petrosky CE (1983). Barrier net to reduce entrainment losses of adult kokanee from Banks Lake, Washington. *North American Journal of Fisheries Management* 3:331–354.

Stokstad E (2003). Can well-timed jolts keep out unwanted exotic fish? *Science* 301:157–159.

Stuart IG and Jones MJ (2002). Ecology and management of common carp in the Barmah-Millewa forest. Final report to AFFA, p. 214. Arthur Rylah Institute, Heidelberg, Victoria

Stuart IG, Williams A, McKenzie J and Holt T (2003). Separation cages for removal of carp from Murray-Darling Basin fishways. Final report of project R2104 to the Murray-Darling Basin Commission.

Stuart IG, Williams A, McKenzie J and Holt T (2006). Managing a migratory pest species: a selective trap for common carp. *North American Journal of Fisheries Management* 26:888–893.

Suarez AV and Tsutsui ND (2008). The evolutionary consequences of biological invasions. *Molecular Ecology* 17:351–360.

Swink WD (1999). Effectiveness of an electrical barrier in blocking a sea lamprey spawning migration on the Jordan River, Michigan. *North American Journal of Fisheries Management* 19:397–405.

Sydney Coastal Member Councils (2004). Sydney Coastal Member Councils Activities report June 2004.

Taft EP (1986). Assessment of downstream migrant fish protection technologies for hydroelectric application — EPRI research project 2694–1. Boston: Stone and Webster Engineering Corporation.

Taft E, Garnett G and Amaral S (1999). Fish protection at cooling water intakes. Status report. California: Electrical Power Research Institute.

Tasmanian Biosecurity Committee (2006). Tasmanian biosecurity strategy. Department of Primary Industries and Water, Devonport, Tasmania

Taylor RM, Pegg MA and Chick JH (2005). Response of bighead carp to a bioacoustic behavioural fish guidance system. *Fisheries Management* and *Ecology* 12:283–286.

Therrien J and Bourgeois G (2000). Fish passage at small hydro sites. Report by Genivar Consulting Group for CANMET Energy Technology Centre. Ottawa, Canada.

Thorncraft G and Harris JH (2000). Fish passage and fishways in New South Wales: A status report. Cooperative Research Centre for Freshwater Ecology, Sydney.

Thwaites L, Fleer D and Smith B (2007). Conceptual development of a 'finger' style pushing trap for common carp. SARDI Aquatic Sciences Publication Number F2007/000790–1.SARDI Research Report Series Number 238. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 33pp.

Tuma D (1990). Control of noxious fish populations in Queensland. In: D Pollard (Ed), *Introduced and translocated fishes and their ecological effects*. Australian Government Publishing Service, Canberra. 93pp.

Turnpenny AWH (1993). Bubble curtain fish exclusion trails at Heysham 2 power station. Fawley ARl Ltd. Client report to Nuclear Electric plc, Report no. FCR 037/93.

Turnpenny AWH, Struthers G and Hanson KP (1998). A UK guide to intake fish-screening regulations, policy and best practice. Crown, UK.

Tuunainen P, Ikonen E and Auvinen H (1980). Lampreys and lamprey fisheries in Finland. *Canadian Journal of Fisheries and Aquatic Science* 37:1953–1959.

Twong'o TK and Sikoyo G (2003). Status of Lake Victoria ecosystems. African Centre for Technology Studies (ACTS), Nairobi, Kenya.

UNEP (2001). Invasion alien species: comprehensive review of activities for the prevention, early detection, eradication and control of invasive alien species.

Valero A, Macías Garcia C and Magurran AE (2008). Heterospecific harassment of native endangered fishes by invasive guppies in Mexico. *Biology letters* 4 (2):149–152.

Vermeij GJ (1996). An agenda for invasion biology. *Biological Conservation* 78:3–9.

Verreycken H, Anseeuw D, Van Thuyne G, Quataert P and Belpaire C (2007). The non-indigenous freshwater fishes of Flanders (Belgium): review, status and trends over the last decade. *Journal of Fish Biology* 71:160–172.

Verrill DD and Berry CR (1995). Effectiveness of an Electrical Barrier and Lake Drawdown for Reducing Common Carp and Bigmouth Buffalo Abundances. *North American Journal of Fisheries Management* 15:137–141.

Vila-Gispert A, Alcaraz C and García-Berthou E (2005). Life-history traits of invasive fish in small Mediterranean streams. *Biological Invasions* 7:107–116.

Vitousek PM, D'Antonio CM, Loope LL, Rejmanek M and Westbrooks R (1997). Introduced species: A significant component of human-caused global change. *New Zealand Journal of Ecology* 21:1–16.

Vitule J, Umbria S and Aranha J (2006). Introduction of the African Catfish *Clarias gariepinus* (Burchell, 1822) into southern Brazil. *Biological Invasions* 8: 677–681.

Wagner CM, Michael LJ, Michael BT and Peter WS (2006). A field test verifies that pheromones can be useful for sea lamprey (*Petromyzon marinus*) control in the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 63:475.

Washington Department of Fish and Wildlife (2000). Draft — Fish protection screen guidelines for Washington State. Washington: Washington Department of Fish and Wildlife.

Welcomme RL (1984). International transfers of inland fish species. In: WR Courtenay Jr and JR Stauffer Jr (Eds), *Distribution, biology and management of exotic fishes*. Johns Hopkins University Press, Baltimore, USA. Pp. 22–40.

Wells A (2007). Community understanding and attitudes to alien fish. In: D Ansell and P Jackson (Eds), *Emerging issues in alien fish management in the Murray–Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Brisbane Qld 30–31 May 2006*. Murray–Darling Basin Commission, Canberra.

Wells FE, McDonald JI and Huisman JM (2009). Introduced marine species in Western Australia. Department of Fisheries, Perth, Western Australia.

Wells RDS, Bannon HJ and Hicks BJ (2003). Control of macrophytes by grass carp *(Ctenopharyngodon idella*) in a Waikato drain, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 37:85–93.

Welton JS, Beaumont WRC and Clarke RT (2002). The efficacy of air, sound and acoustic bubble screens in deflecting Atlantic salmon, *Salmo salar* L., smolts in the River Frome, UK. *Fisheries Management* and *Ecology* 9:11–18.

West P, Brown A and Hall K (2007). Review of alien fish monitoring techniques, indicators and protocols: Implications for national monitoring of Australia's inland river systems. Invasive Animals Cooperative Research Centre, Canberra.

Westphal M, Browne M, MacKinnon K and Noble I (2008). The link between international trade and the global distribution of invasive alien species. *Biological Invasions* 10:391–398.

Weyl O (2008). Rapid invasion of a subtropical lake fishery in central Mozambique by Nile tilapia, *Oreochromis niloticus* (Pisces: Cichlidae). *Aquatic Conservation: Marine and Freshwater Ecosystems* 18:839–851.

Whalls MJ, Shetter DS and Vondett JE (1957). A simplified rotary fish screen and an automatic water gate. *Transactions of the American Fisheries Society* 86:371–380.

Whittingham RJ and Chong R (2007). Global trade in ornamental fish from an Australian perspective: The case for revised import risk analysis and management strategies. *Preventive Veterinary Medicine* 81:92–116.

Wijeyaratne MJS and Perera WMDSK (2001). Trophic interrelationships among the exotic and indigenous fish co-occurring in some reservoirs in Sri Lanka. *Asian Fisheries Science* 14:333–342.

Williamson M and Fitter A (1996b). The varying success of invaders. *Ecology* 77:1661–1666.

Williamson MH and Fitter A (1996a). The characters of successful invaders. *Biological Conservation* 78:163–170.

Wing L (1943). Spread of the starling and English sparrow. *The Auk* 60:74–87.

Wittenberg R and Cock MJW (Eds) (2001). Invasive alien species: a toolkit of best prevention and management practices. CAB International, Wallingford, Oxon, UK.

Ziller SR, Reaser JK, Neville LE and Brandt K (Eds) (2005a). Invasive alien species in South America: national reports & directory of resources. Global Invasive Species Programme, Cape Town, South Africa.

Ziller SR, Neville LE, Rieser JK and Brand K (Eds) (2005b). Prevention and management of invasive alien species: proceedings of a workshop on forging cooperation throughout South America. Global Invasive Species Programme, Cape Town, South Africa.

Personal communication

Astbury C (2008). Department of Fisheries, Western Australia

Bishop K (2008). Glenelg Hopkins Catchment Management Authority

Bissmire S (2008). MAF Biosecurity New Zealand

Brooks S (2008). Department of Employment, Economic Development and Innovation, Queensland

Challen S (2008). Department of Employment, Economic Development and Innovation, Queensland (MDBA Native fish strategy coordinator)

Clunie P (2008). Department of Sustainability and Environment, Arthur Rylah Institute, Victoria

Coleman R (2009). Melbourne Water

Cribb H (2009). Department of Resources – Primary Industry, Fisheries and Resources, Northern Territory (Aquatic Biosecurity)

Diggle J (2008). Inland Fisheries Service, Tasmania

Frances J (2008). Department Industry and Investment, New South Wales

Fulton W (2008). Department of Primary Industries, Victoria

Gilliland J (2009). Department of Primary Industries and Resources, South Australia

Kearns J (2009). Department of Sustainability and Environment, Arthur Rylah Institute, Victoria

McKenzie J (2008). Department of Sustainability and Environment, Arthur Rylah Institute, Victoria

McNeil D (2008). South Australian Research and Development Institute

Sarac Z (2009). Department of Employment, Economic Development and Innovation, Queensland

Scurr G (2008). Tamar region natural resource management

Smith B (2009). South Australian Research and Development Institute

Walker M (2009). Department Industry and Investment, New South Wales

Willett D (2009). Department of Employment, Economic Development and Innovation, Queensland

Glossary

Alien species (non-native, non-indigenous, foreign, exotic) A species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (ie outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce.

Biosecurity The protection of the economy, the environment, society amenity or human health from negative impacts associated with alien species.

Containment Limiting the spread of the alien invasive species and containing its presence within defined geographical boundaries.

Control The application of measures to contain the distribution of and/or reduce the abundance of an alien species according to prescribed standards and for defined periods, with a view to limiting the alien species impacts to acceptable levels.

Emergency response Actions taken in anticipation of, during, and immediately after an emergency to ensure that its effects are minimised.

Eradication The complete removal of a population of a targeted species in a set area within a defined timeframe.

Establishment The process of a species in a new habitat successfully reproducing at a level sufficient to ensure continued survival without infusion of genetic material from outside the system.

Fish In the context of this review, fish also includes crayfish.

Intentional introduction An introduction made deliberately by humans, involving the purposeful movement of a species outside of its natural range and dispersal potential (such introductions may be authorised or unauthorised).

Introduction The movement, by human agency, of a species, subspecies, or lower taxon (including any part, gametes or propagule that might survive and subsequently reproduce) outside its natural range (past or present). This movement can be either within a country or between countries.

Invasive species An alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity.

Management Application of skills or care in the use, manipulation, treatment or control of things or people, or in the conduct of an activity, operation or enterprise.

Native species (indigenous) A species, subspecies, or lower taxon, occurring within its natural range (past or present) and dispersal potential (ie within the range it occupies naturally or could occupy without direct or indirect introduction or care by humans).

Noxious species A term used in government legislation for listing unwanted species which are subject to regulations attempting to control their import or spread.

Pathway The geographic route taken by one or more vectors from point A to point B.

Translocate/Translocation Any deliberate or unintentional movement of an organism or its propagules between disjunct sites beyond their natural range but within the country of origin.

Unintentional introduction An unintended introduction made as a result of a species utilising humans or human delivery systems as vectors for dispersal outside its natural range.

Vector The physical means, agent or mechanism which facilitates the transfer of organisms from one place to another (see *Pathway*).

PESTSMART

feral.org.au

ISBN: 978-1-921777-20-2
Web ISBN: 978-1-921777-21-9