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Priority management actions for alien freshwater fish species in Australia

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Abstract In Australia, alien freshwater fish are continuing to steadily increase in number of species (reported in this paper to be 43), abundance, and distribution. In general however, their impacts are not well quantified in either environmental or economic terms and current management to reduce their impacts is limited and lacking direction. Although carp *Cyprinus carpio* have received some attention, very little is known about the impacts and even the distribution of most species. There is a lack of recognition of the problem, inconsistency in legislation, policy, and approaches across jurisdictions, and no nationally coordinated on-the-ground management actions. Where legislation and policy is available it is not always used to good effect. This paper provides a synthesis of existing knowledge of alien fishes in Australia, suggests a new management approach, and recommends priority management actions.

Keywords invasive fishes; control; impacts; management; benefit:cost; carp

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INTRODUCTION

Alien fish species have received considerable attention internationally with the integrity of aquatic ecosystems being challenged worldwide by species' invasions (Moyle & Light 1996). Biological exchange is considered a relatively more important threat to the biodiversity of freshwater ecosystems compared to other ecosystems because of the intentional and unintentional release of organisms (Sala et al. 2000). The resultant loss of biodiversity caused by alien species is generally severe and well documented (Lodge & Shrader-Frechette 2003), although such losses have not necessarily been well documented in Australia. Some attention has been focused on assessment of potential invaders, however the most likely short-term impacts of alien species will come from those already present in the country, region, or catchment. Concern has been expressed at the lack of recognition, commitment, consistency of approach, coordination, and on-ground actions in relation to alien freshwater fish species in a deteriorating Australian situation. Although many reviews and management plans have been undertaken, few have been fully implemented or widely published and many only consider individual species or particular areas.

The purpose of this paper is to synthesise the Australian literature (including "grey" literature), identify current management frameworks for invasive freshwater fish species in Australia, assess the current status in terms of species knowledge and management, and suggest a new management approach and a list of priority management actions.

METHODS

Information in this paper has been compiled from existing literature, including unpublished reports, and discussions with State and Commonwealth agencies. However, it does not attempt to provide a comprehensive review of all literature relating to alien fish species. Several general reviews of

established aquatic species have been conducted, covering a range of aspects of their biology and management (Arthington & Mitchell 1986; Arthington 1991; Arthington & Bluhdorn 1995; Arthington & McKenzie 1997; Arthington et al. 1999; Clarke et al. 2000). Recently a range of more detailed reviews for some species and regions have also been produced that include management plans and recommendations and these are listed in Table 3. Unfortunately, most of these publications are not widely available but their recommendations have been collated and have assisted in forming the list of priority actions set out in this paper.

The terminology relating to invasive species is large and many terms are used interchangeably. In this paper, alien species refer to those species intentionally or accidentally dispersed by human agency outside their historically known native range (Department of Primary Industries Queensland (DPIQ) 2001; www:iucn.org/themes/ssc/pubs/policy/invasives). Introduced species are those alien species found in the wild, but not yet breeding successfully, whereas established species refer to those species that have bred successfully and formed a self-sustaining population (Williamson & Fitter 1996). Translocation is the movement of living organisms from one area, with free release into another (www.iucn.org/themes/ssc/pubs/policy.transe.htm). Quite clearly, by definition, the term alien species does include favoured angling species such as brown trout and rainbow trout and Australian species translocated outside their natural range. There has been a traditional reluctance by some fisheries agencies, which actively advocate and stock such species, to adequately address their negative environmental impacts (Jackson et al. 2004). Some alien species also meet the criteria to be considered as pest species, a pest being any species that has a negative economic or ecological impact (Olsen 1998; DPIQ 2001).

Current species status

The total number of alien fish species (31) (Lintermans 2004) established on mainland Australia, is greater than the number of established alien mammals (25) and birds (20) and far more than amphibians (1) or reptiles (4) (Bomford 2001). A total of 43 alien fish species have now been recorded in the wild in Australia (this paper) and McNee (2002) identified 1181 alien freshwater fish species that have been present in Australia, mostly in aquaria, over the past 40 years. Only 481 of these are species on the current permitted import list and other species may be present as the result of illegal imports (Kailola 2000), which are estimated to comprise 5–10% of fish imported into Australia (Australian Quarantine Inspection Service (AQIS) 1999). Australia has five of the world's eight "worst" invasive fish taxa as detailed by the International Union for the Conservation of Nature (Lowe et al. 2000): brown trout (*Salmo trutta* L.), carp (*Cyprinus carpio* L.), Mozambique tilapia (*Oreochromis mossambicus* Peters), rainbow trout (*Oncorhynchus mykiss* (Walbaum)), and gambusia (*Gambusia affinis*/*holbrooki* Baird & Girard).

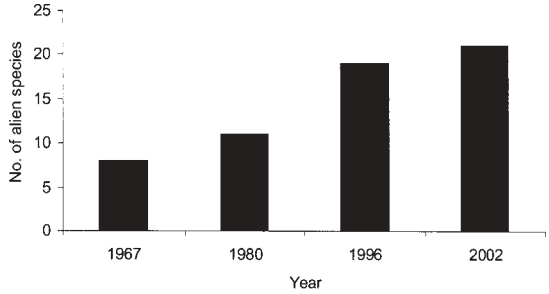

Fig. 1 Numbers of alien fish species reported in popular fish books from 1967 to 2002. Data from: Weatherley & Lake (1967); McDowall (1980, 1996); and Allen et al. (2002).

The number of alien species included in popular fish books may be one measure of public recognition of alien fish species becoming established in Australia. This number of species has grown steadily from eight in 1967 (Weatherley & Lake 1967) to 21 in 2002 (Allen et al. 2002) (Fig. 1). In more specialised publications, McKay (1989) reported the presence of 20 alien freshwater fish, Arthington et al. (1999) reported 37, and this paper reports 43.

Australia has a relatively depauperate freshwater fish fauna by world standards with slightly over 200 species (Allen et al. 2002). More than 16% of these are considered to be under serious conservation threat nationally (Crook 2001) and detrimental interactions with alien species are considered a threat to 77% of these species (Jackson et al. 1993).

The invasion of carp in Australia illustrates how quickly an introduced fish species can spread and dominate fish communities (in numbers and biomass) in the absence of early intervention and an effective management strategy. Following the introduction of the "Boolarra" strain in Victoria in the early 1960s, carp have become the most abundant large freshwater fish in south-east Australia, now

Table 1 Summary of distribution and reason for introduction for established alien freshwater fish species in Australia (Arthington & Bluhdorn 1995; Arthington et al. 1999; Clarke et al. 2000; Clunie et al. 2002). Reason for introduction: P, pet and aquarium; O, ornamental; B, biological control; R, recreational angling; A, aquaculture; and S, ship ballast. (VIC, Victoria; NSW, New South Wales; ACT, Australian Capital Territory; QLD, Queensland; NT, Northern Territory; WA, Western Australia; SA, South Australia; TAS, Tasmania.)

Species				
Family and scientific name	Common name	Reason for introduction	Drainage division	Distribution (States)
SALMONIDAE				
Oncorhynchus mykiss	rainbow trout	R	2, 3, 4, 5, 6	VIC, NSW, ACT, WA, SA, TAS
Salmo trutta	brown trout	R	1, 2, 3, 4, 5, 6	VIC, NSW, ACT, QLD, WA, SA, TAS
Salmo salar	Atlantic salmon	R	2, 3, 4	VIC, NSW, SA, TAS
Salvelinus fontinalis	brook trout	R	2, 3, 4	NSW, TAS
CYPRINIDAE				
Carassius auratus	goldfish	O	1, 2, 3, 4, 5, 6,	VIC, NSW, ACT, QLD, WA, SA, TAS
Cyprinus carpio	carp	O, A	1, 2, 3, 4, 5, 6	VIC, NSW, ACT, QLD, WA, SA, TAS
Rutilus rutilus	roach	R	2, 4	VIC, NSW
Tinca tinca	tench	R	2, 3, 4	VIC, NSW, TAS, SA
COBITIDAE				
Misgurnus anguillicaudatus	oriental weatherloach	O	1, 2, 4, 5	VIC, NSW, ACT, QLD, SA
POECILIIDAE				
Gambusia holbrooki	eastern gambusia	B	1, 2, 3, 4, 5, 6, 7, 8, 10	VIC, NSW, ACT, QLD, NT, WA, SA, TAS
Phalloceros caudimaculatus	caudo/one-spot livebearer	O, B(?)	2, 6	NSW, WA
Poecilia latipinna	sailfin molly	O, B	1	QLD
Poecilia reticulata	guppy	O	1, 2, 6, 8	NSW, QLD, WA, NT
Xiphophorous helleri	green swordtail	O	1, 2, 6, 8, 10	NSW, QLD, WA, NT
Xiphophorous maculatus	platy	O	1, 2, 8, 10	NSW, QLD, NT
PERCIDAE				
Perca fluviatilis	redfin perch	R	2, 3, 4, 5, 6	VIC, NSW, ACT, WA, SA, TAS
CICHLIDAE				
Archocentrus nigrofasciatus	convict cichlid	O	1, 2	VIC, QLD
Astronotus ocellatus	oscar	O	1	QLD
Oreochromis mossambicus	tilapia	O	1, **7**	QLD, WA
Tilapia mariae	black mangrove cichlid	O	1, 2	VIC, QLD
GOBIIDAE				
Acanthogobius flavimanus	yellowfin goby	S	2	VIC, NSW

distributed over more than 1 million km^2 (Koehn et al. 2000). The spread of tilapia in nothern Australia is another example of a species becoming established as a result of a lack of action in the early stages of invasion and continued human movement of fish. Tilapia were released into ornamental ponds in the 1970s and have formed large populations around the cities of Townsville and Cairns (Fig. 1) (Arthington et al. 1984). Tilapia have formed separate, established populations around Brisbane and recently expanded into the Burnett River catchment (DPIQ 2001). Similarly, in Western Australia, tilapia, which were previously restricted to the Gascoyne river in the Pilbara drainage (basin 7), have "spread" to rivers immediately to the north and south (Morgan et al. 2003). Although the distribution of carp and tilapia is reasonably well documented, this is not the situation for most other species. Literature reviews and contact with State agencies have shown that although invasions into new areas are common, few surveys have been conducted, and data have not been collated and are often of poor quality. Reports of many invasions come from the public and research work rather than dedicated alien fish surveys. As such, records of alien species are not reported in a consistent way and even the generalised distributions given in Tables 1 and 2 may be incomplete. In particular, whether or not established populations occur is uncertain for many species.

In addition to alien species, it is believed that at least 51 native fish species have been translocated outside their natural range in Australia (Lintermans 2004). Banded grunter (*Amniataba percoides* Gunther), has been declared a noxious species in

Table 2 Summary of distribution and reason for introduction for introduced alien freshwater fish species in Australia (Allen 1989; Arthington et al. 1999; Raadik 2001, 2003a,b; Webb 1994, cited in Raadik 2003b; Raadik unpubl. data). Reason for introduction: O, ornamental; R, recreational angling. (VIC, Victoria; NSW, New South Wales; ACT, Australian Capital Territory; QLD, Queensland; NT, Northern Territory; WA, Western Australia; SA, South Australia; TAS, Tasmania.)

Family and scientific name	Common name	Reason for introduction	Distribution	
			Basins	States
SALMONIDAE				
Oncorhynchus tshawytscha	Chinook salmon	R	2	VIC
CYPRINIDAE				
Puntius conchonius	rosy barb	O	1, 2	QLD, NSW
Puntius tetrazona	Sumatra barb	O	1	QLD
Tanichthys albonubes	white-cloud mountain minnow	O	2	NSW
CYPRINODONTIDAE				
Jordanella floridae	American flagfish	O	1	QLD
CICHLIDAE				
Aequidens pulchrus	blue acara	O	2	VIC, QLD
Aequidens rivulatus	green terror	O	1	QLD
Amphilophus citrinellus	midas cichlid	O	1	QLD
Amphilophus labiatus	red devil	O	2	VIC
Cichlasoma octofasciatum	Jack Dempsey	O	1	QLD
Cichlasoma severum	banded cichlid	O	1	QLD
Cichlasoma synspilum	redhead cichlid	O	1	QLD
Cichlasoma trimaculatum	three spot cichlid	O	1	QLD
Cichlasoma brasiliensis	pearl cichlid	O	1	QLD
Haplochromis burtoni	Burton's haplochromis	O	1	QLD
Hemichromis guttatus	jewel cichlid	O	1	QLD
Heros severus	green severum	O	1	QLD
Labeotrophus/*Pseudotrophus*	Hybrid?	O	2	VIC
Tilapia zillii	redbelly tilapia	O	1	QLD
Thorichthys meeki	firemouth	O	1	QLD
BELONTIIDAE				
Trichogaster trichopterus	three-spot gourami	O	1	QLD
CYPRINIDAE				
Unidentified cyprinid	?	R, O?	1	QLD

Fig. 2 Map of Australian drainage division boundaries (dotted lines) and State borders (solid lines, bold text).

NSW (NSW Fisheries 2002; Table 1) and concern has been expressed at the potential introduction of Murray cod (*Maccullochella peelii peelii* Mitchell) and golden perch (*Macquaria ambigua* Richardson) into Western Australia for aquaculture and recreational fishing (Morgan et al. 2002). Murray cod have illegally been translocated into waterholes in the south of the Northern Territory, raising concerns that they may find their way onto the Finke River system, a system naturally devoid of a large piscivorous fish (H. Larsen pers. comm.). Native and exotic species may also escape from aquaculture facilities with examples including brown and rainbow trout, the native Australian bass (*Macquaria novemaculeata* Steindachner), trout cod (*Maccullochella macquariensis* Cuvier), and short-finned eels (*Anguilla australis* Richardson). The recent arrival into Victoria of the Barcoo grunter (*Scortum barcoo* McCulloch & Waite), native to Lake Eyre and catchments in Queensland and the Northern Territory, gives cause for concern (Koehn 2002). Records of translocations are erratic, need to be formalised, and should be included as a component of alien species management plans.

Current legislation and management

Australia's 11 main river basin boundaries do not generally coincide with jurisdictional boundaries, meaning that alien fish species are managed, at least in part, by nine different governments (Fig. 2) operating under different legislation, with different management approaches (Arthington & McKenzie 1997). Not surprisingly, there is inconsistency in approach across these jurisdictions. For example, until recently, carp have had a different legal status in States within the Murray-Darling Basin. In Queensland they are declared noxious, which means it is unlawful to possess them live or dead. They are also declared "noxious" in Victoria meaning they cannot be returned to the water alive. However, although they were only declared as a "class 1" noxious species in New South Wales in December 2002, this listing still allows for their continued legal possession, sale, and distribution, including ornamental "Koi" carp (NSW Fisheries 2002). This inconsistency has significant implications for carp dispersal in eastern Australia and it has been recommended that their legal status be changed to enable national coordination to control their spread (Georges & Cottingham 2002). Some States use the terms "controlled", "undesirable", or "pest" in their legislation when referring to alien fish species. The range of terminology used, and inconsistent definitions, make it difficult to compare the legislative status of alien fish between states. The number of taxa listed as "noxious" varies across jurisdictions, from none in the Australian Capital Territory (ACT) to over 80 in Victoria, with many

alien fish species in many States having no legal status at all. It could also be said that where legislation exists, it is generally poorly adhered to, enforced, or publicised. Fisheries compliance is sparcely resourced, is rarely focused on alien fish, and must be accompanied by education aimed to change community attitudes.

It is fair to say that alien fish species management in Australia has been overly focused on carp, with many other damaging species having received little attention (e.g., *Gambusia*, salmonids). Queensland is the only State to develop a multi-species pest management strategy (DPIQ 2001). This document sits under the "Queensland Pest Animal Strategy" (Queensland Department of Natural Resources and Mines 2002) and although a National Carp Strategy was developed and endorsed by the Murray-Darling Basin Ministerial Council, the recommended actions are not necessarily implemented by State agencies. Often, where policy and legislation instruments are available, they have not been used to assist on-ground alien fish species management, and fish are generally not included in State pest management policies. In Victoria, a Potentially Threatening Process encompassing alien fish introductions was listed under the Flora and Fauna Guarantee Act 1992 (Scientific Advisory Committee 1992), but no Action Statement (management plan) detailing an appropriate response to ameliorate this threat has yet been produced. "The Victorian Pest Management—A Framework for Action" (Natural Resources & Environment (NRE) 2001) is focused upon weeds and more traditional terrestrial vertebrates such as rabbits and foxes, rather than freshwater species. The Victorian River Health Strategy (NRE 2002) pays scant regard to alien species, with fish not included as taxa for the monitoring of river health. However, changes in the geographic distribution of indigenous and exotic fish species has been recommended as an environmental health indicator (Office for the Commissioner for the Environment 1988) and fish and alien fish species have been considered in other measures of river health (Harris 1995; Whittington et al. 2001). A recent nomination for listing of "The introduction of live fish to waters outside their natural range within a river catchment after 1770" as a Key Threatening Process under the Commonwealth Environmental Protection and Biodiversity Conservation Act 1999 was unsuccessful. The ability of this legislation to list widespread threatening processes is yet to be proven, although predation by *Gambusia holbrooki* has been listed as a Key Threatening Process under the New South Wales Threatened Species Conservation Act 1995.

Management of vertebrate pests in Australia continues to focus on terrestrial animals despite several alien fish species meeting pest species criteria because "they threaten the environmental and personal resources valued by humans" (Olsen 1998). The inclusion of carp in the Bureau of Rural Sciences Vertebrate pest series (Koehn et al. 2000) is recognition of their potential as a pest species, but formal steps need to be taken for them to be included in the development of vertebrate pest plans and associated funding. Carp are the largest and most visible of introduced fish species, have received the most public attention, and now rate in the public eye along with rabbits and foxes as a vertebrate pest species in south-eastern Australia (Koehn 2001). Fish have only recently been included in papers presented at an Australian Vertebrate Pests Conference (Koehn 2001; Mackenzie & Bryant 2001; Stuart et al. 2001), and changes to the traditional view of vertebrate pests is urgently needed to consider the environmental damage caused by alien fish species.

Current knowledge

Although our understanding of the impacts of alien fish is poor, and there is a lack of coordination, a review of the literature shows there is a range of information available that could form the basis of improved management of alien freshwater fish species in Australia. This information is of three types: (1) general strategic documents; (2) area based assessments; and (3) reviews of individual species. However, a coordinated approach such as that outlined for marine pests (National Taskforce on the Prevention and Management of Marine Pest Incursions 1999) is needed.

General strategic documents

The major issue is not whether we understand what management actions need to be undertaken for alien fish, but whether there is the will to implement these actions in a consistent and coordinated way. Carp have received the most publicity of alien fish species, have been widely reviewed (Hume et al. 1983; Roberts et al. 1997; Koehn et al. 2000), and been the subject of a National Strategy (Braysher & Barrett 2000; Carp Control Coordinating Group 2000a,b). Although this strategy relates only to this species, it can easily be adapted to include other alien species, as has been done in Queensland (DPIQ 2001), forming the basis of a national alien species

management plan. The Action Plan for the Murray-Darling Basin, developed for alien species by the National Carp and Pest Fish Taskforce, a community focused organisation (Murray-Darling Association Inc. 2003), could also be expanded and incorporated into a national strategy. The "National Policy for the Translocation of Live Aquatic Organisms" (Ministerial Council on Forestry, Fisheries and Aquaculture 1999) is seen as a valuable document, whose recommendations and processes unfortunately are not always being followed across the country. This document could be updated from the more detailed 43 recommendations made at the recent Murray-Darling Basin workshop on managing fish translocation and stocking (Phillips 2002). Although concentrating on the Murray-Darling Basin, this document has wider relevance. Issues of alien species relating to interbasin water transfers have been addressed by Todd et al. (2002).

Area based assessments

A risk assessment has been undertaken for alien species within the Murray-Darling Basin (Clunie et al. 2000). A pre-emptive assessment for the management of tilapia, should they enter the Murray-Darling Basin (Braysher 2001), also provides a useful example that could be followed for other species. Carp have been studied comprehensively in the Barmah-Millewa area (Stuart & Jones 2002), which has been identified to be an important area for their recruitment (Stuart et al. 2000). These documents together with regional carp management plans could be adapted more widely to similar areas and other species.

Reviews of individual species

Of the 43 alien species considered in Tables 1 and 2, brief reviews have been conducted for 21 established species (Arthington & Bluhdorn 1995). More comprehensive reviews have also been conducted for several of these species (Table 3) providing important information regarding biology, impacts, management recommendations, and knowledge gaps. However, little information appears to be available on introduced or establishing species (Table 2), and no studies provide detailed predictions for future spread or impacts. There is currently no red list of the worst potential aquatic invaders and, consequently, no additional procedures to stop them before they arrive. However, there is potential under the Environmental Protection and Biodiversity Conservation Act for the establishment and maintenance of a list of non-native species that pose a threat to Australian biodiversity. Kailola (2000) provides initial steps toward such a list. Risk assessment has been considered for some of these species, but no detailed predictions have been made for future spread. It is these more recent introductions that have the greatest potential for spread and further impacts. Clear examples of these include the rapid spread of oriental weatherloach (*Misgurnus anguillicaudatus* Cantor) (Koster et al. 2002a,b) and tilapia (DPIQ 2001) in many regions.

Knowledge gaps

There are few detailed species-specific risk assessments (e.g., Barlow & Lisle 1987; Townsend & Winterbourn 1992) predicting the future impacts of introduced fish species that are already established (Arthington & Bluhdorn 1995; Coates & Ulaiwi 1995; Clunie et al. 2001). Such predictive assessments need to be undertaken for other species in Australia, giving consideration to dispersal pathways (e.g., Lintermans 2004) and climatic limitations (Sutherst et al. 1996, 1999). Our knowledge of the biology and ecology of many of these species, especially under Australia conditions, is limited. Our understanding of the impacts of most alien species is still rudimentary, even for direct impacts such as predation, let alone impacts at the community or ecosystem levels (Townsend 2003). An understanding of impacts is important to build the case for the importance of adequate alien species management and to provide some basis for benefit:cost analyses of management options (Choquenot et al. 2004). Understanding impacts is an essential component of best practice vertebrate pest management, which is based on the concept of managing impacts rather than numbers (Braysher 1993). Evaluation of the environmental and economic impacts of the world's best known biotic invasion, the zebra mussel (*Dreissena polymorpha* (Pallas)) into the North American Great Lakes region, has underpinned public support and management actions (Lodge 1993; Nalepa & Schloesser 1993; Strayer 1999; Pimentel et al. 2000). There is the need for similar evaluations in Australia.

Potential control techniques for most aquatic pest species are limited. Options for carp are explored in detail in Roberts & Tilzey (1997) and Koehn et al. (2000) and include: removal (commercial and recreational); environmental rehabilitation; environmental manipulation; biomanipulation (e.g., adding predators); exclusion; poisoning; and future biological controls (e.g., Thresher unpubl. data). As many of these "biocontrol" options have yet to be

developed and tested, they are not available at present and usually involve long time frames for development, testing, approval, and deployment. Other more specific options for carp (are currently under development) (e.g., separation cages, Stuart et al. 2003). Despite the public favouring fishing and removal, these options are only applicable to some larger species in certain areas, and are unlikely to make a significant contribution to the control of invasive fish species in Australia. It can however have significant value in increasing public awareness of the pest species. This lack of realistic control options highlights the need to support actions of the "National Carp Management Strategy" (Carp Control Coordinating Group 2000a) which utilises a range of management options, highlights the importance of preventing future spread, and recognises the importance of gaining community support. As eradication after establishment is usually impossible, management should concentrate on preventing new introductions and limiting future spread (Lodge et al. 1998). This strategic approach should be adopted for alien fish species other than carp, as has been done in Queensland (DPIQ 2001).

Future management actions

The goal of management for alien species is not a reduction in numbers *per se*, but a reduction in the impacts caused by each species (Lodge & Shrader-Frechette 2003) (e.g., predation, competition, ecosystem changes). This together with the use of pest management principles (Braysher 1993; Bomford & Tilzey 1997) and adoption of integrated approaches will give the best results. Clearly defining the problem, objectives, and measurables is important before action is taken. This will require the development of new skills and organisational links that go beyond the traditional roles of fisheries agencies and current management expertise.

Range expansions within catchments can occur by natural movement, especially for mobile species, but most transfer between catchments is human assisted (Lintermans 2004). Range expansions should be managed on the basis of drainage basins, with a hierarchy of containment to river reach, river basin, then major drainage division (Fig. 1). This requires coordinated efforts across State and jurisdictional boundaries. Transfer of fish as bait by anglers, either through accident or ignorance, or

Table 3 Summary of knowledge for established alien freshwater fish species in Australia. (C, comprehensive; M, mostly; P, partial; N, not at all. Impacts: Pr, predation on native fish; H, habitat ulisation; HD, habitat destruction.)

Common name	Impacts		Management plan /recommendations	Knowledge gaps /research plan	References*
	Reviewed	Known			
Rainbow trout	C	M (Pr)	Yes	Yes	1; 2; 3; 5; 11; 14
Atlantic salmon	C	P (Pr)	Yes	Yes	1; 2; 11
Brown trout	C	M(Pr)	Yes	Yes	1; 2; 3; 5; 11; 14
Brook trout	C	P(Pr)	Yes	Yes	1; 3; 11
Goldfish	P	N	No	No	1; 3
Carp	C	P (H,HD)	Yes	Yes	1; 3; 5; 6; 8; 11; 15; 16
Roach	P	N	Yes	No	1; 3; 11
Tench	P	N	No	No	1; 3; 11
Oriental weatherloach	C	P	Yes	Yes	1; 3; 11; 12
Eastern gambusia	C	M (Pr)	Yes	Yes	1; 4; 5; 8; 9; 11
Caudo/one-spot livebearer	P	M	No	No	1; 3; 11
Sailfin molly	P	M	No	No	1; 3
Guppy	P	M	No	No	1; 3; 5; 11
Green swordtail	P	M	No	No	1; 3; 13
Platy	P	M	No	No	1; 3
Redfin perch	P	M (Pr)	No	No	1; 3; 10
Convict cichlid	P	N	No	No	1; 3; 8
Tilapia	C	N	Yes	Yes	1; 3; 5; 7; 8; 11
Black mangrove cichlid	N	N	No	No	1; 3; 8
Yellowfin goby	N	N	No	No	1; 3

*1, Arthington & Bluhdorn (1995); 2, Cadwallader (1996); 3, Arthington & McKenzie (1997); 4, Gill et al. (1999); 5, Clarke et al. (2000); 6, Koehn et al. (2000); 7, Braysher (2001); 8, DPIQ (2001); 9, McKay et al. (2001); 11, Morgan & Gill (2001); 11, Clunie et al. (2002); 12, Koster et al. (2002a,b); 13, Morgan et al. (2002); 14, Crowl et al. (1992); 15, Hume et al. (1983); 16, Roberts et al. (1997).

deliberately by "coarse" fishers wanting to establish new fishing grounds, has been recognised as a major source of invasion into new catchments both in Australia and New Zealand (McDowall 1997; Koehn et al. 2000). Social research and appropriate education, management, and enforcement options are required for this issue. The inappropriate disposal of fish available in the aquarium trade remains an increasing problem (McDowall 2004), with 12 of the 21 established species and 21 of the 22 introduced species (77% of alien fish overall) (Tables 1 and 2) being introduced to Australia as ornamental fish. Federal legislation needs to be reviewed to be more inclusive of the species present within the aquarium trade, then adequately enforced. States also need to ensure they have a consistent approach to managing introductions from the aquarium trade. Several species have also invaded as a result of interbasin water transfers (Waters et al. 2000; Todd et al. 2002) and the environmental consequences of these transfers need to be factored into the cost of water, a topical issue in Australia at the moment. Screens installed on dams in Queensland to prevent these transfers have cost more than AU$1 million with ongoing arguments about the responsibility for payment. These issues need to be addressed at political and social levels with the support and assistance of aquarium and water industries, recreational anglers, and other stakeholders.

Management of priority species has mostly concentrated on species that are already well-established (Arthington & Bluhdorn 1995). While prevention of further spread remains a priority in the management of alien fish, concentrating on newly introduced and establishing species may often provide greater benefits. Most alien fish species occur in south-eastern Australia, particularly the Murray-Darling Basin (Clarke et al. 2000). The alien fish problem in the Murray-Darling Basin provides an important perspective on the future of many other river basins if continued invasion is not prevented. Areas such as the Lake Eyre drainage basin (with a catchment of more than 1.3 million km^2), the Kimberley, Pilbara, and Northern Territory need priority protection from invasive species such as carp and *Gambusia*.

Dedicated monitoring is essential to alien species management and must relate to clear objectives. However, current resources are insufficient to enable research and management agencies to carry out this monitoring without support from the community. To date, despite significant public interest, there has been no organised community monitoring and management programme for alien fish. Groups such as "Carpbusters" in Queensland have huge community support and enthusiasm but this needs to be harnessed to provide information suitable for management. Waterwatch is a national community-based monitoring network with 2000 groups monitoring more than 6000 sites in over 200 catchments across Australia. The extent of their monitoring means there are opportunities for Waterwatch to provide data on the occurrence of alien fish species in waterways. With the appropriate training and resources, this existing network could provide an extensive monitoring network (J. McCoy pers. comm.). Involving the community in monitoring activities also provides them with a sense of ownership of the pest fish issue and an improved understanding of the complexities of managing alien fish species.

Community education is a vital component of pest fish management for a number of reasons. First, by raising community awareness of the issue there is less potential for humans to spread alien species. Second, the public can assist with reporting infestations and finally, funding for on-ground natural resource management activities in Australia is largely directed through regional Natural Resource Management (NRM) bodies. These bodies determine NRM priorities for their region and funding is allocated according to those priorities. They also co-ordinate and support other community based activities such as Landcare and Integrated Catchment Management. Therefore, to access funding and support for on-ground alien species management, regional bodies need sufficient information about the significance of the alien species threat and how the community can assist. A broad range of information needs to be developed regarding the threat alien species pose, methods of transferral, and potential management actions. There also needs to be an improved approach to reporting of pest fish sightings by the public with well-publicised and staffed telephone "hotlines". Queensland has developed a pest fish reporting kit that contains detailed instructions on the information required, how to identify fish, describe their location and other useful information, with a more detailed version provided to Queensland Boating and Fisheries Patrol officers.

Encompassing four States, the ACT and Commonwealth Government jurisdictions, the Murray-Darling Basin (basin 4) can be seen as a microcosm of the rest of Australia in terms of natural resource management. The multi-jurisdictional

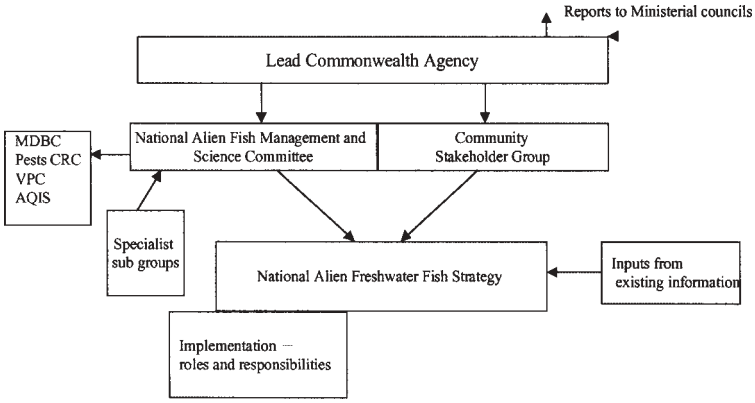

Fig. 3 Potential management framework for coordinated alien freshwater fish species management in Australia.

management currently provided by the Murray-Darling Basin Commission (MDBC) for fish (www.mdbc.gov.au) could potentially provide a model framework for the management of alien species across Australia. A suggested national management framework involves a lead coordinating agency (probably Environment & Heritage or Agriculture, Fisheries & Forestry Australia), that reports to relevant Ministerial Councils and oversees the formulation and implementation of a National Alien Freshwater Fish Management Plan through the combined efforts of a Management and Science Committee (comprising State and technical representation) and a Community Stakeholder Committee (Fig. 3). The Community Stakeholder Committee could be derived from a restructure of the membership of the existing National Carp and Pest Fish Taskforce (MDA Inc. 2003). The management and science committee may subsequently need to form specialist working groups for particular areas of concern (e.g., angling, water transfer, aquariums). Links to organisations such as the Vertebrate Pests Committee, MDBC, Cooperative Research Centre for Pest Animal Control, AQIS, and research institutions also need to be considered. In recognising that there is a clear need for representation from State agencies, management of pest fish undertaken in Australia must also be supported and coordinated at a Commonwealth level.

This paper deals with only alien fish species, but it is logical that other aquatic invaders (e.g., plants and invertebrates) can be linked into the suggested national strategy. Benchmarking of native and alien fish populations and other environmental parameters are needed before the implementation of management actions to provide baseline data against which the success of actions can be measured.

Recommended priority actions

The priority actions listed may be conducted over both short and long time frames and should be subjected to a rigorous ranking process undertaken by the managing agencies. Importance will vary between species, areas, and actions already undertaken. The difficulties of comparing the effects of smaller scale interventions to wider actions such as habitat improvement (Harris 1997) and assessing the impacts of alien fish species with those of flow regulation (Gehrke et al. 1995) and other human impacts (Driver et al. 1997) will always be problematic. The integration of science (e.g., alien species biology) with applied management actions however, will improve enviromental outcomes (see: Department of Conservation 2003).

Nationally coordinated management

(1) Engage an appropriate national agency to coordinate alien freshwater fish species management in Australia.
(2) Adopt a suitable management framework for the development and implementation of a National Alien Fish Management Strategy, recognising roles, responsibilities and cost sharing arrangements.
(3) Ensure national consistency in jurisdictional legislation and management approaches including compliance.
(4) Stringently review and revise existing national permitted and “noxious” fish species lists. Organise a national summit to ensure consistency of lists and compliance across jurisdictions.
(5) Develop an appropriate strategic process for the non-proliferation and disposal of noxious or unwanted species.

(6) List deleterious actions of alien fish (e.g., predation) as a Key Threatening Process under relevant State and Commonwealth legislation.
(7) Recognise fish as potential vertebrate pests in national and State vertebrate pest policies, programmes, and legislation.
(8) Recognise translocation and stocking of native fish outside their natural range as a component of alien species management.
(9) Update the National Translocation Policy (see: Phillips 2003) and ensure compliance.
(10) Develop a national distributional database for alien species and fish translocations.
(11) Develop crtieria to prioritise alien fish species management actions.

Use of existing information

(12) Include alien fish management in existing natural resource management frameworks.
(13) Undertake recommended actions in existing management reports on alien species.

On-ground management

(14) Quantify impacts and threats posed by alien fish species within the broader ecosytem context.
(15) Use pest management principles as a basis for management of alien species.
(16) Minimise future spread of established and establishing species.
(17) Engage non-fisheries agencies in alien fish management such as regional NRM bodies.
(18) Integrate alien fish species management into other natural resource management plans and place in context with other rehabilitation measures for aquatic ecosystems.
(19) Determine priority native species/habitats for protection e.g., Lake Eyre Basin.
(20) Develop a consistent strategy for the control of trade and movement of fishes.
(21) Include alien species distribution and abundance as a measure of river health.
(22) Establish and resource rapid response plans, processes, and teams to eradicate new infestations and facilitate reporting processes for new invasions.
(23) Rank sites for control actions.

Knowledge

(24) Undertake distributional surveys and collate distributional data on alien fishes.
(25) Undertake risk assessments for the potential spread and impacts of alien fish species.
(26) Initiate dedicated alien species monitoring at a community and scientific level.
(27) Determine appropriate resources necessary for alien species management. Undertake and report bioeconomic assessments (benefit:costs) and evaluation of potential and existing management actions.
(28) Initiate a research strategy—with priority areas being: alien species knowledge, control and management techniques (including ecosystem rehabilitation), predictive capabilities, quantification of impacts, risk assessment.

Community

(29) Restructure and fund National Carp and Pest Fish Taskforce to provide the role of engaging the community in alien fish management.
(30) Engage key stakeholder groups such as anglers, aquarium and water industries.
(31) Develop and implement an education and awareness programme to improve community education about alien fish species at a range of levels—political, departmental, enforcement, waterwatch, fisheries, aquarium trade, general public.
(32) Engage the community in alien species management and regional planning and through "demonstration" alien fish sites. Utilise existing community networks to incorporate alien species awareness e.g., Landcare, conservation groups, Invasive Species Council Inc.
(33) Undertake social research to minimise deliberate transfers (especially "coarse" anglers).
(34) Incorporate alien fish into Waterwatch and other community monitoring schemes.

CONCLUSION

A review of the current state of knowledge in Australia indicates that there is much information on many alien freshwater fish species, and we propose a management approach that can be used to formulate a national framework for managing and reducing the impacts of alien species in Australia. It is not lack of knowledge that is impeding our progress managing alien fish but a lack of coordination and perhaps a lack of will at all levels to acknowledge that alien fish really are a problem.

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