4. Ecological impacts of ornamental fish

4.1 Introduction

This chapter provides information on the origins, geographical range, habitat preference, physical tolerance, reproductive behaviour, feeding and diet of each of the ornamental fish species covered in this report. It also reports on a range of the intrinsic characteristics of these species that contribute to their invasiveness and it reviews the known impacts by these species, both globally and in Australia.

A comprehensive literature search was carried out in order to undertake this review using both the common and scientific names of each species and including alternative names where these occur. The main databases searched included: Aquatic Sciences and Fisheries Abstracts (CSA), Web of Science (WOS), Fish and Fisheries Worldwide (FFW) and Scopus. The citations of all references recovered were downloaded into ENDNOTE and an electronic version of this database will be made available to the public with this report as a downloadable file from the DEWHA website.

Variation in the total number of references obtained per genus (Table 4.1) indicates the variability in coverage. The genera *Carassius* (goldfish), *Oreochromis* (tilapias) and *Poecilia* (sailfin molly and guppy) have received more attention (over 100 references) than other species. For example, we found less than 10 references for the genera *Amphilophus, Haplochromis*, *Hemichromis, Labeotropheus, Tanichthys* and *Trichogaster*.

Table 4.1: Number of references retrieved from the literature searches. Databases searched included CSA (Aquatic Sciences and Fisheries Abstracts, Conference Papers and Abstracts, Environmental Sciences and Pollution Management), Web of Science (WOS), Fish and Fisheries Worldwide (FFW) and SCOPUS.

Genus of fish	Database searched				Total references found (excluding duplicates)
	CSA	WOS	FFW	SCOPUS	
Aequidens	6	0	6	0	12
Amphilophus	6	0	1	0	7
Archocentrus	25	0	1	0	26
Astronotus	16	0	11	3	30
Puntius/Barbus	20	0	6	0	26
Carassius	59	41	111	7	218
Cichlasoma	10	1	3	0	14
Haplochromis	0	0	0	0	0
Hemichromis	2	0	4	0	6
Labeotropheus	0	0	1	0	1
Misgurnus	10	6	5	0	21
Oreochromis	44	26	112	12	194
Phalloceros	10	1	2	0	13
Poecilia	45	16	44	6	111
Tanichthys	1	0	1	0	2
Tilapia	17	0	26	2	45
Trichogaster	1	0	6	1	8
Xiphophorus	6	1	9	0	16

The grey literature is much harder to access than scientific publications and to a large extent coverage of this depends on familiarity with the species and with researchers undertaking studies on them. State agencies and a number of key contacts in Australia were solicited for information on the listed species. The information garnered from the grey literature often proved to be more relevant to this review than that in the scientific literature, perhaps reflecting the fact that much of the work carried out on ornamental fish in Australia is funded by state agencies and therefore only reported in the grey literature.

The literature on many of the species did not provide comprehensive coverage of the species characteristics listed above. Thus, we also utilised information in web-based databases (e.g., FishBase, the U.S. Geological Service Fact Sheets on alien species in North America (USGS), and the Global Invasive Species Programme database on invasive fish species (GISP)) to derive information on the species reviewed. The largest of these, Fishbase (Froese & Pauly 2006) lists the countries to which a species has been introduced and indicates whether adverse ecological impacts have been recorded in the scientific literature for any of these introductions. However, it does not provide a critical revue of such reports. It should be noted that much of the information in these databases is often derived from sources that are themselves derivative and without explicit data support. For example, FishBase[4] is an international 'on-line' compendium of information on virtually all known fishes. One of the key sources of information in FishBase is a series of books known as the Baensch aquarium atlases (Riehl and Baensch, 1991; Baensch and Riehl, 1993). These are, themselves, derivative and furthermore provide no documentation of the sources of their information. As the conclusions in the Baensch volumes cannot be verified, there is a danger of being caught up in a 'game of Chinese whispers'. This caveat needs to be kept in mind.

4.2 Species assessments

(a) Hybrid cichlid (*Labeotropheus/Pseudotropheus* cross)

No information was available for this hybrid, but we were able to find some details in FishBase for the species *Labeotropheus fuelleborni* (Mbuna cichlid) that can be expected to reflect its biology.

[4] FishBase is a database that presents information that has been summarised from a variety of reports. The authors of these reports are not cited in the conventional scientific manner in FishBase. Only a bibliography is provided. Thus wherever we refer to FishBase, it should be assumed that information has come from a variety of sources.

Indigenous range: Tropical, latitudes 9-15°S (corresponding with ambient water temperatures of 22-25°C). Native to Africa, in Lake Malawi, including offshore islands (FishBase).

Introduced range: None reported.

Maximum size: Males reach 30.0 cm SL, but female is much smaller, c. 9 cm SL (FishBase).

Habitat preferences: Lentic systems similar to Lake Malawi with hard, rocky substrates. Often found feeding in shallow waters between 1 and 6 m depth (FishBase). Based on information about the diet and feeding behaviour of *L. fuelleborni*, rocky substrates may be required as a feeding habitat.

Environmental tolerances: *Labeotropheus fuelleborni* occurs only in fresh water and prefers pH of 7.5-8.5 (FishBase). The fact that it is endemic to Lake Malawi may also suggest a narrow environmental range.

Behaviour: Usually feeds alone, or in small groups with other species, but can form feeding schools of several hundred fish which 'raid' the feeding grounds of other species (FishBase). If the hybrid cichlid exhibits similar behaviour, this could represent either a form of inter-specific competition or a form of habitat modification that could affect Australian native fish. Exhibits territoriality over food supply growing on rocky substrates and can be aggressive.

Reproduction: Not known.

Generation time: Minimum population doubling time 1.4 - 4.4 years, which FishBase equates with medium level resilience. The hybrid cichlid generation time may differ from this.

Diet: Has a relatively broad diet, and feeds on everything from algae and aufwuchs cover on rocks (its main diet), to crustaceans, insects and plant matter.

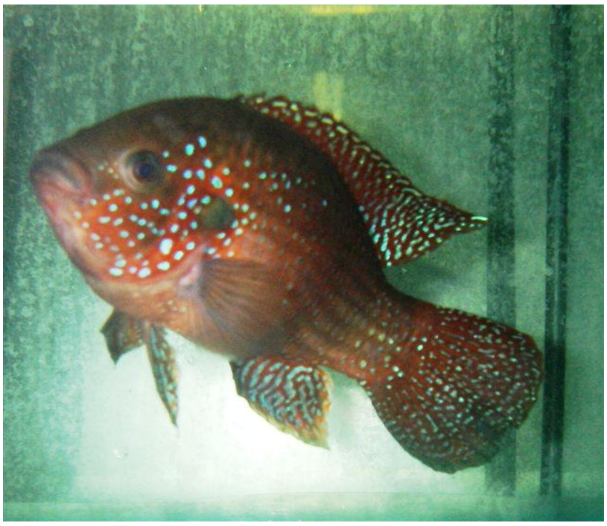
Likelihood of natural dispersal: Uncertain. Invasiveness rated as moderate to high by Arthington et al. (1999).

Risk of human spread: Depends on popularity amongst aquarists and their behaviour. The volume of fish sold in Australia is relatively low (Table 7.1).

Impacts overseas: FishBase regards *L. fuelleborni* as harmless, but that is not to say that the hybrid cichlid is as well. The aggressive territorial behaviour exhibited by *L. fuelleborni* could be a potential impact mechanism for this hybrid, as could intra-specific competition for algal food resources, were the hybrid cichlid forms schools that raid the feeding grounds of native species. This behaviour could indicate potential for competition over food with some Australian native fish.

Impact in Australia: Unknown. None reported to date. Current known distribution in Australia limited to Hazelwood Power Station ponds.

(b) Jewel cichlid (*Hemichromis bimaculatus*)



Indigenous range: Tropical, latitudes 4-11°N (corresponding with ambient water temperatures of 21-23°C). Native to Africa and considered to be widely distributed in West Africa. Specific locations where found include coastal basins from Southern Guinea to Central Liberia, where it is associated with forested biotopes, Côte d'Ivoire and Ghana, coastal basins of Cameroon, the Democratic Republic of the Congo and Nile basins, as well as Gambia and Senegal (FishBase).

Introduced range: Canada, Hawaii, Philippines, United States (FishBase).

Maximum size: Reportedly up to c. 14 cm SL and 10.0 g in weight in the wild (FishBase).

Habitat preferences: Occurs in mud- and sand-bottomed canals some distance inland from the coast, associated with areas of intact or recently disturbed forest cover (FishBase).

Environmental tolerances: Broad salinity tolerance but a narrow pH tolerance range of 6.5 to 7.5 (FishBase). Its association with forested biotopes within its native range may be an indication that this species is less tolerant of highly disturbed or polluted conditions compared to some of the other ornamental fish species established in Australia, but this would need to be tested. Shafland & Pestrak (1982) reported a lower lethal temperature of 9.5˚C for this species so it has a potentially broad temperature range over which it can survive. This could allow it to occur in many parts of Australia but temperature requirements for spawning and egg survival are unknown and these may restrict its distribution.

Behaviour: Considered aggressive (FishBase), but no information given as to whether this is at all times or only at certain times (e.g., during spawning). Riehl and Baensch (1991) class it as “territorial and peaceful except during spawning, then the species is aggressive and intolerant”. Is also reported to disturb sediments when digging nests.

Reproduction: This species is potamodromous (FishBase), and probably requires a migration for spawning, which might limit its ability to establish in closed systems. Sediment is disturbed to create nests. Both sexes become bright red when mating (Midgalski & Fichter 1977) and so may be more vulnerable to other predators at this time. Spawning is probably stimulated by factors associated with rainfall (e.g. water level rise, increased water movement) and eggs are attached to hard objects (Siddarth 2005).

Generation time: Minimum population doubling time less than 15 months, which FishBase equates with a high degree of resilience. Believed to reach maturity in less than one year and to be capable of multiple spawnings in a given year.

Diet: Diet quite broad, eating everything from algae and aufwuchs to macrophytes, crustaceans and insects.

Likelihood of natural dispersal: Tolerates brackish water conditions, so unassisted range expansion in open systems is not likely to be restricted by reaches of brackish water connecting freshwater systems, such as harbours or bays into which several rivers flow. Invasiveness rated as very high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: Relates to its popularity as an aquarium fish and the behaviour of aquarists. This species is rated as of medium importance to the aquarium trade in Australia and relatively small numbers are sold (Table 7.1). Risk of spread is therefore relatively low.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown. None reported to date. Currently known from only two sites in Australia (Rapid Creek near Darwin and Ross River in northern Queensland).

(c) Victoria Burton's haplochromis (*Haplochromis burtoni*)

Indigenous range: Tropical, latitudes 3-9°S (corresponding to ambient water temperatures of 20-25°C). Native to Africa, specifically Lake Tanganyika and associated rivers and Lake Kivu (FishBase).

Introduced range: Not reported elsewhere.

Maximum size: Grows to 15.0 cm SL (FishBase).

Habitat preferences: Inhabits slow streams, river mouths and shallow parts of lakes near the confluence with rivers (FishBase).

Environmental tolerances: Some members of the genus *Haplochromis* can tolerate low oxygen conditions, whereas others prefer oxygen-rich water (Galis & Smit 1979 cited in Obordo & Chapman 1997). Oxygen tolerance is yet to be determined.

Behaviour: Nothing reported.

Reproduction: Little reported; eggs deposited on rocky substrates, young brooded in mouth of adult.

Generation time: Minimum population doubling time is less than 15 months, which indicates a high degree of resilience (FishBase).

Diet: Dietary preferences are not reported in FishBase, or elsewhere.

Likelihood of natural dispersal: Unknown. Invasiveness rated as very high by Arthington et al. (1999) but low by Bomford & Glover (2004). This difference reflects differences in the metrics used by these two methods to rate invasiveness.

Risk of human spread: Usual risks associated with keeping the species in captivity. The importance of this species to the ornamental fish industry is relatively low (Table 7.1) so the risk of spread is also low.

Impact overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown. None reported to date. Currently known from only two sites in Australia (Ross River in northern Queensland and Hinze dam in southeastern Queensland).

(d) Black mangrove cichlid (*Tilapia mariae*)

Indigenous range: Tropical, latitudes 2-9°N (corresponding to ambient temperatures of 20 – 25°C). Native to Africa, specifically the coastal lowlands and lagoons of the Tabou River (Côte d'Ivoire), southwest Ghana and southeast Benin to the Kribi River in Cameroon (FishBase).

Introduced range: Florida (FishBase, USGS).

Maximum size: To c. 40 cm TL; maximum published weight 1,360 g (FishBase).

Habitat preferences: Occurs in warm springs and in mud-bottomed to sand-bottomed canals (FishBase). Cadwallader et al. (1980) indicated that it is found in both still and flowing waters, over both rock and mud substrates and below overhanging banks as well as where there is no cover (i.e. a wide range of habitats).

Environmental tolerances: Reasonably broad, given that it can occur in brackish and fresh water and in waters of pH 6–8 (FishBase). Shafland & Pestrak (1982) found that the lower lethal temperature for this species was 11.2˚C so it has a relatively broad temperature range for survival. This may enable it to occur in many parts of Australia but the minimum temperatures for spawning and egg survival are unknown. If these are higher they may restrict it to warmer latitudes than its temperature tolerances suggest.

Behaviour: Florida populations of this species are aggressive towards other species of fish (Courtenay & Hensley 1979, cited in Arthington & Blühdorn 1995). This aggression may be a potential risk for some Australian native fish. Regarded as territorial and pugnacious by Riehl & Baensch (1991).

Reproduction: Sterba (1966) suggests 150-200 offspring per spawning, but FishBase and Riehl & Baensch (1991) state around 2,000 eggs. Sterba (1966) indicated that this species requires well-cleaned stones on which to lay eggs but McKay (1984) indicated that submerged logs and aquatic plants are also utilised as a spawning substrate.

Generation time: Minimum population doubling time given as 1.4 - 4.4 years, giving this species a medium level of resilience. Time to reach maturity is less than 1 year (FishBase).

Diet: Demersal in habitat, thus unlikely to feed on prey found in the middle and upper reaches of the water column (FishBase). Is primarily herbivorous (Riehl & Baensch 1991). All tilapia are voracious feeders and many prefer algae and soft-leaved plants (Sterba 1966). This feeding behaviour may potentially result in habitat modification with indirect effects on water quality and hence the native biota.

Likelihood of natural dispersal: Ability to tolerate brackish conditions would enable it to move between waterways in open systems connected by brackish water reaches more easily than many of the other established ornamental fish. Relatively large size as adults may afford it a greater degree of mobility than many other ornamental fish species, making it less likely that its distribution would be restricted by high flow conditions. Invasiveness rated as very high by Arthington et al. (1999) and high by Bomford & Glover (2004).

Risk of human spread: As above, but the risk of spread from one catchment to another will depend on the behaviour of the public and their knowledge of the potential impacts of releases into natural waters. The number of fish sold in Australia is relatively low (Table 7.1) so the risk of spread is also relatively low.

Impacts overseas: FishBase regards this species as harmless, but Courtenay & Hensley (1979) indicated that it is now dominant in many canals in south east Florida, so has the potential to affect other fish. It is also dominant in Roger's Spring (Nevada) where there is concern over its effect on native fish because of competition for food (Courtenay & Deacon 1983).

Impacts in Australia: Classified as a noxious species in Queensland under the Fisheries Act (Arthington & Blühdorn 1995) but this is based more on its potential for impact than on measurement of actual effects. Rated as a high-risk species under the Bomford & Glover (2004) risk assessment model. All *Tilapia* species are included in the Natural Resource Management Ministerial Council proposed noxious fish list (NRMMC 2006) as well as in the Queensland noxious fish list (DPIQ 2000) indicating serious concerns about their potential to cause ecological impacts. However, none have been reported to date for this species. Currently well established in lowland waters near the coast in northern Queensland and also present in Lake Burley Griffin (Canberra) and the Latrobe River (Victoria).

(e) Redbelly tilapia (*Tilapia zillii*)

Indigenous range: Tropical to sub-tropical, 35°N and 10°S (equating to temperatures of 7- 43°C). Native to Africa and Eurasia, specifically, the Senegal River in the Niger-Benue system of South Morocco, the Sassandra and Bandama Rivers in the Volta system of the Côte d'Ivoire, the Ubangi-Uele-Ituri Rivers in the Chad-Shari system of the Democratic Republic of the Congo, the Lake Mobutu in the Nile system and in Lake Turkana and the Jordan system (FishBase).

Introduced range: Widespread; including Ethiopia, Guam, Hawaii, Japan, Madagascar, Philippines, Singapore, Syria, Tanzania, United States (FishBase).

Maximum size: According to published figures, reaches 40.0 cm SL and 300 g. Can reportedly live for 7 years (FishBase).

Habitat preferences: Prefers shallow, vegetated areas. Fry are common in marginal vegetation and juveniles are found in the seasonal floodplain. Typically found in waters up to 1m in depth (FishBase).

Environmental tolerances: Very broad in terms of survival, but probably less so in terms of requirements for spawning (see above). Can tolerate brackish as well as freshwater conditions; wide water temperature ranges (see above); pH 6-9.

Behaviour: Mainly solitary but occasionally forms schools (FishBase). Sterba (1966) classed it as pugnacious, exhibiting strong brood care behaviour. Such behaviour may represent a potential impact mechanism as far as Australian native fish are concerned, but this remains to be tested. Territorial and pugnacious, and is a substrate burrower (Riehl & Baensch 1991).

Reproduction: Not a mouth-brooder (FishBase; Sterba 1966). Can produce up to 1000 eggs per spawning (Sterba 1966). Young are tended by adults. Is potamodromous, so a movement to spawning habitats is probably required. Is also a substrate spawner, requiring clean stones to lay eggs on (Sterba 1966). Larvae of this species develop in close association with the substrate (FishBase). There may, therefore, be opportunities for control involving access to suitable spawning habitats.

Generation time: Minimum population doubling time 1.4 - 4.4 years, giving this species a medium level of resilience; time to reach breeding maturity between 2-3 years (FishBase).

Diet: Relatively restricted compared to other tilapiine species established in Australia. Generally herbivorous, feeding on aquatic plants and epiphyton, but will eat invertebrates – worms, insects, zooplankton, shrimps, gastropods (FishBase). Sterba

(1966) stated that it feeds eagerly on plants; this may result in alteration of habitats and/or deplete preferred foods of native fish species in Australia.

Likelihood of natural dispersal: Ability to tolerate brackish conditions would allow it to move between waterways in open systems connected by brackish reaches. Its relatively large size may possibly afford greater mobility, but the extent of upstream distribution would be limited by the presence of high water velocities or small rapids and falls. Invasiveness rated as very high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: Is a prized commercial aquaculture and fisheries species in other countries (FishBase). Potential to reach a relatively large size as adults could result in this species being targeted and dispersed further by coarse fish anglers. It was introduced widely in the southern USA for control of aquatic plants as well as for control of mosquito and chironomid larvae (USGS). Could also be dispersed through use as live bait. However, the stunted growth of Australian populations of this species in south western Australia (Blühdorn & Arthington 1990b) and their mainly herbivorous diet may reduce their suitability as an angling species.

Impacts overseas: FishBase noted that several countries have reported adverse ecological impacts following the introduction of this species so regards it as a potential pest. No further details are provided in FishBase about the mechanisms or manifestations of those impacts. Sterba (1966) stated that the species is a great 'digger' implying a potential impact on substrate created when it excavates nests for spawning. However, vegetation is also uprooted as a consequence of feeding on vegetation and while foraging for invertebrates. A potential impact mechanism is therefore modification of aquatic substrates. It has been implicated in the decline of the desert pupfish (*Cyprinodon macularius*) and is reported to be highly aggressive in California waters (USGS). It poses a threat to fish dependent on aquatic plants. Crutchfield (1995) reported that all macrophytes were removed from a Wyoming reservoir two years after its introduction and several native fish species subsequently declined. However, the redbellied tilapia thrived because it could feed on other foods.

Impacts in Australia: All *Tilapia* species are included in the Natural Resources Management Ministerial Council proposed noxious fish list (NRMMC 2006) as well as in the Queensland noxious fish list (DPIQ 2000) indicating concern over their impact. However, no impacts of this species have been reported in Australia to date. Currently known to be present in only one location in Australia (Chapman River, Western Australia).

(f) Mozambique tilapia (*Oreochromis mossambicus*)

Indigenous range: Tropical, at 13°S and 35°S (equating to temperatures of 8 – 42°C). Native to Africa, specifically the lower Zambezi, the lower Shiré and coastal plains from Zambezi delta to Algoa Bay and southwards to the Brak River in the eastern Cape and in the Transvaal in the Limpopo system (FishBase).

Introduced range: Most commonly used species in aquaculture and once also stocked for aquatic plant and insect control in the USA. Now widely established beyond its natural range in most Caribbean countries and in the Czech Republic, Central America, Fiji, French Polynesia, Hawaii, Hong Kong, India, Kiribati, Nauru, Niue, Seychelles, Singapore, Solomon Islands, Thailand, Vietnam; and widely in the southern States of the USA (FishBase).

Maximum size: Maximum published size 39.0 cm SL or 1,130 g; individuals can live for up to 11 years (FishBase).

Habitat preferences: Prefers well-vegetated shallow waters, usually still, or gently flowing waters, most common in blind estuaries and coastal lakes, but also found in warm, weedy pools of sluggish streams, canals, and ponds. Found in waters up to 20 m in depth (FishBase). Normally lives in brackish water and grows more slowly in fresh water (Midgalski & Fichter 1977), so could proliferate in the estuarine regions of rivers and/or in inland brackish lakes.

Environmental tolerances: Has broad temperature and salinity tolerances. FishBase states that this species can be reared under hyper-saline conditions; also that *O. mossambicus* exhibits considerable plasticity in feeding habits and reproductive biology, suggesting that it can modify these according to the prevailing environmental conditions. Arthington (1986) reviewed the international literature on this species and reported a salinity range of 0-120 g/L after acclimation, with breeding between 0-49 g/L. The pH range tolerated was 4-11 and a lower temperature tolerance of 8-10ºC. Shafland & Pestrak (1982) found that the lower lethal temperature for this species was 9.5˚C. Its relatively broad temperature range, reported as 8-42ºC in McKenzie et al. (2000), could allow this species to occur in many parts of Australia, although Brisbane is considered by some to be its likely southern-most limit. It will stop feeding at temperatures below 8-10°C according to Clarke et al. (2000) and below 15ºC according to Philippart and Ruwet (1982) as cited in Arthington (1986).[5] Bruton and Bolt (1975) were cited in Arthington (1986) as reporting a temperature range of 20-24ºC for breeding but the temperature requirements for egg survival are unknown. Arthington & Mitchell (1986) reported that *O. mossambicus* has a capacity to tolerate

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[5] Differences in temperature thresholds for a species often occur in the literature because temperature tolerances can vary with fish size and the size of fish tested is sometimes not reported.

low oxygen conditions and can survive levels as low as 1 mg L-1. Furthermore, it can tolerate high turbidity, allowing it to live in silty lagoons or degraded waterways often found in association with urban areas (Arthington & Mitchell 1986). Of more concern, perhaps, is its reported ability to bury itself in the moist upper layers of sediment in sandy streams (up to 3 m deep) as a drought survival mechanism (Donnelly 1978 cited in Arthington & Blühdorn 1995; Clarke et al. 2000). If established populations in Australian waterways were to do the same, this species may survive in some ephemeral inland waterways.

Behaviour: Usually solitary, but may form schools (FishBase). Males require large territories and defend them against each intruder with aggressive behaviour (Sterba 1966). Such behaviour may present a potential impact for Australian native fish.

Reproduction: FishBase reports reproductive outputs of between 150-200 offspring per spawning. Arthington (1986) reported fecundities of 438-490 per 100g of female fish for two reservoirs near Brisbane. However, Arthington & Mitchell (1986) stated that a 100 g female can produce up to 600 eggs, though brood sizes are much smaller, and around 250. Although Clarke et al. (2000) suggested production of up to 1,700 offspring per spawning, fecundity can be expected to increase with fish size. Whereas large females may well produce 1,000-2,000 eggs, fecundity in stunted populations, which are the norm, is likely to be much less. The males excavate a shallow, basin-shaped depression where eggs are laid and these are picked up by the female and fry hatch in her mouth after 3-5 days. Fry are protected (in the mouth of females) for around three weeks (Clarke et al. 2000). Males often mate with several females over a short period of time (Arthington & Cadwallader 1996), giving this species an advantage in terms of reproductive output. Water temperatures above 23°C are required to induce spawning (Clarke et al. 2000), suggesting that this species could not undertake spawning in many parts of Australia during winter, though spawning could be achieved almost year-round in tropical regions. In Queensland, the breeding season extends from September-October and March-May (Arthington & Mitchell 1986; McKenzie et al. 2000).

Generation time: Minimum population doubling time 1.4 - 4.4 years, which, equates to a medium level of resilience (FishBase). Time to reach breeding maturation is less than 1 year (FishBase). Arthington & Mitchell (1986) regard this species as reproductively precocious and capable of reaching breeding maturity in 3-4 months. New broods can be produced every 4-6 weeks (Arthington & Mitchell 1986).

Diet: Very broad and plastic; a benthopelagic, omnivorous species, which, according to FishBase, feeds on almost anything from algae to insects (including terrestrial insecta). Exhibits ontogenetic shifts in diet, however, so dietary requirements for different life stages are probably more specific than the above indicates. Juveniles are carnivorous, but adults tend to be herbivorous (FishBase). Adults become increasingly herbivorous, preferring algae and soft-leaved aquatic plants (Sterba 1966). Sterba (1966) states that "all *Tilapia* are voracious feeders", which means that this species may have the potential to rapidly remove aquatic plant-based habitat and indirectly affect both the native flora as well as the associated fauna. Dietary studies in Australia indicate that feeding modes may differ depending on location. For example juveniles in the Chapman River, Western Australia were detritivores whereas in the Gascoyne they were insectivores (ASFB 2003b).

Likelihood of natural dispersal: Ability to tolerate brackish conditions would allow this species to move between waterways in open systems connected by brackish reaches, especially in harbours and river estuaries, and to do so more easily than many of the other established ornamental fish. The relatively large size of adults would possibly afford them a greater degree of mobility than many other ornamental fish species, making it less likely their distribution would be restricted by high flow conditions. Invasiveness rated as very high by Arthington et al. (1999) and extreme by Bomford & Glover (2004).

Risk of human spread: Is a highly prized aquaculture species in many parts of the world so could be spread because of its aquaculture potential. It was once stocked in the USA for plant and insect control as well as a sports fish and a food source. It may therefore be targeted and dispersed by coarse fish anglers, which Norm Milward (formerly senior lecturer in zoology and aquaculture at James Cook University) raised as a concern (Arthington & Blühdorn 1995). It has already been introduced to ornamental ponds at Port Douglas (A. Arthington, pers. comm.).

Impact overseas: FishBase reports this species as a potential pest and it has established itself in the wild in many countries where adverse ecological impacts have been reported. Competition with local species for resources is one perceived impact mechanism (FishBase). In Hawaii, this species is suspected of reducing the population of a valuable mullet species, *Mugil cephalus*, by competing aggressively for the same food resources – detritus and soft algae (Randall 1987 cited in Casal et al. 1999). Populations of mullet and other benthophagous species, including bonefish and milkfish, decreased after this species was introduced to Kiribati (Eldredge 1994 cited in Casal et al. 1999). Attempts to eradicate the Kiribati populations proved unsuccessful (Lobel 1980 cited in Casal et al. 1999). A similar impact occurred on milkfish in Nauru and the authorities here also failed to eradicate established populations of this species (Nelson & Eldredge 1991; Eldredge 1994 cited in Casal et al. 1999). Swift et al. (1993) considered this species a major factor in the decline of the desert pupfish (*Cyprinodon macularius*) in the Salton Sea area. The introduction of tilapia has even been blamed for the extinction of two duck species (*Anas superciliosa* and *A. gibberifrons*) in the Solomon Islands (Nelson & Eldredge 1991; Eldredge 1994 cited in Casal et al. 1999). While the evidence for these impacts is mainly circumstantial, the number of negative reports indicates that there is an urgent need for investigation of the potential impacts of this species on native Australian fish, especially benthivorous species such as *Mugil cephalus*. Canonico et al. (2005) reviewed the effects of tilapias throughout the world and found correlative evidence for the decline of native fish in Madagascar, Nicaragua and Mexico following the introduction of a number of tilapia species, including *O. mossambicus*. Unfortunately the role of *O. mossambicus* in Madagascar could not be determined because of the number of other alien fish present. In the Philippines, both *O. niloticus* and *O. mossambicus* were introduced to enhance fisheries. Although *O. niloticus* is thought to have played a role in the decline of native fish in lakes Lanao and Buhi, the impact of *O. mossambicus* is not clear (Canonico et al. 2005). However, in Mexico, *O. mossambicus* became the dominant species in Lake Chichincanab and competed with a native cyprinodont fish for habitat resulting in its decline and threatening extinction.

Impacts in Australia: Arthington & Mitchell (1986) regard this species as a major threat, based mainly on its invasiveness and the potential for its dispersal to be heavily human-assisted because of its fisheries and aquaculture values. They recommended further investigation of the ecological effects of this species in Australia. Arthington & Cadwallader (1996) classed it as a pest in Australia. Arthington & Milton (1986) stated that the most likely impact mechanisms for *O. mossambicus* on native Australian fish was either competition for food or predation, while the manifestation of these impacts would most likely be the displacement of native fish species. Arthington & Blühdorn (1994, 1996) and Arthington et al. (1994) found no direct evidence of environmental impacts on the native fish fauna in a reservoir in the Brisbane area and Clarke et al. (2000) reported that although a few studies had been carried out on the impacts of this species in disturbed conditions within modified waterways (e.g., water reservoirs), no significant adverse impacts were observed. However, when drought conditions and low river flows resulted in the formation of pools in the Gascoyne River (western Australia), the Murchison River hardyhead (*Craterocephalus cuneiceps*) rarely occurred where the Mozambique tilapia was present (ASFB 2003b). Male tilapia were observed to be aggressive to native fish, and much of the substrate was covered by their nests. Although this suggests displacement of native fish by the tilapia, mechanistic studies (e.g., manipulations of tilapia abundance in such pools) are now needed to confirm this. McKenzie et al. (2000) indicated that there was anecdotal evidence that macrophyte beds were disturbed during nest building. This species is rated an extremely high-risk species under the Bomford & Glover (2004) risk assessment model which assesses the potential of a species to spread and become prolific (i.e. its invasiveness). Temperature tolerances suggest establishment is most likely in northern waters. The Mosambique tilapia has been declared a noxious species in Queensland, the Northern Territory, New South Wales and Victoria with heavy penalties for transport and possession (Arthington & Blühdorn 1995). Possession is prohibited in South Australia and commercial utilisation of this species is not permitted in Western Australia (Arthington &

Blühdorn 1995). All *Oreochromis* species are included in Queensland's list of noxious fish (McKenzie et al. 2000) and in the Natural Resource Management Ministerial Council proposed list of noxious fish for Australia (NRMMC 2006). Such listing is clearly a precautionary approach as there is currently little solid evidence of impacts despite major concern over this species. Currently known to occur in four widely separated locations in Queensland and two in Western Australia.

(g) Oscar (*Astronotus ocellatus*)

Indigenous range: Tropical (latitude 4°N-15°S, equating to a temperature range of 22-25°C). Native to South America: Orinoco and Amazon River basins in Peru, Columbia, Brazil. Also in French Guiana to north Paraguay (FishBase, USGS).

Introduced range: Guam, Puerto Rico, Singapore. Reported widely in the USA (Lee et al. 1980) and established in Florida and Hawaii (USGS, FishBase).

Maximum size: 40 cm TL, but known for its slow growth rates (FishBase).

Habitat preferences: Prefers quiet, shallow waters, primarily mud or sand-bottomed ponds or canals (FishBase).

Environmental tolerances: Has relatively broad temperature tolerances, based on the lower lethal temperature of 12.9˚C reported for this species by Shafland & Pestrak (1982). This could allow it to occur in many northern parts of Australia, but as for other species of cichlid, the minimum temperatures for spawning and egg survival may restrict it to warmer waters. Restricted to fresh water (FishBase) so is unlikely to disperse between sites where migration spanning brackish or marine water is required. Its pH range of between 6 and 8 (FishBase) indicates a tolerance of moderately acidic as well as basic waters. Is capable of surviving large fluctuations in oxygen levels and is reported to be highly hypoxia-tolerant. It is believed to cope with these conditions by reducing its metabolic rate (Muusze et al. 1998). The capacity to tolerate low oxygen conditions may allow this species to readily colonise degraded waterways often associated with urban areas.

Behaviour: Basically peaceful in captivity, except when spawning, but is known to eat other fish under laboratory conditions and this may extend to native fish in the wild in Australia. Is also known to bite other fish and show aggressive fin displays when defending territory during spawning (Beeching 1997). Such behaviour is undertaken by both sexes, though males are inclined to display some attack behaviours (such as charging) more frequently than females. A laboratory study by Beeching (1992) found that this species can assess the size of other fish visually and use this information to establish the intensity of its aggressive response. He also found that smaller intruders are more likely to be targeted. This could mean that smaller native freshwater fish co-occurring with *A. ocellatus* are potentially more vulnerable to intra-specific competition for space posed by this species. Is territorial but peaceful in aquaria but has a tendency to burrow into substrate (Riehl & Baensch 1991).

Reproduction: Fecundity 300-2000 progeny per spawning (FishBase). Is a substrate spawner (Beeching 1992), but few details given. Eggs deposited on rocks, hatch in 2-3- days; young are guarded.

Generation time: Minimum population doubling time is less than 15 months, giving this species a high resilience (FishBase).

Diet: Feeds on small fish, invertebrates, including crayfish, worms and insect larvae (FishBase). Ingested live goldfish and *Gambusia* in laboratory experiments (Beeching 1992; 1997) and may well exhibit some piscivorous tendencies towards Australian native fish in the wild.

Likelihood of natural dispersal: No explicit risks identified. Temperature tolerances suggest mostly northern. Invasiveness rated as very high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: Highly prized food fish in South America (FishBase) and recognised as a sport-fish species in Florida (Kushlan 1986), so it could be introduced into new water bodies by coarse fish anglers. In Australia, this species is important to the ornamental fish trade with the number of fish sold being rated as medium (Table 7.1). The risk of spread by humans is considered to be relatively high.

Impacts overseas: FishBase regards this species as harmless. It is now a substantial part of the recreational catch in Florida, but is considered a potential competitor for food and spawning space with native centrarchids or sunfishes (USGS).

Impacts in Australia: Unknown. None reported to date. Known to be present in only two locations in northern Queensland.

(h) Three-spot cichlid (*Cichlasoma trimaculatum*)

Indigenous range: Tropical, equating to water temperatures between 21 and 30°C. Native to Central America, specifically catchments draining into the Pacific from Mexico to El Salvador.

Introduced range: Singapore (FishBase), and Florida from where it was subsequently eradicated (USGS).

Maximum size: Can reach up to 36.5 cm TL, though the maximum length reported for a female of this species 25 cm TL (FishBase).

Habitat preferences: Inhabits lakes and slow-moving waters of the lower river valleys and prefers mud and sand bottoms where it lives among the roots and weeds.

Environmental tolerances: Has relatively broad temperature tolerances. Shafland & Pestrak (1982) reported a lower lethal temperature for this species of 10.9˚C. This could enable the species to survive in many parts of Australia but temperatures for spawning and egg survival may result in a narrower geographic range. Is more likely to thrive in lentic conditions rather than faster flowing streams with rocky substrates.

Behaviour: Is one of the most aggressive cichlids, widely aggressive to conspecifics, and digs a lot at spawning time (Baensch & Riehl 1993).

Reproduction: Little known, but is a clutch guarder and produces c. 1000 eggs; reaches maturity at 80-100 mm length.

Generation time: Minimum population doubling time 1.4 - 4.4 years, which suggests a medium level of resilience (FishBase).

Diet: Has a broad diet including small fish, aquatic macro-invertebrates and both aquatic and terrestrial insects.

Likelihood of natural dispersal: Reaches a relatively large size, so potentially has the ability to cope with higher flow velocities, though its preference for slower moving water might suggest otherwise. Only found in fresh water (FishBase), and so may be unlikely to move unassisted between waterways connected by reaches of brackish water. Invasiveness rated as very high by Arthington et al. (1999) and moderate by Bomford & Glover (2004).

Risk of human spread: Is of no value to commercial or recreational fisheries at present (FishBase) and is unlikely to be introduced into new waterways by coarse fish anglers. However, as with some other established ornamental species, it could be introduced through use as live bait. The number of fish sold in Australia is relatively small and it is of medium importance to the industry (Table 7.1). The risk of spread by humans is therefore low.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown as none reported to date. Known to occur in only one location in Australia to date (the Hinze Dam, southeast Queensland).

(i) Jack Dempsey (*Cichlasoma octofasciatum*)

Indigenous range: Tropical, latitudes 14-21°N (corresponding with ambient water temperatures of 22-30°C). Native to North and Central America, specifically on the Atlantic slope from southern Mexico (Papaloapán River) to Honduras (Ulua River).

Introduced range: Thailand, Florida in the USA (FishBase, USGS).

Maximum size: Up to 25.0 cm TL (FishBase).

Habitat preferences: Occurs in lentic systems, ranging from swampy areas with warm, murky water to weedy, mud-bottomed and sand-bottomed canals and drainage ditches, to slow moving waters of lower river valleys and coastal plains (FishBase).

Environmental tolerances: May have relatively narrow salinity tolerances, since it is found only in fresh water. Also has narrow pH tolerances of 7-8 (FishBase), but Shafland & Pestrak (1982) reported a lower lethal temperature for this species of 8.0˚C so it may have a relatively broad temperature range. This could allow it to survive in many parts of Australia, but minimum temperatures for spawning and egg survival may restrict its geographic range. Can also tolerate low oxygen conditions. Obordo & Chapman (1997) found that it can tolerate hypoxic conditions and that it undertakes air surface respiration when oxygen levels are low (< 5mm Hg). Its ability for metabolic depression and large gills relative to body size, compared with other fish species, aids the ability to tolerate low oxygen conditions. The capacity to tolerate low oxygen conditions could facilitate establishment in the degraded waterways often found in urban areas. It may, however, be at increased risk of avian predation when undertaking air-surface respiration behaviour (Obordo & Chapman 1997).

Behaviour: Parents incubate eggs and guard young (FishBase), so are likely to undertake aggressive behaviour towards other species or con-specifics during breeding times. Named after a famous American fighter because of its pugilistic temperament (Midgalski & Fichter 1977). A laboratory study conducted by Ratnasabapathi et al. (1992) on the effects of water temperature on aggressive behaviour demonstrated that this behaviour was positively correlated with water temperature, with statistically higher levels of aggression exhibited at 30°C than at 26°C. They believed that this may have been related to the stimulation of convict cichlids to establish territories and spawn at about 30°C.

Reproduction: Between 500 and 800 young per spawning; eggs laid on the substrate, but preferred substrate not specified (FishBase).

Generation time: Minimum population doubling time less than 15 months, which FishBase equates to a high degree of resilience. Time required to reach breeding maturity is less than 1 year and can undertake multiple spawning in a given year (FishBase).

Diet: Reasonably broad. Includes worms, crustaceans, insects and fish (FishBase).

Likelihood of natural dispersal: Brackish water may be a barrier to unassisted dispersal given that it is only found in freshwater systems (though stenohalinity should not be assumed). Obordo & Chapman (1997) suggest that this species' physiological adaptations to cope with low oxygen conditions are traits that enable them to colonise wetland areas, temporary ponds and other habitats that experience large diel fluctuations in oxygen concentrations. These traits, and the documented behaviour of moving between permanent and ephemeral water bodies, could also allow them to readily extend their range in Australia. Use of ephemeral pools that form after flooding could provide refugia, and this could allow these fish to bypass brackish water when inundation of ephemeral pools by fresh water during floods creates access to new waterways. Invasiveness is rated as very high by Arthington et al. (1999) and high by Bomford & Glover (2004).

Risk of human spread: Related mainly to release into the wild of unwanted fish by aquarists unaware of the risks. The number of fish sold in Australia is relatively small and this species is of medium importance to the industry (Table 7.1). The risk of spread by humans is therefore low.

Impacts overseas: Impacts are not described, though FishBase regards this species as harmless. Riehl and Baensch (1991) describe it as "territorial, intolerant and a biter" in captivity.

Impacts in Australia: Unknown as none reported to date. Known to occur in only one location in Australia to date (Angourie, northern New South Wales).

(j) Red devil (*Amphilophus labiatus*)

Indigenous range: Tropical regions (temperature range 28 – 33°C); native to Central America: Atlantic slope of Nicaragua, in Lakes Nicaragua and Managua. (FishBase).

Introduced range: Established in Hawaii, Singapore (FishBase).

Maximum size: 24.0 cm TL (FishBase).

Habitat preferences: Mostly lentic habitats (i.e. lakes), rarely in slow-flowing rivers (FishBase).

Environmental tolerances: Believed to be restricted to fresh water, though cichlids generally are recognised as having some tolerances of brackish-water salinities; seems unlikely to disperse between sites where migration spanning brackish or marine water is required, though this should not be assumed.

Behaviour: No information found.

Reproduction: Is a nest guarder with 600-700 eggs; little else reported.

Generation time: Minimum population doubling time 1.4 - 4.4 years; recorded as having a medium level of resilience (FishBase).

Diet: Moderately broad given its benthopelagic feeding habitats. Feeds on small fish, snails, insect larvae, worms and other bottom-dwelling organisms (FishBase).

Likelihood of natural dispersal: Inhabits lakes and rarely enters rivers, therefore may be relatively easy to contain where populations have established in Australia. Temperature tolerances suggest mostly northern. Invasiveness rated as high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: No explicit risk beyond the usual concerns about behaviour and attitudes of aquarists. Not highly favoured as an ornamental fish species, at least internationally. The number of fish sold in Australia is relatively small and this species is of medium importance to the industry (Table 7.1). The risk of spread by humans is low.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown as none reported to date. Known to be present in only three locations to date (the Ross River in northern Queensland, the Hinze Dam in south-east Queensland, and the Hazelwood Power Station ponds in Victoria).

(k) Midas cichlid (*Amphilophus citrinellus*)

Indigenous range: Tropical, latitudes 8-15°N (corresponding with ambient temperatures of 23-33°C). Native to Central America: specifically the Atlantic slope of Nicaragua and Costa Rica (San Juan River drainage, including Lakes Nicaragua, Managua, Masaya and Apoyo) (FishBase).

Introduced range: Hawaii, Singapore, Florida; possibly Philippines (FishBase).

Maximum size: 24.4 cm TL (FishBase).

Habitat preferences: Found mostly in lakes; uncommon in rivers, and only where slow-flowing. In native range, this species lives in box-cut canals with rocky vertical sides.

Environmental tolerances: Restricted to fresh water (FishBase), so unlikely to disperse between sites where movement through brackish or marine water is required.

Behaviour: Nothing found.

Reproduction: Rocky crevices used for spawning and protection of the young; availability of this habitat may restrict ability to establish new populations. Spawning frequency unrecorded; 300-1000 eggs per spawning event (FishBase).

Generation time: Minimum population doubling time 1.4 - 4.4 years. FishBase regards this as a medium level of resilience.

Diet: Fairly broad, mostly aufwuchs, snails and small fishes but will also consume insect larvae, worms and other bottom-dwelling organisms.

Likelihood of natural dispersal: Can move up-river and into tributaries provided the water is slow-flowing or tranquil (FishBase), so could undertake unassisted dispersal during low flow conditions in river systems. Temperature tolerances suggest a mostly northern potential distribution. Invasiveness rated as very high by Arthington et al. (1999).

Risk of human spread: No explicit risk beyond concerns about releases by aquarists and escapes from garden ponds during flood events. The number of fish sold in Australia is relatively small and this species is of medium importance to the industry (Table 7.1). The risk of spread by humans is low.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: The red devil is included in the proposed grey list for ornamental fish indicating that it is of some concern but that more information is required (NRMMC 2006). Currently known to be present in only one location (Ross River, northern Queensland).

(l) Convict cichlid (*Archocentrus nigrofasciatus*)

Indigenous range: Tropical, latitudes 8-15°N (corresponding with ambient temperatures of 20–36°C). Native to Central America, ranging from Guatemala to Costa Rica (Tárcoles River) on the Pacific side, and from Honduras (Aguan River) to Panama (Guarumo River) on the Atlantic side of Central America (FishBase).

Introduced range: Canada (in thermal waters), Hawaii, Japan, United States.

Maximum size: 10.0 cm SL (FishBase).

Habitat preferences: Inhabits flowing water ranging from small creeks and streams to the shallows of large, fast-flowing rivers. Prefers rocky habitats and finds sanctuary in the cracks and crevices provided by this type of environment, or among roots and debris. Can also occur in warm pools of springs and their effluents (FishBase).

Environmental tolerances: Fairly narrow. Found only in fresh water at pH 7-8. Ratnasabapathi et al. (1992) reported spawning at about 30°C. Therefore this species' reproduction may be limited to sub-tropical and temperate regions of Australia. A study by Winckler & Fidhiany (1999) demonstrated that the exposure of this species to UVA radiation resulted in metabolic depression, which allowed exposed individuals to tolerate a wider range of temperatures. This may enable it to become established over a wider geographic range in Australia, provided appropriate UVA irradiation conditions prevail. Exhibits anti-predator behaviour cued by chemicals released into the water column when injuries occur to conspecifics, or when conspecifics become frightened (Wisenden & Sargent 1997). Another laboratory study found that young fish exhibited predator-avoidance behaviour, such as schooling or area avoidance, despite parental care (Alemadi & Wisenden 2002).

Behaviour: Young tend to school as an anti-predator fright response (Alemadi & Wisenden 2002). Both parents defend their territory and protect young during breeding activities (Townshend & Wootton 1984). Keenleyside et al. (1985 cited in Beeching 1992) reported that larger males may be more aggressive during the spawning season and they may therefore present a risk to smaller native fish species at this time. However, the energetic cost of defending a large territory may outweigh the benefit of a larger territory for the convict cichlid (Praw & Grant 1999). If so, a large territory may limit aggressive behaviour to other species. The extent to which this is manifested in terms of changes in the relative abundance of native species or of community structure may depend on the extent to which the patch size (local habitat occupied by individuals) of convict cichlids is regulated by the combination of food resource availability and the territorial defence effort required. If larger patch sizes are required, or can be easily defended, the scale of impacts of this species on native fish species could increase.

Reproduction: Is described as substrate-spawning by Townshend & Wootton (1984), though more specific information on the types of substrates preferred was not provided. Fecundity according to FishBase is between 100 and 150 offspring per spawning event. McKay (1984) indicated 130-400 based on studies by Sterba (1973) and Cadwallader & Backhouse (1983). Can undertake multiple spawning events within a given year; however, Arthington & Cadwallader (1996) reported 600-3,300 eggs, laid on submerged logs and debris which the adults clean prior to spawning. Eggs are guarded by one or both parents, which also care for the young (Townshend & Wootton 1984). Parents care for eggs and defend nests for up to 4-6 weeks (Alemadi & Wisenden 2002).

Generation time: Minimum population doubling time of less than 15 months. FishBase regards this species as having a high resilience. A study by Townshend & Wootton (1984) found that clutch sizes increased and times between spawning and egg size decreased with reduced food rations independent of changes in weight. Thus, minimum doubling time for wild populations of this species are likely to be affected by food availability at sites where they have become established.

Diet: Feeds on worms, crustaceans, insects, fish and plant matter (FishBase). Trujillo-Jimenez (1998) reported this species as omnivorous, with carnivorous tendencies following a study in the Amacuzac River in Mexico, where animals constituted around 64% of stomach contents. The 26 different prey items among the stomach contents of this species included many dipteran larvae (simuliids and ephemeropterans) though plant debris was the most frequently represented item. In a predator recognition behaviour study conducted by Brown & Godin (1999), convict cichlids were fed and readily consumed two species of fish (the glowing tetra, *Hemigrammus erythozonus* and swordtail, *Xiphophorus hellerii*).

Likelihood of natural dispersal: Nothing explicit points to a high likelihood of natural dispersal apart from constraints relating to salinities in estuaries and beyond river mouths. Temperature tolerances suggest a mostly northern potential distribution. Invasiveness rated as high by Bomford & Glover (2004).

Risk of human spread: Release by aquarists or escape from garden ponds during flood events poses the greatest risk. Englund & Eldredge (2001) suggested a role for aquarists in the liberation of this species in Hawaii. Existing populations are based on such liberations and are indicative of public attitudes to the release of aquarium fish. In Australia, the number of fish sold is relatively small and so the species is of medium importance to the industry (Table 7.1). The risk of spread by humans is therefore low.

Impacts overseas: FishBase regards this species as a potential pest. Trujillo-Jimenez (1998) reported correlation-based evidence that *C. nigrofasciatus* displaced a socially-important cichlid that constituted a forage item for local people in Mexico. She concluded that although differences in both the feeding behaviour and apparatus of the two species would tend to reduce dietary overlap, it may nevertheless occur under restricted circumstances (e.g., times when prey species were also restricted). This reinforces the need for dietary studies comparing the diet of this and other established ornamental species with Australian native fish species over a range of environments and seasons. Englund & Eldredge (2001) report that in Hawaiian streams “native aquatic species are non-existent or rare where convict cichlids occur”, and cited its use as a bait by anglers as responsible for increasing its range.

Impacts in Australia: Unknown as none reported to date. Known to occur in only two locations to date (the Ross River near Townsville, and the Hazelwood Power Station ponds, Victoria).

(m) Blue acara (*Aequidens pulcher*)

Indigenous range: Tropical, latitudes 5-11°N (corresponding with ambient water temperatures of 18-23°C). Native to Central and South America: Trinidad and Venezuela (FishBase).

Introduced range: Indonesia; perhaps Philippines (FishBase).

Maximum size: Up to 16.0 cm TL (Fishbase) but some aquarists report a maximum size of 20 cm. Males grow bigger than females (FishBase).

Habitat preferences: Inhabits turbid standing waters as well as clear, free-flowing streams.

Environmental tolerances: Only found in fresh water, so may have relatively low salinity tolerances; can tolerate highly turbid conditions. Has moderate pH range between 6.5 and 8 (FishBase) so can tolerate moderately acidic as well as basic waters. Has plasticity in the range of water body and hydrological regimes it can inhabit. Although it occurs in latitudes corresponding to a temperature range of 18-23ºC, in aquariums it prefers warmer waters (21-28ºC).

Behaviour: Nothing reported.

Reproduction: Unknown, but perhaps not too specific given that this species reproduces readily in captivity (FishBase).

Generation time: Not described**.**

Diet: Moderately broad; is known to feed on worms, crustaceans and insects (FishBase). Was fed on *Poecilia reticulata* (guppy) during laboratory experiments (Krause & Godin 1995; Kelley & Magurran 2003). The former conducted experiments to test whether the feeding position of prey affected predation rate. They found that the blue acara preyed preferentially on guppies that were foraging in a head-down feeding mode than on those foraging in a horizontal feeding mode. Guppies are a natural food item for blue acara (Krause & Godin 1995) and brightly coloured guppies are particularly vulnerable to predation (Godin & McDonough 2003). It may be that similar sized, brightly coloured native fish species occupying the same position in the water column and/or the same trophic niche as the guppy may be more at risk than others. Another possibility arising from the above finding is that blue acara may be potentially used as predators to control or eradicate very confined populations of guppies. However, the blue acara is considered a less significant predator of guppies than other co-existing fish species in its native range (Kelley & Magurran 2003). The potential risks and costs of using this control method would clearly need very careful investigated before it could be field tested. The blue acara is reported to root up the bottom making it difficult to keep plants in aquaria (Midgalski & Fichter 1977). Such behaviour in the wild could, if the blue acara was sufficiently abundant, lead to habitat changes affecting the native fauna in some shallow water environments.

Likelihood of natural dispersal: Unlikely to be restricted by high flood flows. Is found only in fresh water, so may have a low salinity tolerance and not move unassisted between water bodies connected by brackish reaches. However, low salinity tolerance should not be assumed given the known euryhalinity of some cichlids. Invasiveness rated as very high by Arthington et al. (1999) and moderate by Bomford & Glover (2004).

Risk of human spread: Likely to be related, at least in part, to how widely the species is kept by aquarists. In Australia, the number of fish sold is relatively small and it is of medium importance to the industry (Table 7.1). Reported to have been used for mosquito control in the USA.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown as none reported to date. Known to be present in several streams around Brisbane and in the Hazelwood Power Station ponds, Victoria.

(n) Green swordtail (*Xiphophorus hellerii*)

Indigenous range: Tropical to subtropical, at latitudes 12°-26°N (corresponding with ambient water temperatures of 22-28°C). Native to North and Central America, specifically Rio Nantla, Veracruz in Mexico to northwestern Honduras (FishBase).

Introduced range: Established in more than 20 countries in Asia, Africa, Caribbean, Middle East, Indian Ocean Islands. Widely established in the USA (e.g. Hawaii, Texas, Colorado, Florida, California and in some geothermal waters in Idaho).

Maximum size: Males can grow to 14 cm TL, females to 16 cm TL (FishBase, USGS).

Habitat preferences: Found mainly in rapidly flowing streams and rivers, preferring heavily vegetated habitats, but also occurs in warm springs and associated streams, weedy canals and ponds (FishBase).

Environmental tolerances: Has relatively limited salinity tolerance (<3 ppt) (Englund 2002), and can occur in fresh or slightly brackish water. Little is known about temperature tolerances, although reproduction (fry production) does not occur below 15°C and above 29°C. Has a broad oxygen tolerance, being able to survive in low dissolved oxygen conditions through surface air breathing (Arthington et al. 1986, cited in Morgan & Gill 2001). Appears to tolerate a range of hydrological conditions, including rapidly flowing waters where vegetative cover is available. Its affinity with vegetation cover may also indicate that it is vulnerable to predation in open water, though this remains to be tested. Has a relatively narrow pH tolerance (7-8) but can survive in man-made or modified habitats such as urban streams (Arthington et al. 1983).

Behaviour: Males are aggressive towards each other under aquarium conditions (FishBase). Morgan & Gill (2001) cite Franck & Robowski (1993) as reporting that *X. hellerii* form long-term hierarchies and are, to an extent, territorial. Males spend much of their time fighting with conspecifics. Such aggression may or may not extend to native species under field conditions. Franck and Robowski (1993, cited in Morgan & Gill 2001), believe that interactions with native species are at least possible and seem likely, given reports that it is capable of dominating the aggressive and highly successful invader, *Gambusia holbrooki* (Arthington et al. 1996, cited in Morgan & Gill 2001). Sterba (1966), however, regarded this species as a peaceful, but lively fish in captivity. The aggressive status of *X. hellerii* and the potential for it to have impacts on Australian native fish clearly needs to be evaluated as soon as possible.

Reproduction: Is a livebearer, producing repeated batches of 20-240 young (FishBase). Spawning may be a monthly event and occur all year round provided water temperatures are suitable. Is a polymagous species (no mating pairs) and females may undergo a sex change to male (Sterba 1966), though Riehl & Baensch (1991) claim that this is unsubstantiated. If there is sex reversal, there is the potential to form breeding populations even if only females are present initially. The swordtail readily hybridises with the platy (Fuller et al. 1999).

Is non-migratory (FishBase), so does not need to move between waterways to spawn. The reproductive cycle of females ceases when water temperatures fall below 15˚C (Milton & Arthington 1983 cited in Morgan & Gill 2001). Such conditions are only met in winter in the subtropical and temperate regions, so it is capable of breeding for extended periods in much of Australia. A testament to this is the fact that 30% of females *X. hellerii* were pregnant in every month of the year except June in the Brisbane region (Milton & Arthington 1983 cited in Morgan & Gill 2001).

Reaches maturity at about 25-30 mm at an age of 10-12 weeks (Milton & Arthington 1983) and females can store sperm for up to 2 years (Axelrod & Wishnath 1991).

Generation time: Gestation is 24-30 days (Breder & Rosen 1966). Minimum population doubling time of less than 15 months, which FishBase equates with a high degree of resilience. Time required to reach breeding maturation is less than 1 year (FishBase) and in northern Australian waters was 10-12 weeks (Milton & Arthington 1983).

Diet: Relatively broad; feeds on worms, crustaceans, insects and plant matter (FishBase). Arthington (1989) in a study in Queensland found that dipteran larvae were among the dietary components, as were oligochaete worms, molluscs, filamentous algae, diatoms and fish (based on the presence of fish scales), though plant material was preferred. Kailola (2000) considered the species to be omnivorous.

Likelihood of natural dispersal: Allen et al. (2002) attributed establishment to “disposal or intentional release of aquarium pets, or possibly flooding of outdoor ponds.” Merrick & Schmida (1984) cite “environmental changes in the Brisbane area” as having advantaged this species. This species’ broad salinity tolerance range means that its unassisted range expansion in Australia will probably not be restricted in open systems where freshwater streams are connected by brackish reaches. It is also able to tolerate higher flow conditions compared with other established poeciliids, suggesting that lentic conditions are not likely to hinder its unassisted range expansion provided that streams have reasonable aquatic vegetation cover. However, its non-migratory life mode may limit the rate of unassisted spread in Australia. Invasiveness rated as very high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: Used for genetics research. It has been spread quite widely in Australia, presumably from releases by aquarists, and there seems no reason to believe its spread will not continue. In Australia, the volume of fish sold is relatively high and it is of high importance to the industry (Table 7.1) so the risk of further spread is also high.

Impacts overseas: It has been implicated in the decline of Utah sucker (*Catostos ardens*) in a Wyoming thermal spring (Courtenay et al. 1988) and in the decline of damselflies in Hawaiian waters (Englund 1999). FishBase regards this species as a potential pest and states that several countries report adverse ecological impact after introduction. No further details are provided.

Impacts in Australia: The presence of large numbers of swordtails has been linked with suppression of native fish species in Australia (Arthington 1989). Kailola (2000) reported a negative relationship between swordtail abundance and that of seven native fish species. Furthermore, an examination of this species in the Irwin River found that it was the only fish present suggesting that other species had been displaced (Morgan & Gill 2001). Because of its omnivorous diet (Arthington 1989), its fast breeding capacity, its lack of environmental constraints and especially its ability to coexist with gambusia (Milton & Arthington 1983), Morgan & Gill (2001) concluded that the green swordtail should be declared a pest species. Later, Warburton & Madden (2003) found that, in combination with other poeciliids, the swordtail displaced several native fish species by fin-nipping. However, the evidence of impacts on native fish in Australia is still not clear cut. This species is rated as a very high-risk species under the Bomford & Glover (2004) risk assessment model. It is also rated as having a very high potential for establishment in Australian waterways under the Arthington et al. (1999) risk assessment model, especially in northern and central latitudes. Currently recorded from eight widely spaced locations throughout Australia including Western Australia, Northern Territory, Queensland, and New South Wales.

(o) Platy (*Xiphophorus maculatus*)

Indigenous range: Tropical and sub-tropical, latitudes 17-23°N (corresponding with ambient water temperatures of 18-25°C). Native to North and Central America, specifically Ciudad Veracruz, Mexico to northern Belize.

Introduced range: Established in at least 12 countries including Africa, Asia, Canada, the Caribbean and the USA (FishBase). In the USA it occurs in Florida, Colorado, Hawaii and Montana (USGS).

Maximum size: Can grow up to 6.0 cm TL (FishBase).

Habitat preferences: Occurs in warm springs, canals and ditches with typically slow-moving water, silt bottoms and weedy banks (FishBase).

Environmental tolerances: Has limited temperature, salinity and hydrological tolerances, and is found only in warm, slow-flowing fresh water. Also seems restricted to waterways with silt bottoms and vegetation cover. Has a relatively restricted pH range of 7-8.

Behaviour: Sociable and non-aggressive in aquaria.

Reproduction: Is a livebearer that reproduces easily some plasticity in spawning requirements; is non-migratory, so does not need to move between waterways to spawn (FishBase). Time required to reach breeding maturation is less than 1 year (can attain sexual maturity after 3-4 months). No information is given in FishBase about spawning frequency. Hybridises readily with the green swordtail (USGS).

Generation time: Minimum population doubling time is less than 15 months, which give the species high resilience (FishBase).

Diet: Relatively broad, feeding on worms, crustaceans, insects and plant matter (FishBase). Arthington (1989) found that crustaceans such as atyid and caridian shrimp were among the foods consumed by these fish in streams in the Brisbane region, as was a range of aquatic and terrestrial insects and algae. Algae were a minor component of the diet of this species, despite being a more major component of the diet of this species in an Indonesian lake (Green et al. 1978, cited in Arthington 1989). Such diverse findings probably reflect its trophic plasticity.

Likelihood of natural dispersal: Restricted tolerances for water temperature, salinity and hydrological conditions, coupled with the fact the *X. maculatus* is non-migratory (FishBase), are likely to limit the rate of unassisted range expansion in Australia. This could also aid in the control and eradication of this species. Invasiveness rated as very high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: Dependent on its release by aquarists (and escape from outdoor ornamental ponds). In Australia, the number of fish sold is relatively high and it is of high importance to the industry (Table 7.1). The risk of spread as a consequence of human use is therefore high.

Impacts overseas: FishBase regards this species as a potential pest and states that several countries report adverse ecological impact after introduction. No further details are provided in FishBase. This species has, along with the green swordtail, been implicated in the decline of damselflies in Hawaiian waters (Englund 1999).

Impacts in Australia: Unknown as none reported to date. Now widely distributed in eastern Queensland but only two populations in the Northern territory.

(p) Sailfin molly (*Poecilia latipinna*)

Indigenous range: Subtropical and temperate, latitudes 16-40ºN (corresponding with ambient water temperatures of 20-28 ºC). Native to North America, specifically Cape Fear drainage in North Carolina, United States south to Veracruz in Mexico (FishBase).

Introduced range: Countries of Asia, Africa, Canada, some Caribbean islands, Guam, Hawaii, Middle East, New Zealand (geothermally influenced streams), South America (FishBase) and widely in the USA (e.g., Arizona, California, Colorado, Montana, Nevada and Texas – USGS).

Maximum size: Males of this species can reach 15 cm TL, while females can reportedly grow up to 10 cm (FishBase).

Habitat preferences: Occurs in ponds, lakes, sloughs and quiet, often vegetated backwaters or slow-flowing reaches of streams. Has been found in abundance in artificial habitats such as ditches and tidal canals. Generally found in water bodies less than 1 m deep (FishBase).

Environmental tolerances: Broad salinity tolerance means that it can occur in fresh and brackish water (FishBase). Ability to colonise man-made habitats such as ditches and drains suggests flexibility in terms of habitat requirements, though its restriction to still or slow-flowing waters suggests that spread may be limited by hydrological conditions. Frequent association with vegetation may indicate vulnerability to predators in open water, though this remains to be tested. Reported to require a pH of 7-8.5 in aquaria, so may be restricted mainly to neutral and basic waters.

Behaviour: Sociable and non-aggressive in aquaria.

Reproduction: Is a livebearer that can produce between 10 and 300 offspring per spawning (FishBase), and reproduces repeatedly. Is non-migratory (FishBase), so does not need to move between waterways to spawn.

Generation time: Minimum population doubling time of less than 15 months gives this species a high resilience (FishBase). Time required to reach breeding maturation is less than one year and can undertake multiple spawnings in a given year (FishBase).

Diet: Relatively restricted. Is considered benthopelagic, and feeds mainly on algae (FishBase). Courtenay & Meffe (1989) indicated that it is mainly herbivorous.

Likelihood of natural dispersal: This species' broad salinity tolerance means that its unassisted range expansion in Australia will not be restricted to systems where freshwater streams are connected by brackish reaches. However, it does not migrate to spawning or feeding grounds and this may limit its rate of unassisted spread in Australia. Furthermore, it is found only in slow-flowing or still waters, suggesting that higher stream flows may hinder its unassisted range expansion in Australia. These factors may collectively assist in the ability to control or eradicate populations of this species. Invasiveness is rated as very high by both Arthington et al. (1999) and Bomford & Glover (2004).

Risk of human spread: A distinctive feature of this species is that rearing in natural habitats produces much larger 'sail-fins' in the males, and this is an incentive to establish feral populations which can be harvested at a later data for sale. In Australia, the number of fish sold is relatively high and it is of high importance to the industry (Table 7.1). The higher value placed on fish with large 'sail-fins', coupled with the high demand for this species, increases the risk that it will be released into the wild.

Impacts Overseas: FishBase regards this species as a potential pest and states that adverse ecological impacts have been reported after its introduction, but other information on the impact mechanisms, consequences or manifestations is not provided. It is reputed to be responsible for the decline of the desert pupfish (*Cyprinodon macularius*) in California (US Fish & Wildlife Service 1983) and, with other introduced poeciliids, for the decline of damselflies in Hawaii (Englund 1999).

Impacts in Australia: Regarded as having a potential for adverse effects on some native fish (Arthington 1989). While its breeding and habitat plasticity may seem to point to this species having reasonable invasive capacity, the relatively restricted diet and absence of records of aggressiveness appear to make competition for food with native fish species, competition for space by means of aggressive territoriality, or predation, unlikely impact mechanisms. Given that algae are a major component of its diet, it may have adverse impacts on native fish species through habitat modification (e.g., through degradation of their habitat or that of their preferred prey). Recorded from three geographically separated locations in eastern Queensland

(q) Guppy (*Poecilia reticulata*)

Indigenous range: Tropical, latitudes 2-14°N (corresponding with ambient water temperatures of 18-28°C). Native to South America, specifically Venezuela, Barbados, Trinidad, northern Brazil and the Guyanas (FishBase).

Introduced range: Very widespread in > 40 countries, from Russia to New Zealand (in geothermal waters) and the Americas, Asia, Africa and Europe.

Maximum size: Males grow to 3.5 cm SL, females to 5.0 cm SL (FishBase) but reports of 6 cm in aquaria.

Habitat preferences: Occurs in warm springs and associated streams, weedy ditches and canals. Found in various habitats, ranging from highly turbid ponds, canals and ditches at low elevations to pristine mountain streams at high elevations (FishBase).

Environmental tolerances: Has wide salinity tolerances, but requires fairly warm temperatures (23-24 °C) and quiet vegetated water for survival (FishBase). However, it has been found in many temperate countries (Welcomme 1988), so its actual temperature tolerances could be much greater than FishBase suggests. *P. reticulata* also appears to tolerate a range of turbidities ranging from clean water in pristine streams to highly turbid canals and ditches. Also seems to have plasticity in terms of its habitat requirements given the range of water bodies it has been found in, though the frequent association with vegetation suggests that this species may be vulnerable to predation in open water. Has relatively narrow pH tolerances of 7-8 (FishBase). Colourful males are vulnerable to predation, but can overcome this by changing colour to become less colourful when predators are prevalent (Gomez & Ferriz 2002). This species also has the capacity to increase its growth rates when under high predation pressure, however, this response to predation will depend largely on food availability (Arendt & Reznick 2005).

Behaviour: May form schools as part of its predator avoidance behaviour (Reznick & Endler 1982). In areas where it has been introduced overseas it has had a negligible effect on native fish populations (FishBase). This probably indicates a lack of aggressiveness, but it is not possible to rule out aggressiveness of this species towards Australian native fish without further investigation.

Reproduction: Is a livebearer, typically producing batches of between 20 and 40 offspring, but sometimes many more. Undergoes sex change from female to male

(Sterba 1966) when there are few or no males in populations, and so has the potential to form breeding populations even if a population is originally all female. Is non-migratory (FishBase), so does not need to move between waterways to spawn. Male colouration provides a visual cue for female choice (Gomez & Ferriz 2002).

Generation time: Minimum population doubling time less than 15 months, which FishBase equates with a high degree of resilience. Time required to reach breeding maturation is between 0.16 and 0.25 years (males may mature at 2 months and females at 3 months of age) and this species can spawn multiple times per year (FishBase). Reznick & Endler (1982) found that, when in the presence of predators that have this species as a major component of their diet, the young reach maturity more quickly and produce more offspring. Hence, figures given for time to reach maturity and clutch size given in FishBase may be underestimates for some sites. They also state that these changes can take place rapidly (within 2.5 years). These findings demonstrate a capacity to compensate for natural population control by predators, which may reduce the usefulness of predator introduction as a means of control or eradication.

Diet: Reasonably broad; feeds on zooplankton, small insects and detritus. Has been introduced in some countries for mosquito control, and so is thought capable of feeding on these and other dipteran larvae, but this is unverified. Arthington (1989) found that populations around Brisbane included ants along with chironomid midge larvae (diptera) as major components of their diet. This contrasts with the diet of this species in Trinidad streams, which comprised larger proportions of aquatic insect larvae, unicellular algae, diatoms and plants (Dussault & Krumer 1981, cited in Arthington 1989). Such diverse findings probably reflect the trophic plasticity of this and other poeciliids (Arthington 1989). Also eats the eggs of other fish (Welcomme 1988), which may be a potential impact mechanism in Australian streams and ponds. This requires further examination.

Likelihood of natural dispersal: This species' broad salinity tolerances mean that its unassisted range expansion is likely in open systems where freshwater streams are connected by brackish reaches. However, its non-migratory life mode may limit the rate of unassisted spread in Australia. Furthermore, it is found mainly in lentic systems, suggesting that higher flow conditions may be a barrier to its unassisted range expansion in Australia. These factors may assist in the control or eradication of populations. Gomez & Ferriz (2002) found that larger, long-tailed individuals of this species tolerate velocities of 15.4 cm s^{-1} for almost an hour at 24°C before fatigue sets in. This is probably more of an adaptation for predator avoidance than for migration (Gomez & Ferriz 2002). *P. reticulata* is known to coexist with predators and to be a favoured food source of others (Reznick & Endler 1982). Little published information exists regarding predation of this species by Australian native fish, so it is difficult to gauge whether its populations might be kept under control by predation. A number of studies (cited in Reznick & Endler 1982) have reported that *P. reticulata* is known to become brighter, larger, tends to school less often, and reacts at shorter distances to the presence of predators where different generations are exposed to higher predation pressure. A later study, published by Kelley & Magurran (2003), reached similar conclusions and stated that this adaptive behaviour was a heritable trait. Assessment of morphologies and behaviour at different sites in Australian waterways may, therefore, in part, determine the degree to which the population is controlled by predation at a local scale. Populations in geothermally influenced streams near Rotorua in the North Island of New Zealand have not become established in the somewhat colder, ambient waters further downstream (D. Rowe, pers. comm.). Invasiveness in Australia rated as very high by Arthington et al. (1999) and extreme by Bomford & Glover (2004).

Risk of human spread: In Australia, the number of fish sold is relatively high and it is of high importance to the industry (Table 7.1). The risk of spread by humans is therefore high.

Impacts overseas: FishBase regards this species as a potential pest and states that several countries report adverse ecological impact after introduction, but provided no details.

Impacts in Australia: Unknown as none reported to date. Now spread widely through the eastern waters of Queensland and northern New South Wales. Isolated populations also recorded in western Australia and the Northern Territory.

(r) Caudo or one-spot livebearer (*Phalloceros caudimaculatus*)

Indigenous range: Tropical latitudes corresponding with ambient water temperatures of 20-24°C. Native to South America, specifically Rio de Janeiro, Brazil southward to Uruguay and Paraguay (FishBase).

Introduced range: Malawi, New Zealand (establishment uncertain).

Australian range: Low elevation waters of coastal New South Wales (Sydney, Newcastle); also near Perth in Western Australia.

Maximum size: Males reach 3.5 cm SL, while females can grow to 6 cm TL (FishBase; Sterba 1966).

Habitat preferences: Still waters and small ponds and margins.

Environmental tolerances: Relatively broad salinity tolerances, being found in both fresh water and brackish water (FishBase). Sterba (1966) states that this species is resistant to low temperatures and can be kept in unheated aquaria at temperatures of 12-18ºC, but prefers 20-24ºC. Has narrow pH tolerance of 7-8 (FishBase) indicating that it prefers basic to acidic waters.

Behaviour: Is a very peaceful and easily satisfied species (Sterba 1966).

Reproduction: Is a livebearer, with large females producing clutches of up to 80 young per spawning (Sterba 1966). Spawning requirements are minimal. Does not undertake any migration for spawning (FishBase). In Western Australia, it spawns continually throughout the year (Morgan & Beatty 2006a).

Generation time: Minimum population doubling time is less than 15 months, giving this fish a high resilience (FishBase).

Diet: Regarded as omnivorous (FishBase). No further details were given in FishBase other than that it has been introduced for mosquito control. Thus, its diet is likely to include mosquito larvae and pupae and possibly other dipterans.

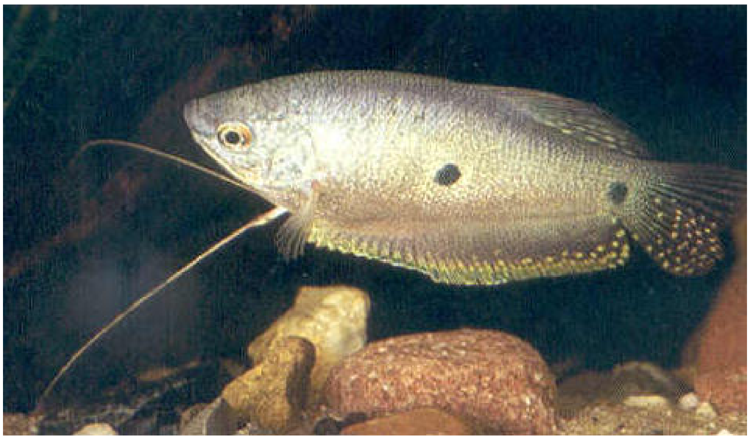
Likelihood of natural dispersal: This species' broad salinity tolerances mean that unassisted range expansion in Australia is likely. Will probably not be prevented from invading freshwater streams connected only by brackish reaches. However, the fact that this species is non-migratory (FishBase), coupled with its limited mobility owing to a small maximum size might suggest that the rate of unassisted range expansion rate would be slow. This supposition remains to be tested. Invasiveness rated as very high by Arthington et al. (1999) and high by Bomford & Glover (2004).

Risk of human spread: If feral populations are easily established its spread may be rapid, but there is little field evidence for this yet. In Australia, it is of low importance to the industry (Table 7.1) so the risk of spread by humans is low.

Impacts overseas: FishBase regards this species as a potential pest and stated that at least one country reports adverse ecological impact after introduction. No further details are provided, so the impact mechanisms in those countries are unclear.

Impacts in Australia: Observations of this species in the Perth region indicated that it may have resulted in the displacement of *Gambusia holbrooki* from one location (ASFB 2003c; Morgan & Beatty 2006). The mechanism may be competition for food or hybridisation (Morgan & Beatty 2006a). Very similar observations were made by Rowley et al. (2005) for a population in Sydney. If this species has displaced *Gambusia*, which is a well known pest fish species that often displaces small native fish species, then the caudo may well be able to displace small native fish species. There is no quantitative evidence for this at present so data on its interactions with other fish are urgently required. It is rated as a high-risk species under the Bomford & Glover (2004) risk assessment model. It is also rated as having a very high potential for establishment in Australian waterways under the Arthington et al. (1999) risk assessment model. Given this high 'invasive' potential plus the probability of impact on small native fish species, concerns over its potential impact are warranted. Currently present in a number of waters around Perth and in two locations in New South Wales.

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



Indigenous range: Tropical (latitudinal range 26-10°N), and found at temperatures of 22-28°C; native to southeast Asia: Mekong basin in Laos, Yunnan, Thailand, Cambodia and Viet Nam.

Introduced range: Introduced quite widely elsewhere including Colombia, Dominica, Namibia, Papua New Guinea, Philippines, Sri Lanka (FishBase) and Florida (USGS).

Maximum size: 15.0 cm SL (FishBase).

Habitat preferences: Found in marshes, swamps and canals. Prefers shallow sluggish or standing-water with abundant aquatic vegetation; pH 6-8 (FishBase) indicating tolerance of mildly acidic as well as basic waters.

Environmental tolerances: Restricted to fresh water, so can't disperse between sites where migration through brackish or marine water is required. Relatively narrow pH tolerance range, 6-8 (FishBase). Has auxiliary breathing mechanisms so can tolerate low oxygen conditions (Arthington and Marshall 1999). These authors considered that it has a moderate to high probability of establishment in Australia.

Behaviour: Is benthopelagic and solitary. Regarded as 'peaceful and contented' Sterba (1966) and Riehl &Baensch (1991) in aquaria.

Reproduction: Constructs a bubble nest near the water surface where it deposits 1500-2000 eggs; these are guarded by the male, and hatch in 1.0-1.5 days; larvae are tiny and not robust. Reaches maturity at 70-80 mm length.

Generation time: Minimum population doubling time less than 15 months; multiple spawning per year. This equates with a high degree of population resilience (FishBase).

Diet: Moderately broad, primarily invertebrates including zooplankton, crustaceans and insect larvae; Riehl and Baensch (1991) describe it as "omnivorous".

Likelihood of natural dispersal: In the Mekong, this species has a tendency to undertake migrations from permanent waters bodies to flooded areas and then return to permanent water bodies at the onset of the dry season (FishBase). This behaviour might result in unassisted movements to new locations in Australia should it occur in regions where inundation of floodplains allows its escape from permanent water bodies. This might pose a particular risk of invasion of billabongs. Is regarded as freshwater-limited, which means that dispersal around coasts or in harbours and inlets, in brackish water, is unlikely. Invasiveness rated as very high by Arthington et al. (1999) and extreme by Bomford & Glover (2004).

Risk of human spread: In Australia, this species is of high importance to the industry but the numbers sold are not high (Table 7.1). The risk of spread is therefore moderate.

Impacts overseas: FishBase regards this species as harmless, though the basis for this judgement is unclear.

Impacts in Australia: None reported. Populations known to occur in the Ross and Burdekin Rivers in Queensland.

(t) Oriental weatherloach (*Misgurnus anguillicaudatus*)

Indigenous range: Subtropical to cold, temperate latitudes 27-53°N (corresponding with ambient water temperatures of 10-25°C). McMahon & Burggren (1987 cited in Lintermans et al. 1990) described this species as eurythermal and suggested that it can thrive in water temperatures from 2-30ºC. Native to Asia, specifically Myanmar and northeastern Asia and southward to central China (FishBase). Greatest densities in southeast Asia and the Malay Archipelago (Sterba 1962).

Introduced range: Eastern Europe, Hawaii, Mexico, Palau, Philippines (FishBase). Established in Oregon and Washington as well as in a number of southern States in the USA (USGS).

Maximum size: Up to 24.8 cm TL (FishBase).

Habitat preferences: Occurs in rivers, lakes and ponds, swamps and rice fields at depths down to 5 m. Prefers cool, slow-flowing waters with muddy or weed covered bottoms. It creates shallow burrows in the substrate where it can hide with only its head sticking out. This behaviour is also associated with 'overwintering' (Burchmore et al. 1989), but is also believed to be a form of predator avoidance (Sterba 1962). In Hawaii, where it has been introduced, it has been found living in association with algal/macrophyte mats (FishBase). Tabor et al. (2001) found that it was associated mainly with macrophytes in shallow waters.

Environmental tolerances: Has broad habitat tolerances and is found in a wide range of habitats. Typically regarded as a cool water species (Welcomme 1988). Can tolerate highly turbid and deoxygenated conditions (Burchmore et al. 1990; Welcomme 1988), which allows it to colonise degraded aquatic habitats often found in association with large urban areas. Can also tolerate low oxygen conditions, partly through its ability to swallow air and pass it through its highly vascularised intestine (McMahon & Burggren 1987 cited in Lintermans et al. 1990). Can survive in highly modified waters, this being an indication of its habitat plasticity. Ip et al. (2004) noted that it is drought resistant and buries in the mud to avoid dehydration. Lintermans et al. (1990) report that, at one site in the ACT, weatherloach was abundant in association with an artificial soil structure consisting of wire cages containing rock fill. It is even said to be able to tolerate pesticide contamination (Lee & Lee 1985, cited in Lintermans et al. 1990), which begs the question how effective chemical control mechanisms will be in eradication or reducing populations. Perhaps more disturbingly, from an invasiveness perspective, is its reported ability to crawl out of water, survive in damp soil and even move across land (comments attributed to A.K. Morrison cited in Burchmore et al. 1990).

Behaviour: Not known as aggressive; primarily solitary.

Reproduction: Up to 2000 offspring per spawning (FishBase). Under laboratory conditions has been induced to spawn every 20 days or so for 13 months (Suzuki 1983 cited in Burchmore et al. 1990). Whether or not this is replicated in the wild in Australia remains to be determined. Spawning is linked to water levels and access to floodplains in its native range (Tanaka 1999), which might also hold for this species in Australia.

Generation time: Minimum population doubling time is 1.4 - 4.4 years, which FishBase equates with a medium level of resilience.

Diet: Broad. Feeds on worms, small crustaceans, insects, insect larvae, and other small aquatic organisms (FishBase). A study by Katano et al. (2004) found that *M. anguillicaudatus*, along with several other species studied, consumed mainly dipterans (chironomid and ephemeropteran larvae). Tabor et al. (2001) found that it fed mainly on benthic prey such as chironomids and detritus and used chemical stimulation to locate its prey. In Australia, the diet of this species was more or less consistent with that listed in FishBase, but also included detritus as a major component (mean of 36% by volume) (Burchmore et al. 1990). However, this was based on the stomach contents of only 5 individuals, and the list of prey items consumed was probably greater than this, so the relative importance of detritus in the diet may have been exaggerated. Some workers believe that the preference of this species for muddy substrates is linked to its preference for detritus as a dietary component (Watanabe & Hidaka 1983 cited in Lintermans et al. 1990). The relative importance of the various prey items this species consumes in Australia at various times of the year (or at various locations) awaits a more thorough assessment.

Likelihood of natural dispersal: Is probably restricted to fresh water so that brackish water would likely prove an obstacle to the unassisted range expansion of this species. In its native range, it moves via creeks and drainage networks from permanent water bodies to rice fields on the flood plains where it reproduces. It then returns to permanent water bodies to 'overwinter' (Tanaka 1999). Thus, inundation of floodplains in Australia may provide this species with a spawning cue and be a means of dispersal. However, the ability of this species to move across land means that it may spread more readily from one water body to another in low-lying or relatively flat areas. Burrowing activities during overwintering may affect some environments and mean that sampling needs to be carried out in summer, especially if netting or trapping are the main techniques used (Burchmore et al. 1990). Invasiveness rated as very high by Arthington et al. (1999) and high by Bomford & Glover (2004).

Risk of human spread: Is valued as a fishery and aquaculture species in other countries, so has potential for dispersal to new waterways by coarse fish anglers and aquaculturists. The USGS fact sheet on this species indicates that it has been spread within the USA from aquarium facilities, by asian immigrants as a food source and by anglers as a bait fish. Lintermans et al. (1990) stated that it is 'not desired' by Australian anglers. Is also considered for commercial bait harvest in some countries (FishBase) and could be transferred to new waterways in Australia through use as live bait. Allen et al. (2002) attribute establishment to "thoughtless disposal of unwanted fish by aquarists" and escapes when used by anglers as live bait. This species' ability to survive in turbid and deoxygenated conditions may allow easy expansion of range into degraded urban waterways.

Impacts overseas: FishBase regards this species as a potential pest and states that adverse impacts have been reported in at least one country where established. Burchmore et al. (1990) reported assessments from different countries, ranging from 'benign' in mainland USA, to 'uncertain' in Mexico, to 'intermediate' in Hawaii.

Impacts in Australia: Was declared a banned import in 1986 owing to its 'feral habits' (Burchmore et al. 1990), but it is unclear whether this was based on its potential invasiveness alone or incorporated perceived potential environmental impacts. Burchmore et al. (1990) argued that it should be declared a noxious species, but this appears to have been based purely on its successful establishment and the impossibility of eradication, rather than actual adverse ecological impacts. *M. anguillicaudatus* is designated as a noxious species in the ACT (Lintermans et al. 1990).

Suggested potential impacts relate to this species' habitat preferences, its burrowing activities, diet, competition with native fish for spawning sites, disturbance or predation of eggs, competition with native species for planktonic food (particularly with larval fish), competition for shelter, and habitat alteration (Lintermans et al. 1990b). Lintermans et al. considered these impacts speculative and we have not been able to uncover studies investigating any of these perceived potential impacts.

Evidence of impacts is based primarily on correlative observations, as is almost always true of evaluations of the impacts of invasive species. Lintermans (1993) found that *Galaxias olidus* and oriental weatherloach were never found together in a small stream near Canberra, though the galaxiid was present 150 m upstream. He observed that it was not possible to determine whether this finding reflected competitive exclusion, or exploitation of habitats by weatherloach that were unsuitable for the galaxiid. Arthington & Blühdorn (1995) cited personal comments from Lintermans that there was 'preliminary evidence' of the impacts of weatherloach on the mountain galaxias. Environment ACT (2002) indicated that it may be responsible fore a localised decline of Mountain Galaxias and Western Carp gudgeon in part of the Ginninderra Creek catchment.

This species is rated as a high-risk species under the Bomford & Glover (2004) risk assessment model and is on the proposed noxious species list in the strategic approach to the management of ornamental fish in Australia (NRMMC 2006). It is also regarded as having a moderate to high probability of establishment under the Arthington et al. (1999) risk assessment model. Now widely distributed in south-eastern New South Wales and Victoria.

(u) Goldfish (*Carassius auratus*)

Indigenous range: Subtropical to temperate latitudes of 22-53°N (corresponding with ambient water temperatures of 0-41°C). Native to Asia, specifically central Asia and China, and Japan (FishBase).

Introduced range: Very widespread from the cold temperate to sub-tropics, all over the world.

Maximum size: Reportedly grows to 59.0 cm TL and 3,000 g in weight. Can live as long as 30 years (FishBase).

Habitat preferences: Inhabits rivers, lakes, ponds and ditches with stagnant or slow-flowing water (FishBase). Tropical populations of this species are generally found at altitudes of 200-1000 m (Welcomme 1988).

Environmental tolerances: Occurs in habitats where there is a wide range of temperatures. Also has broad salinity tolerances, and can tolerate salinities as high as 17 ppt, but can't cope with prolonged exposure above 15 ppt. Occurs in a variety of habitats and tolerates low oxygen conditions associated with stagnant water. Broad tolerance of acidity indicated by pH range of 6 to 8 (FishBase).

Behaviour: Peaceable and sociable showing little aggression.

Reproduction: Lays a few to many thousands of eggs on submerged vegetation; larvae are pelagic; no parental care (FishBase). According to Holcik (1980), this species can breed independently of water levels, and this was one of the factors that contributed to its success in the Danube system compared with native species of carp that need water levels to be high enough to allow access to floodplains to breed. Establishes self-sustaining populations easily in small ponds to large lakes, especially where there is plentiful aquatic vegetation.

Generation time: Minimum population doubling time 1.4 - 4.4 years, which FishBase equates with a medium level of resilience. Maximum time taken to reach breeding maturity is around 1 year.

Diet: Consumes a wide range of foods including plants, small crustaceans, insects, and detritus (FishBase; Arthington and Mackenzie 1997). Goldfish will suck up a mouthful of sediment when feeding on benthos and the sediment is then spat out raising turbidity levels (Richardson et al. 1995). Has also been known to prey on salamander eggs (Monello & Wright 2001), and so may pose a threat to some Australian frog species, though this would require further investigation.

Likelihood of natural dispersal: Is probably unable to disperse between river catchments through coastal, brackish estuaries and seas, but is likely easily to spread into billabongs that are intermittently connected to mainstem rivers where it is present. This is a likely explanation for the species' present broad range in southeastern Australia. Invasiveness rated as very high by Arthington et al. (1999) and extreme by Bomford & Glover (2004).

Risk of human spread: Holcik (1980) demonstrated population explosions of goldfish in the Danube River system corresponding to decreased catches of local predators caused by a combination of fishing pressure, barriers to fish passage, altered hydrological regimes and atypically low water levels that restrict access to breeding sites on the floodplains. Many of the progeny of recently released goldfish often have bright colouration making it vulnerable to predation (A. Moore pers. obs.), but this is likely to result in strong selection against such colouration persisting in wild populations. If fishing pressure reduces predation on goldfish in Australian waterways through removal of piscivores, or if human activities or natural factors affect the access of those predator species to their spawning sites, there is potential for similar population explosions of goldfish in this country. Arthington & Blühdorn (1995) reported that this species was probably being sold as rock lobster bait which, if true, is a cause for concern as conflicts of interest may drive those who profit from this to introduce goldfish into new waterways to guarantee a continued supply. There are anecdotal reports of this species being used as live bait by anglers (Arthington & Blühdorn 1995) which, regardless of legislation introduced in some states to stop this activity, poses another mechanism for further spread in Australia. In Australia, the volume of fish sold is very high (Table 7.1) so the risk of further spread by humans is high.

Impacts overseas: FishBase regards this species as a potential pest and states that several countries report adverse ecological impact after introduction; no further details are provided on the mechanisms or manifestations of these impacts. Welcomme (1988) suggested that the environmental effects of *C. auratus* are somewhat neutral and that its nuisance value has more to do with its capacity to produce stunted populations that are of little use in terms of forage. Crivelli (1995) provides a Mediterranean example of this, whereby populations introduced into Lake Kastoria in Greece resulted in neither increased yields nor income for local fishers, despite representing 80% of their catch.

Other workers have reported increases in turbidity levels and damaged or uprooted aquatic plants in muddy sediment ponds where this species has been introduced, and that their diets have overlapped with some Canadian frog species (Richardson & Whoriskey 1993; Richardson et al. 1995). These workers also stated that avian predation pressure on this species may actually be reduced owing to the role of goldfish in increasing turbidity. Richardson et al. (1995) clearly demonstrated that *C. auratus* was able to increase turbidity levels in muddy pools by 10 times compared with experimental control muddy pools. Goldfish were, however, not able to achieve significant changes in turbidity where experimental pools had sand/gravel beds. The increase in turbidity generated by goldfish in these experimental trials resulted in changes in temperature regimes as well, but did not significantly affect the growth of aquatic plants. Plants were, however, commonly up-rooted by goldfish in this trial, though they were not observed being eaten by these fish. An earlier study by Richardson et al. (1992) demonstrated that turbidity generation by *C. auratus* was positively correlated with body size, so populations of larger-sized fish of this species have the most potential to increase turbidity levels (and by association, have impacts on native fish or their prey).

Archibald (1975) used manipulative laboratory experiments to determine the influence of increasing vertebrate predation pressure on zooplankton communities, using *C. auratus* as the vertebrate predator of choice. The response of zooplankton to different levels of predation pressure in these experiments was complex, with some species increasing in density at low-to-intermediate predation levels, while a decline in most zooplankton species occurred under high predation pressure. This study demonstrates that 1) juvenile *C. auratus* are capable of feeding on elements of zooplankton communities in Australian waterways and, 2) that complex changes in the community structure could occur in conjunction with fluctuating densities of this species. Given that *C. auratus* has been known to numerically dominate some fish communities in Australia, there is potential for zooplankton densities to decline markedly as a result of high predation pressure from this species. This could have cascading ecological effects that impact on Australian native fish, particularly those zooplankton grazers that feed largely in the middle of the water column.

Impacts in Australia: Wager & Jackson (1993 cited in Arthington & Blühdorn 1995) and also *in* Arthington & Mackenzie (1997), suspected that *C. auratus* may have adverse impacts on the 'endangered' indigenous trout cod *Maccullochella macquariensis*. A control programme is being undertaken to remove a newly established population in the Vasse River, Western Australia, because of concerns that it will feed on fish eggs, reduce macrophytes, increase turbidity and stimulate blue-green algal blooms (Morgan & Beatty 2005; 2006b). Although there is as yet no compelling evidence for such impacts, the concerns are valid, especially in environments where goldfish will proliferate. Pritchard et al. (2004) found that goldfish were a minor component of the fish fauna in the waterways of the Lake Eyre Basin in both 1986-1992 and 2000-2003. Goldfish are regarded as a prescribed non-indigenous fish in Queensland under the Fisheries Act, but this only means that it is illegal for it to be released; it may be kept in aquaria (Arthington & Blühdorn 1995). Is rated as an extremely high-risk species in terms of its invasive potential under the Bomford & Glover (2004) risk assessment model. Also rated as having a very high risk of establishment under the risk assessment model of Arthington et al. (1999). Its existing, broad range may be close to that which it can achieve in eastern Australia, though there is no doubt some potential for the species to occupy many more water bodies within that range. Its current distribution probably reflects the species high popularity and its long presence in Australia (since the 1860s – Allen et al. 2002). Very widely distributed throughout the southeast of Australia, including parts of Tasmania. Also present in the southwest of Western Australia.

(v) Rosy barb (*Puntius conchonius*)

Indigenous range: Subtropical to temperate, latitudes 8-40°N (corresponding with ambient water temperatures of 18-22°C). Native to Asia, specifically Afghanistan, Pakistan, India, Nepal, and Bangladesh (FishBase).

Introduced range: Canada, Colombia, Mexico, Puerto Rico, Singapore (FishBase) and Florida (USGS).

Maximum size: Up to 14.0 cm TL (FishBase).

Habitat preferences: Inhabits lakes and fast-flowing hill streams (FishBase).

Environmental tolerances: Considered to be one of the hardiest of the barbs (FishBase), with broad environmental tolerances. Its fairly restricted latitudinal temperature range may limit its unassisted range expansion in Australia to the subtropics. Has limited salinity tolerance and is only found in fresh water. Tolerates pH between 6 and 8. According to Sterba (1966), water quality conditions are generally unimportant to members of the genus *Puntius*, but these fish prefer water that has been "well matured by plants". The young of this species are vulnerable to damage by copepods (such as *Cyclops* spp.) and ostracods (Sterba 1966), which are likely to occur in most water bodies in Australia. There may, therefore, be potential for producing populations of these invertebrates for use in controlling recruitment of the rosy barb, but this remains to be tested and any side-affects examined.

Behaviour: According to Sterba (1966), members of the genus *Puntius* often occur in large shoals. Such behaviour might also be exhibited by *P. conchonius,* though this requires further investigation. Aggressiveness is probably limited given that this species can be kept together with other small fishes (FishBase) and is considered a peaceful fish (Sterba 1966; Riehl & Baensch 1991).

Reproduction: All members of the genus *Puntius* are oviparous. Young hatch 24-36 hours after eggs are laid and avoid predation by staying in close proximity to the substrate and vegetation for 1-2 days. Parents are notorious spawn-robbers and can devour their young (Sterba 1966). For breeding in aquaria, Sterba (1966) recommends a soft and not too pale substrate with a loose and not too dense screen of floating plants. While this recommendation was not specific to *P. conchonius*, or wild populations of this species, it may be that *P. conchonius* requires these habitat conditions in the field for sustaining its populations. Sterba (1966) states that all fine-leafed plants are suitable for egg deposition. However, breeding of members of the genus *Puntius* is said to be a relatively simple process (Sterba 1966), which might indicate plasticity in their spawning requirements. For some species of *Puntius*, spawning may be triggered by influxes of fresh water in combination with light incidence during mornings (Sterba 1966).

Generation time: Minimum population doubling time less than 15 months and can reach breeding maturation in less than 1 year (FishBase). Sterba (1966) states that aquarium-reared populations of the genus *Puntius* can begin spawning between 9 and 12 months. Considered to have a high level of resilience (FishBase).

Diet: Relatively broad. Food consists of everything from worms, crustaceans and insects to plant matter. Considered to be a gluttonous feeder (Sterba 1966), which may allow it to quickly deplete food resources that might be shared with other species.

Likelihood of natural dispersal: Can tolerate fast-flowing conditions and so may be able to move between waterways. However, it cannot tolerate brackish water, so its unassisted range expansion in situations where water bodies are separated by brackish reaches is unlikely. Invasiveness rated as high by Arthington et al. (1999) and very high by Bomford & Glover (2004).

Risk of human spread: Again, this risk relates to how widely the species is kept in captivity and the behaviour of those who keep them (or no longer wish to keep them!). Even though it is of high importance to the ornamental fish industry in Australia, the volume of fish sold is moderate (Table 7.1). The risk of spread is therefore moderate.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown. None reported to date. Currently only reported from streams in and around Brisbane.

(w) White cloud mountain minnow (*Tanichthys albonubes*)

Indigenous range: Tropical, latitudes 9-30°N (corresponding with ambient water temperatures of 18-22°C). Native to Asia, specifically China and Vietnam (FishBase).

Introduced range: Colombia, Madagascar, possibly Canada, Philippines, United States.

Maximum size: Up to 4.0 cm TL (FishBase).

Habitat preferences: Prefers weedy streams and ponds.

Environmental tolerances: Found only in freshwater ecosystems and, being a cyprinid, probably has narrow salinity tolerances. Despite the relatively restricted water temperature ranges in its native range, this species can tolerate water temperatures as low as 5°C (FishBase); also tolerates pH of 6-8, but occurs only in fresh water (FishBase). No information regarding its tolerance to a range of hydrological conditions is provided in FishBase. Seems to need cool winter temperatures.

Behaviour: Peaceable and sociable in captivity (Riehl and Baensch 1991), and likely to be the same in nature.

Reproduction: Likely to have low fecundity owing to small adult size, less then 250 small eggs, but may repeat spawn often; ova spread on substrate.

Generation time: Minimum population doubling time less than 15 months and can reach breeding maturation in less than 1 year (FishBase). Considered to have a high level of resilience (FishBase).

Diet: Relatively restricted. Given its demersal habitat (FishBase) it is likely to prey mainly on benthic species. However, FishBase states that it feeds on zooplankton as well as detritus.

Likelihood of natural dispersal: Can tolerate a range of water temperatures and so has the potential to survive in many parts of Australia (though it could be that winter minimum temperatures in some areas affect its reproductive output or production rates). This is yet to be tested. *T. albonubes* is only found in fresh water, so brackish water may provide a barrier to its unassisted dispersal in open systems where freshwater reaches are connected by brackish water reaches. Invasiveness rated as moderate to high by Arthington et al. (1999) and high by Bomford & Glover (2004). Has been publically proposed as an alternative to gambusia for mosquito control (pers. comm.. M Abell), which may greatly accelerate its spread.

Risk of human spread: The ease with which this species may establish populations in small ponds may add to the risk of spread. Otherwise, this depends, again, on how often it is kept and the attitudes of aquarists. Its seemingly small size may promote the thought that it is harmless. In Australia, the volume of fish sold is relatively high and it is of high importance to the industry (Table 7.1). Its risk of spread is therefore high.

Impacts overseas: FishBase regards this species as harmless.

Impacts in Australia: Unknown. None reported to date. Reported to be in two locations (a creek in Brisbane and another near the coast in New South Wales).

4.3 Summary

One point that is immediately obvious is the paucity of impact studies carried out for many of these ornamental species, both in Australia and overseas. Exceptions to this included Mozambique tilapia, goldfish, oriental weatherloach and some of the live-bearing (Poeciliidae) species, which were somewhat more thoroughly studied. However, even for these species, evidence of impacts is often conflicting, based on correlative data or perceptions, or other factors that have been deemed to be potentially responsible for observed patterns in native fish communities. This conclusion is unsurprising, as globally there are very few instances where ecological impacts of alien fish on the receiving fish communities are well understood. This problem has multiple sources, but relates to: 1) inadequate knowledge of implicated species' natural history (habitat requirements, diet, reproduction and behaviour) and their place in their native habitats; 2) similarly inadequate knowledge of the ecosystems into which such species have been inserted as alien species; summing up to a far from adequate understanding of the impacts of the alien species in receiving habitats. All of this generates the attitude, consistent with the precautionary principle, that Simberloff (2003) summed up as "shoot first and then ask questions". Fundamentally, this was his recognition that for the majority of instances, the only safe way of avoiding adverse impacts on an ecosystem by an alien species is to prevent its release and establishment. This sentiment is also expressed in Arthington et al. (1999) and in our view certainly applies to the alien fish species established in Australian waters.

McDowall (2004) concluded for New Zealand that the safest criterion to apply when that country was endeavouring to establish protocols for providing protection from alien aquarium fishes was temperature. In New Zealand, the temperate climate means that the alien species requiring warm temperatures for reproduction and growth are unlikely to establish, except in isolated habitats below geothermal springs. However, Australia encompasses a much wider range of climate zones and there is a high likelihood that any alien fish species can find congenial temperatures somewhere in Australian fresh waters. Consequently, all alien species can potentially establish in the wild somewhere in Australia.

There have been few impact studies focussing on the link between the impact mechanism and impact manifestation for any of the species known to be established in Australian fresh waters. Such mechanistic studies linking cause with effect may help reduce some of the uncertainty surrounding the potential impacts associated with these species because they provide an indication as to whether observed changes in native species composition or relative abundance are due to their displacement, to mortality, reduced reproductive output, or a combination of these. However, it needs to be recognised that determining the actual or potential impacts of any of these species is a major, and therefore costly, exercise, especially given the limited knowledge of the fish involved, of the Australian ecosystems, and the very broad range of habitats available for freshwater fish species to occupy.

Apart from the knowledge gaps relating to evidence of physical impacts on other fish, there are also knowledge gaps relating to the basic biology of many of the listed established ornamental species. As stated earlier, some of these gaps may reflect our inability to secure all relevant information for each species as part of this study. More focussed literature searches on one or a few of these species may well be able to fill some of these gaps without the need for field investigations. We have listed aspects of the biology of each of the listed fish species for which we could find no information. These aspects relate to species' traits linked to potential invasiveness, which is just one side of the potential risk associated with such alien fish. It is therefore, important that these gaps be filled if the risk associated with the 23 established ornamental fish species is to be predicted with any greater certainty.

In this review we have focussed on the impacts of individual fish species, but combinations of alien species often occur at the same location and their effects may be compounding. For example, McKay (1984) noted that one poeciliid fish appeared to have an appreciable effect on small surface dwelling native species of *Melanotaenia*, *Pseudomugil*, *Craterocephalus* and *Retropinna* in Queensland streams but this affect increased when two or more poeciliids were present. Furthermore, impacts of alien fish on native species also need to be disentangled from the changes to the physical environment induced by human activities. These two factors (multiple species and physical changes to habitats) pose large challenges to the identification of impacts of ornamental fish in the wild and future research on impacts will need to address such issues.

We could find no information on the hybrid cichlid (*Labeotropheus/Pseudotropheus* cross) so, instead, information is presented for a species from the genus *Labeotropheus*. Given the potential for hybrid fish species to have a different set of environmental tolerances and/or behaviour, all aspects of the biology of this hybrid and impacts associated with it require further investigation. Hybrid vigour can result in fish with better growth performance than pure species, implying greater potential for competition with native species (c.f., Arthington 1991; Mather & Arthington 1991).

While there is general agreement, in term of the risk assessment outputs for the 23 listed ornamental species, between the reports by Arthington et al. (1999) and Bomford & Glover (2004) (Table 3.1) their findings are sometimes at odds with information presented in FishBase, even though these studies, and ours were based on a similar set of criteria relating to potential invasiveness[6]. The basis for risk assessment used by FishBase is unknown, though it appears that reporting of impacts in at least one country where each of these species is known as an alien might be the primary basis. Of this we cannot be sure. Certainly little information about the nature of associated impacts is given for many species listed by FishBase as being potential pests, and this is quite disconcerting.

We included information about the likelihood of natural dispersal for each of the listed established ornamental fish species and also an assessment of the risk of human-induced spread, but these appraisals are at best conjectural. They are intended to point to where the greatest risks lie. Such information has rarely been included in previous risk assessments. Without such information, risk assessments, based predominantly on traits linked to potential invasiveness, are likely to be highly conservative. Many of the species are likely to have their unassisted dispersal and successful establishment in new waterways limited by minimum winter water temperatures in some parts of Australia, by hydrological conditions, low tolerances of elevated salinity levels, the absence of some preferred spawning requirements, or a combination of these. Clearly, the acquisition of such information is also a high priority for refining estimates of dispersal and impact risk for these species.

We believe that temperature tolerances and preferences may be a good place to start with if for no other reason than that there is some information available associated with the international ornamental fish trade, and this might provide an ability to

[6] Even though the assessment frameworks were different.

estimate the potential geographic ranges of the species involved. Measurement of temperature tolerances is also a relatively straightforward exercise. One caveat to this is that the temperature range required for spawning and egg survival may be higher than that for survival. Both are therefore required to assess the potential geographic range of the species.

Some species, such as the mozambique tilapia, the oriental weatherloach and the oscar are prized angling species in some countries, and could be spread deliberately by coarse fish anglers in Australia. Similarly, the fact that male sailfin mollies exhibit much greater growth of the enlarged dorsal fin in wild habitats could be an incentive to establish feral populations. If this occurs, then assessments of risk based mainly on invasiveness traits could underestimate their potential spread.

There is a wide perception that some alien species are better than native species at controlling pest populations of mosquitoes and though this generally applies to species of *Gambusia*, some poeciliids are also regarded as having value for this control (e.g., guppies were released for this purpose around Brisbane, pers. comm. A. Arthington). Furthermore, it seems that some adherents of animal rights see it as preferable to release unwanted fish into natural habitats, rather than to destroy them or return them to the ornamental fish trade. For some people, the establishment of wild populations is simply seen as adding to the natural biodiversity of Australian fresh waters. There is clearly an array of factors that we see as having potential to lead to increased ranges for these fish species that broadly cover both natural and human influences, and which need to be managed through public education programmes targeted to change behaviour.

In terms of prioritising the species that require more immediate research attention, our task is somewhat difficult due to the potential for circular processes surrounding choosing species for which there is greater knowledge with respect to risk. If prioritising were to be based purely on known risk, this would favour those species that have already received research attention. Many of these species are listed as noxious or are targeted for risk reduction by existing management plans anyway, despite there being inconclusive evidence with respect to their ecological impacts. On the other hand, there are many species for which there is little information available on any aspect of their potential impacts, and we are in a position of not knowing enough to identify or quantify risk. It is therefore difficult to quantify or rank the risk, and so to know where to start if prioritisation is based on the need to fill as many knowledge gaps as possible. We have acknowledged the disparity between the risk level stated for some species by different workers and, the fact that two of the risk assessments were based mainly on potential invasiveness. Further criteria that we felt might prove helpful in terms of prioritising the risk of species that should receive more immediate future research attention are:

- traits associated with known impact mechanisms such as piscivory and aggression as well as traits associated with indirect effects on fish such as habitat modification;
- traits linked to invasiveness possessed by a particular species including the diversity of habitats it could occupy, its potential geographic range in Australia and propensity to migrate or breed readily;
- whether there is potential for assisted spread by humans;
- reports associating the species with a decline in native fish (or other species).

Clearly, it is difficult to rank the various traits and reports on these species in any objective way and any prioritisation based on an appraisal of all of these factors is necessarily based on what is known about each species, even if this information is meagre. Where there was no information for a particular trait this does not mean that it does not exist, only that its presence or absence has not been reported yet. The absence of information on impacts does not prove that impacts are absent and this, more than anything else, characterises the current status of our knowledge of ornamental fish in the wild in Australia.

The prioritisation of the ornamental fish species is therefore somewhat subjective and likely to be skewed by a lack of information. The rankings provided below in Table 4.12 should therefore be used as a guide only. There is potential for any of the species to be associated with unpredicted impacts should they spread to new locations or should new strains emerge or be introduced into Australia (i.e. the ‘residual risk’ noted in Arthington et al. (1999)). The ranking therefore establishes the priorities for research to establish the impacts, not the risk of impact itself.

A number of variables were derived from the species assessments carried out in this study to fit under the criteria above and these are listed and explained in Table 4.2 below. Species clearly capable of impacting on a wide range of native fish or already associated with a decline in native fish are colour-coded red. These are regarded as high priorities for research. Other priority species are colour-coded yellow.

Table 4.2: Summary of impact potential based on the reported occurrence of species traits related firstly to direct and indirect effects on other fish populations and secondly to invasive potential based on likely geographic range, habitat range and factors increasing the risk of spread.

Common name	Scientific name	Impact mechanisms					Invasive potential							
		Size[1]	Diet		Behaviour		Likely temperature range[2]		Habitat range[5]			Factors increasing risk of spread		
			Adults	Includes fish	Aggressive	Substrate digger	Preference[3]	Range[4]	Flowing water	Brackish water	Low oxygen	Migratory[6]	Utilisation[7]	Livebearer
Hybrid cichlid	*Labeotropheus-Pseudotropheus*		omnivore		yes									
Jewel cichlid	*Hemichromis bimaculatus*	small	omnivore		yes	yes	warm	narrow		yes		yes		
Victoria Burton's haplochromis	*Haplochromis burtoni*	small					warm	narrow						
Black mangrove cichlid	*Tilapia mariae*	large	herbivore				warm	narrow		yes				
Redbelly tilapia	*Tilapia zillii*	large	herbivore		yes	yes	warm	wide		yes			yes	
Mozambique tilapia	*Oreochromis mossambicus*	large	herbivore		yes	yes	warm	wide		yes	yes		yes	
Oscar	*Astronotus ocellatus*	large	carnivore	yes	yes	yes	warn	narrow			yes		yes	
Three-spot cichlid	*Cichlasoma trimaculatum*	large	carnivore	yes	yes	yes	hot	narrow						
Jack Dempsey	*Cichlasoma octofasciatum*	medium	carnivore	yes	yes		hot	narrow			yes			
Red devil	*Amphilophus labiatus*	medium	carnivore	yes			hot	narrow						
Midas cichlid	*Amphilophus citrinellus*	medium	omnivore	yes			hot	narrow						
Convict cichlid	*Archocentrus nigrofasciatus*	v. small	carnivore	yes	yes		warm	wide	yes					
Blue acara	*Aequidens pulcher*	small	carnivore	yes		yes	warm	narrow	yes				yes	
Green swordtail	*Xiphophorus hellerii*	small	omnivore	yes	yes		hot	wide	yes	yes	yes			yes
Platy	*Xiphophorus maculatus*	v. small	omnivore				warm	narrow						yes
Sailfin molly	*Poecilia latipinna*	v. small	herbivore				hot	narrow		yes			yes	yes
Guppy	*Poecilia reticulata*	v. small	omnivore				hot	narrow		yes				yes

Table 4.2: (cont.)

Caudo	*Phalloceros caudimaculatus*	v. small	omnivore				warm	wide		yes			yes	yes
Three-spot gourami	*Trichogaster trichopterus*	small	omnivore				cool	narrow			yes	yes		
Oriental weatherloach	*Misgurnus anguillicaudatus*	medium	omnivore				cool	wide			yes	yes	yes	
Goldfish	*Carassius auratus*	large	omnivore				warm	wide					yes	
Rosy barb	*Puntius conchonius*	medium	omnivore	egg eater			warm	narrow	yes					
White cloud mountain minnow	*Tanichthys albonubes*	v. small	carnivore		yes		warm	narrow	yes					

NOTES

[1]Maximum potential size (large >37 cm, medium 24-25 cm, small 14-16 cm, very small <10cm)

[2]Water temperature range associated with native latitudinal distribution (from FishBase)

[3]Water temperatures expected to be suitable for the species

[4]Width of suitable temperature range (wide = >15 degrees, narrow =<10 degrees)

[5]In general, most species inhabit well oxygenated, still or slow-flowing, freshwaters. This records species with broader habitats

[6]Migratory fish include those that undertake large seasonal migrations to/from spawning areas within river systems

[7]Utility includes use for aquaculture, sports fishery, mosquito control, bait production

5. Impacts associated with the spread of parasites and pathogens

5.1 Introduction

There is no doubt that diseases carried by ornamental fishes represent a significant threat to the ecology and sustainability of Australia's native aquatic fauna. Numerous examples of deleterious impacts from disease agents introduced by ornamental fishes have been recorded both in Australia and overseas (Ashburner 1976; Langdon 1988; Bauer 1991; Stewart 1991; Lumanlan et al. 1992; Arthington & McKenzie 1997; Torchin et al. 2002). Live ornamental fishes are recognised as posing the highest risk group for introducing aquatic animal diseases into Australia, because they are known or potential vectors of numerous diseases of high quarantine significance, are traded widely internationally, and are imported in large numbers into Australia each year (Nunn 1995). Unfortunately, as has been found in other areas of the world (Freyhof & Korte 2005), it appears that the release of imported aquarium fishes into the wild by ill-informed or misguided hobbyists appears inevitable. These actions in turn provide opportunities for alien disease agents to become established in the Australian environment. Sadly, it is already clear that significant disease agents such as the ciliates *Ichthyophthirius multifiliis*, *Chilodonella hexasticha*, *Trichodina* spp. and *C. cyprini*, and helminths *Gyrodactylus* spp. and *Bothriocephalus acheilognathi* have been spread into native fish populations from alien fish (both ornamental fish and salmonids) released into the wild, causing significant disease and ecological damage (Ashburner 1976; Langdon 1988; 1990; Rowland & Ingram 1991; Humphrey 1995a; 1995b; Dove et al. 1997; Dove 1998; 2000; Dove & Ernst 1998; Dove & Fletcher 2000; Dove & O'Donoghue 2005). In all cases, these adverse effects are most likely to be permanent and irreversible, and in many cases (e.g., for *I. multifiliis*) will continue to have significant economic consequences for fisheries and fish culturists nationwide.

Another classic example is the spread of goldfish ulcer disease, caused by atypical strains of the alien bacterium *Aeromonas salmonicida*. This bacterium was first recorded in Australia in 1974 and is thought to have been introduced via infected Japanese goldfish (*Carassius auratus*) (Trust et al. 1980). The disease was first detected at a goldfish farm in South Gippsland, Victoria, in 1975 and spread to other goldfish farms and eventually to populations of feral goldfish (Whittington et al. 1987) and other species, including native fish such as silver perch (*Bidyanus bidyanus*) all through translocation of live, infected goldfish (Langdon 1988; Humphrey & Ashburner 1993). The disease is now considered endemic in southeastern Australia, causing morbidity and mortality in wild, cultured and ornamental fish. Due to the high susceptibility of salmonids to infection, the spread of this disease has resulted in severe restrictions of movements of goldfish into Tasmania, to protect the Atlantic salmon aquaculture industry.

Some authorities even suspect that Australia's first recorded finfish virus, the iridovirus EHN virus in redfin perch and various native fishes, may have been introduced by ornamental fish. This is because iridoviruses isolated from ornamental fish (*Poecilia reticulata, Labroides dimidatus*) entering Australia were closely related to EHN virus, leading Hedrick and McDowell (1995) to speculate that EHN virus may have entered Australia in ornamental fish. More recent work, however, suggests that EHN virus may have originated from frogs (Daszak et al. 1999). Redfin that survive epizootics can carry EHN virus, which has also been shown to be highly pathogenic to silver perch, mountain galaxias, Macquarie perch and Murray cod (Langdon & Humphrey 1987; Langdon 1990). In the ACT, where mass mortalities of juvenile redfin have been attributed to the EHN virus, some authorities consider that this disease has been responsible for major declines in populations of Macquarie perch (Lintermans 1991).

The introduction of these aforementioned disease agents into Australia, and their subsequent establishment in endemic fish species, illustrates the potentially major implications involved with disease transfers from alien fish. Not only are significant mortality and morbidity experienced by both wild and cultured endemic aquatic animals due to the presence of these disease agents, but also the ongoing economic implications for commercial and recreational fisheries, aquaculture and the ornamental fish industry are significant, and far reaching both spatially and temporally. Even to the casual observer, it is clear there is much potential for irreversible harm to the aquatic environment and fauna of Australia through introduction of disease agents via ornamental fishes, which inevitably, it seems, are eventually released into the wild at some stage by members of the public.

Some may contend that the issue of introduction of disease via imported ornamental fish is not worthy of significant attention as attempts to address the problem are akin to 'shutting the gate after the horse has already bolted'. This is far from the case. Review of the literature shows the problem is clearly ongoing and some may argue, has intensified in recent years due to improvements in transport technology. We must consider recent infections that have spread through fish introductions across the world in the last decade causing serious losses. Good examples include the recent spread of Koi Herpes Virus (KHV) from Japan to Europe and North America (Hedrick et al. 2000), and *Anguillicola crassus* from Asia to Europe, Africa and North America (Peters et al. 1986; Kirk 2003). With further intensive rearing of ornamental fish, without doubt many currently unrecognised infections will become prominent and will be spread through movements of infected fish around the world.

This review was commissioned to examine the impacts of diseases introduced by alien ornamental fish species that have established wild populations in Australia. Many hundreds of other species of ornamental fish are permitted entry into Australia as part of the approved list of ornamental fish species maintained by the Commonwealth Department of the Environment, Water, Heritage and the Arts under Part 1 of the live import list established under the Environment Protection and Biodiversity Conservation Act (see http://www.environment.gov.au/biodiversity/trade-use/lists/import/pubs/live-import-list.pdf). Though many of these species harbour disease agents of concern (AQIS 1999), most will not be considered here. Instead, a short list of 23 alien species, which have already established in Australia (Table 1.2), was considered. A review of the available literature on their diseases was undertaken, with the aim of identifying:

- the potential for introduction of significant disease agents via these fish;
- any gaps in the knowledge of the diseases of these fish;
- criteria for prioritising which species represent the biggest threat; and
- to detail practical approaches towards filling in knowledge gaps and mitigating threats posed by these species.

In the following pages we list the disease agents found in the available scientific literature for the 23 listed species. Despite our best efforts, it is very likely that these lists are not complete, however it is expected the most significant groups of disease agents will be included as significant disease agents, by definition, cause problems which readily become apparent and are therefore more likely to be recorded in the literature. Other problems commonly found during literature searches on disease agents of ornamental fishes include (from Hine and Diggles 2005):

1) The taxonomy of parasites and pathogens of ornamental fish is often uncertain, with species being lumped together one minute, and split the next. Many ornamental fish species originate from developing countries, which generally lack scientific training and expertise on fish diseases. If reports of fish parasites and diseases in developing countries are published, they are often in publications that are very difficult, impossible to obtain, and they are written in the national language. The only method available for access to the abstracts of obscure papers is to use computerised databases, which usually miss out several papers. The abstracts also often lack the details necessary to draw accurate conclusions. A large percentage of such papers are purely taxonomic and give no clues about the pathogenicity of the organism.

In most cases disease agents which are not picked up in electronic database searches will be either purely of taxonomic interest, or not yet well known to science. It is the latter disease agents that generate significant concern when evaluating risks of their introduction, as undoubtedly for many of the 23 fish species listed here, there is little, and sometimes no knowledge of the disease agents present in their countries of origin. It is almost certain that in the next decade or two, some of these new disease agents, most previously unknown to science, will emerge from the ornamental fish trade and cause significant problems in some parts of the globe.

In addition there is a suite of ubiquitous disease agents that are well known to cause disease in ornamental fishes worldwide (e.g., *Ichthyophthirius multifiliis*, *Mycobacterium* spp., *Saprolegnia* spp.). These are listed at the end of the sections devoted to each individual fish species, and it should be considered that each fish species can also be infected by any of the ubiquitous disease agents. *Ichthyophthirius multifiliis*, *Mycobacterium* spp., *Saprolegnia* spp. and indeed most of the other ubiquitous disease agents, have already been recorded from fishes in Australia, many through their introduction in imported ornamental fishes (Humphrey 1995b, AQIS 1999, Evans and Lester 2001).

5.2 Importation of ornamental fish

The importation of ornamental fish is regulated by DEWHA and AQIS. The DEWHA live import list (Part 1, Schedule: List of specimens taken to be suitable for live import – Environment Protection and Biodiversity Act 1999) specifies the species of ornamental fish that may be imported based on their potential to damage ecological values. AQIS implements quarantine risk management measures, based on advice from Biosecurity Australia and the outcomes of the Import Risk Analysis on Live Ornamental Finfish (AQIS 1999). Those species on the DEWHA live import list that were the subject of the Import Risk Analysis on Live Ornamental Finfish (AQIS 1999) or subsequent risk assessments undertaken by Biosecurity Australia are permitted entry by AQIS.

The quarantine risk management measures include pre export (14 days) and post import quarantine periods (7, 14 or 21 days depending on the species). A veterinary health certificate is required from the competent authority for all imports of ornamental fish based on inspection and for goldfish, surveillance and monitoring for specific diseases and treatment with an effective parasiticide prior to export to Australia. Full details of the quarantine risk management measures can be found on the AQIS website at http://www.aqis.gov.au/icon.

Biosecurity Australia is responsible for assessing the quarantine risks associated with the importation of ornamental fish, taking into account Australia's international obligations under the World Trade Organisation (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS agreement). The quarantine policy for the importation of ornamental finfish may be reviewed when relevant scientific information becomes available that demonstrates that current risk management measures may not be effective. Biosecurity Australia is undertaking a review of the policy in relation to iridoviruses which was announced in March 2005 (Animal Biosecurity Policy Memorandum (ABPM) 2005/01) as a result of research conducted by a student at the University of Sydney which detected gourami iridovirus (GIV) in several species of ornamental gouramis sourced from a pet shop. GIV was considered to be alien to Australia, however it is unclear if GIV has established in Australia.

5.3 Identification of pathogens associated with ornamental fish species

Relevant literature on the disease agents of the 23 short-listed fish species was obtained through database searches, updating and expanding on previous work done on the species listed in Table 1.2 during the previous reviews of Australian Quarantine Policies and Practices for Aquatic animals and their Products (Humphrey 1995a, 1995b) and the AQIS Import Risk Analysis on live ornamental finfish (AQIS 1999). Web based search engines such as Google, PubMed, IngentaConnect, and Scirius were also utilised in an attempt to generate the most up to date list of disease agents possible for each species. The prefix symbols below are used in the host/parasite lists that follow to provide the reader with a better understanding of the disease status of each fish species and its potential for introduction of alien disease agents. Absence of a prefix indicates that the pathogen is not considered endemic to Australia. Locations for the records are provided when known.

- # disease agents were not able to be identified to species, but the same genus has been reported in Australia from fish in the wild and/or aquaria or quarantine;
- * disease agents previously recorded from Australia in aquaria or quarantine, but may not necessarily occur in wild fish populations;
- + disease agents are considered endemic in the Australian environment, including wild fish populations (endemic disease agents identified using various resources including Humphrey 1995b, AQIS 1999 and other literature).

(a) Hybrid cichlid (*Labeotropheus/Pseudotropheus* cross)

Bacteria
Mycobacterium peregrinum (in *Pseudotropheus*) (Pate et al. 2005)

Algae
Chlorochytrium spp. (in *Pseudotropheus*) algal dermatitis (Yanong et al. 2002)
Scenedesmus spp. (in *Pseudotropheus*) algal dermatitis (Yanong et al. 2002)

(b) Jewel cichlid (*Hemichromis bimaculatus*)

Virus
*+*Lymphocystis* experimental infection, New York (Nigrelli and Ruggieri 1965)

Bacteria
*+*Mycobacterium fortuitum* (Nigrelli & Vogel, 1963)
Mycobacterium ulcerans Ghana (Eddyani et al. 2004)

Metazoa
Gyrodactylus cichlidarum (Paperna 1968)

(c) Victoria Burton's haplochromis (*Haplochromis burtoni*)

No specific disease agents found

(d) Black mangrove cichlid (*Tilapia mariae*)

Myxozoa

Myxobolus nounensis Cameroon (Fomena and Bouix 2000)

Metazoa

Cichlidogyrus testificatus (Justine 2005)
"Heavy intestinal infections by nematode parasites" - Nigeria (King and Etim 2004)

(e) Redbelly tilapia (*Tilapia zillii*)

Virus

* Reo Grande cichlid rhabdovirus (Wolf 1988) – isolated in 1 case from a laboratory based peracute disease syndrome.

Protozoa

*+ *Chilodonella cyprini* (Paperna 1980)
*+ *Chilodonella hexasticha* Israel and Sth Africa, (Paperna and van As 1983)
Cryptosporidium nasorum Egypt (Mahmoud et al. 1998)
Eimeria sp. swimbladder (Landsberg and Paperna 1985)
Eimeria vanasi intestine (Landsberg and Paperna 1987)
Nosemoides tilapeae Africa (Sakiti and Bouix 1987, Lom and Dykova 1992)
*+ *Trichodina heterodentata* Philippines (Duncan 1977), Israel (Van As and Basson 1989)

Myxozoa

Myxobolus dahomeyensis (gonad) Benin (Grankoto et al. 2001)
Myxobolus dossoui (gill arch cartilage West Africa) (Grankoto et al. 2001)
Myxobolus heterospora (West Africa) (Gbankoto et al. 2003)
Myxobolus microcapsularis (conjunctive tissue West Africa) (Gbankoto et al. 2001)
Myxobolus zillii (branchial filament, West Africa) (Gbankoto et al. 2001)

Metazoa

Centrocestus sp. (Hine and Diggles 2005)
Cichlidogyrus arthracanthus (Paperna 1996)
Cichlidogyrus aegypticus (Justine 2005)
Cichlidogyrus cubitus (Justine 2005)
Cichlidogyrus digitatus (Justine 2005)
Cichlidogyrus ornatus (Justine 2005)
Cichlidogyrus tiberianus imported from Africa to Israel and established (Hoffman 1970)
Cichlidogyrus yanni (Justine 2005)
Clinostomum sp. (Aloo 2002)
Contracaecum sp. (Aloo 2002)
Gyrodactylus cichlidarum (Paperna 1968)
Haplorchis pumilio (Hine and Diggles 2005)
Polyacanthorhynchus kenyensis (Aloo 2002)

(f) Mozambique tilapia (*Oreochromis mossambicus*)

Virus

*+Bohle iridovirus (BIV) (Ariel and Owens 1997)
Nodavirus (experimental infection) (Skliris and Richards 1999)

Bacteria

*+*Aeromonas hydrophila* India (Paperna 1980)
*+*Chlamydia* and *rickettsia* (Paperna 1980)
Edwardsiella sp. (Paperna 1996)
*+*Flavobacterium* sp. India (Paperna 1980)
*+*Mycobacterium marinum* - resistant carriers (Wolf and Smith 1999)
*+*Pseudomonas* sp. India (Paperna 1980)
#*Piscirickettsia*-like organism (Mauel et al. 2003)
**Staphylococcus faecalis* (Bunkley-Williams and Williams 1994)
*+*Streptococcus iniae* India (Mukhi et al. 2001)
*+*Vibrio alginolyticus* (Bunkley-Williams and Williams 1994)
*+*Vibrio vulnificus* (Bunkley-Williams and Williams 1994)

Fungi

*+*Aphanomyces invadans* (Thailand) (Tonguthai 1985; Lio-Po et al. 2000)
#*Branchiomyces*-like fungus Israel (Paperna and Smirnova 1997)

Protozoa

*+*Amyloodinium ocellatum* (Paperna 1996)
Eimeria vanasi intestine (Landsberg and Paperna 1987)
Goussia cichlidarum experimental infection (Paperna and Landsberg 1985)
*+*Ichthyophthirius multifiliis* – this fish species was more resistant than other species (Subasinghe and Sommerville 1990)
Trypanosoma choudhuryi India (Mandal 1977)
*+*Trichodina heterodentata* (Dove and O'Donoghue 2005)
Trichodina mutabilis (Hine and Diggles 2005)

Metazoa

Argulus sp. Bangaledesh (Arthur and Ahmed 2002)
*+*Bothriocephalus acheilognathi* Southern Africa (Paperna 1996)
Centrocestus formosanus (Hine and Diggles 2005)
Cichlidogyrus sp. Imported from Africa to USA and established (Hoffman 1970)
Cichlidogyrus sclerosis Philippines (Humphrey 1995a)
Cichlidogyrus tilapiae (Bunkley-Williams and Williams 1994)
Euclinostomum heterostomum (Donges 1974)
Enterogyrus cichlidarum Africa, Paperna 1996, introduced into SE Asia (Natividad et al.1986)
Gyrodactylus cichlidarum (Bunkley-Williams and Williams 1994)
Gnathostoma binucleatum Mexico (Almeyda-Artigas 1991)
Neobenedenia melleni (Bunkley-Williams and Williams 1994)
Scutogyrus chikhii Republic of Congo (Pariselle and Euzet 2003)
Ophiotaenia sp. (Bunkley-Williams and Williams 1994)
Ophiovalipora minuta (Bunkley-Williams and Williams 1994)

(g) Oscar (*Astronotus ocellatus*)

Virus
Iridovirus (Yanong and Terrell 2003)

Bacteria
*+ *Aeromonas hydrophila* (Soltani et al. 1998)
*+ *Pseudomonas fluorescens* (Humphrey 1995b)
**Salmonella typhimurium* Sweden (Lundborg and Robertsson 1978, Hongslo et al. 1987)

Protozoa
**Hexamita* sp. (hole in the head) (Humphrey 1995b)
*+ *Ichthyobodo necator* (Humphrey 1995b)

Metazoa
Ancyrocephalus sp. (Bunkley-Williams and Williams 1994)
Argulus japonicus (Bunkley-Williams and Williams 1994)
Dactylogyrus sp. (Humphrey 1995b)
Goezia sp.(Humphrey 1995b)
Gussevia asota Korea (Kritsky et al. 1989, Kim et al. 2002a)
Procamallanus sp. (Humphrey 1995b)

(h) Three-spot cichlid (*Cichlasoma trimaculatum*)

Metazoa
Gnathostoma binucleatum zoonotic nematode in skeletal muscle Mexico (Martinez-Salazar and León-Règagnon 2005).
Sciadicleithrum mexicanum Guatamala (Mendoza-Franco et al. 2000)

(i) Jack Dempsey (*Cichlasoma octofasciatum*)

Metazoa
Ascocotyle nunezae (metacercaria) Mexico (Scholz et al. 1997)
Bothriocephalus musculosus (Baer 1937, Scholz et al. 1996)
Crassicutis cichlasomae Mexico (Scholz et al. 1995, Salgado-Maldonado et al. 2005)
Capillaria pterophylli Czechoslovakia (Moravec and Gut 1982)
Genarchella isabellae Mexico (Scholz et al. 1995)
Neoechinorhynchus golvani Mexico (Salgado-Maldonado et al. 2005)
Oligogonotylus manteri Mexico (Salgado-Maldonado et al. 2005)
Sciadicleithrum mexicanum Mexico (Mendoza-Franco et al. 1999)
Sciadicleithrum bravohollisae Mexico (Salgado-Maldonado et al. 2005)
Spiroxys sp. Mexico (Salgado-Maldonado et al. 2005)

(j) Red devil (*Amphilophus labiatus*)

Metazoa
Sciadicleithrum nicaraguense Nicaragua (Vidal-Martinez et al. 2001)

(k) Midas cichlid (*Amphilophus citrinellus*)

Metazoa
#*Procamallanus* sp. (Martinez et al. 2002)
Sciadicleithrum nicaraguense Nicaragua (Vidal-Martinez et al. 2001).

(l) Convict cichlid (*Archocentrus nigrofasciatus*)

Metazoa
Sciadicleithrum bicuense Nicaragua, (Vidal-Martinez et al. 2001)
Sciadicleithrum meekii Nicaragua (Mendoza-Franco et al. 2003)
Spiroxys sp. Mexico (Martinez et al. 2002)

(m) Blue acara (*Aequidens pulcher*)

Virus
*+*Lymphocystis* Trinidad (found by a tropical fish dealer in New York, Nigrelli and Ruggieri 1965).

(n) Green swordtail (*Xiphophorus hellerii*)

Virus
Platyfish virus-like particles (Wolf 1988)
Iridovirus (Paperna et al. 2001)

Protozoa
*+*Trichodina heterodentata* Brisbane (Dove 2000, Dove and O'Donoghue 2005)
#*Trichodina* sp. Sri Lanka (Thilakaratne et al. 2003)

Metazoa
Ascocotyle mcintoshi Mexico (Salgado-Maldonado et al. 2005)
Ascocotyle nana Mexico (Salgado-Maldonado et al. 2005)
Ascocotyle tenuicollis Mexico (Salgado-Maldonado et al. 2005)
*+*Bothriocephalus acheilognathi* Hawaii (Vincent and Font 2003)
**Camallanus cotti* Singapore, Hawaii (Vincent and Font 2003)
Centrocestus formosanus Mexico (Salgado-Maldonado et al. 2005)
Clinostomum complanatum Mexico (Salgado-Maldonado et al. 2005)
#*Dactylogyrus* sp. Sri Lanka (Thilakaratne et al. 2003)
#*Ergasilus* sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Gyrodactylus bullatarudis* Queensland (Dove and Ernst 1998)
Gyrodactylus rasini Czech Republic (Lucky 1973)
#*Gyrodactylus* sp. Sri Lanka (Thilakaratne et al. 2003)
Mexiconema cichlasomae Mexico (Montoya-Mendoza et al. 2004)
Pygidiopsis pindoramensis Mexico (Salgado-Maldonado et al. 2005)
Saccocoelioides sogandaresi Mexico (Salgado-Maldonado et al. 2005)
Rhipidocotyle sp. Mexico (Salgado-Maldonado et al. 2005)
Spiroxys sp. Mexico (Salgado-Maldonado et al. 2005)
Uvulifer ambloplitis Mexico (Salgado-Maldonado et al. 2005)
Urocleidoides vaginoclaustrum India (Jogunoori et al. 2004)

(o) Platy (*Xiphophorus maculatus*)

Virus
Platyfish virus-like particles (Wolf 1988)

Protozoa
*+*Trichodina heterodentata* Brisbane (Dove 2000, Dove and O'Donoghue 2005)
#*Trichodina* sp. Sri Lanka (Thilakaratne et al. 2003)

Metazoa
Argulus sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Bothriocephalus acheilognathi* Australia –post-quarantine (Evans and Lester 2001)
**Camallanus cotti* Singapore (Levsen and Berland 2002)
**Centrocestus formosanus* Australia –post-quarantine (Evans and Lester 2001)
#*Dactylogyrus* sp. Sri Lanka (Thilakaratne et al. 2003)
#*Trichodina* sp. Sri Lanka (Thilakaratne et al. 2003)
#*Ergasilus* sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Gyrodactylus bullatarudis* Korea (Kim et al. 2002a)
#*Gyrodactylus* sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Prototransversotrema steeri* Brisbane (Dove 2000)
**Urocleidoides reticulatus* Australia –post-quarantine (Evans and Lester 2001)

(p) Sailfin molly (*Poecilia latipinna*)

Protozoa
#*Ambiphyra* sp. Texas (Tobler et al. 2005)
*+*Ichthyophthirius multifiliis* (McCallum 1986)
#*Ichthyobodo* sp. Texas (Tobler et al. 2005)
#*Oodinium* sp. Texas (Tobler et al. 2005)
#*Trichodina* sp. Texas (Tobler et al. 2005)

Metazoa
Acanthocephalus cf. alabamensis Texas (Tobler et al. 2005)
Ascocotyle leighi USA (Burton 1956)
**Camallanus cotti* (Langdon 1988)
#*Dactylogyrus* sp. Texas (Tobler et al. 2005)
#*Lernaea* sp. Texas (Tobler et al. 2005)
#*Postodiplostomum minimum* Texas (Tobler et al. 2005)
Saccocoelioides sogandaresi USA (Lumsden 1963)
Transversotrema patialense (Whitfield et al. 1986)
Unidentified nematode Texas (Tobler et al. 2005)
Uvulifer ambloplitis Texas (Tobler et al. 2005)

(q) Guppy (*Poecilia reticulata*)

Virus

Iridovirus (Hedrick and McDowall 1995)
#Nodavirus Singapore (Hegde et al. 2003)
*Reo-like virus Australia-quarantine (Humphrey 1995a)

Protozoa

*+*Tetrahymena pyriformis* (experimental) (Ponpornpisit et al. 2000)
**Tetrahymena corlissi* Australia –post-quarantine (Evans and Lester 2001), Korea (Kim et al. 2002a)
#*Tetrahymena* sp. Sri Lanka (Thilakaratne et al. 2003), Israel (Pimenta Leibowitz et al. 2005)
*+*Trichodina heterodentata* (Dove and O'Donoghue 2005)
*+*Trichodina acuta* (Dove and O'Donoghue 2005)
#*Trichodina* sp. Sri Lanka (Thilakaratne et al. 2003)

Myxozoa

Myxobolus nuevoleonensis Mexico (Segovia-Salinas et al. 1991)

Metazoa

*+*Bothriocephalus acheilognathi* Australia –post-quarantine (Evans and Lester 2001)
**Camallanus cotti* Australia –post-quarantine (Evans and Lester 2001), Korea (Kim et al. 2002a)
#*Capillaria* sp. Sri Lanka (Thilakaratne et al. 2003)
**Centrocestus formosanus* Australia –post-quarantine (Evans and Lester 2001)
#*Dactylogyrus* sp. Sri Lanka (Thilakaratne et al. 2003)
Diplostomum pseudospathaceum (Hine and Diggles 2005)
#*Ergasilus* sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Gyrodactylus bullatarudis* Queensland (Dove and Ernst 1998)
Gyrodactylus turnbulli (Harris 1986)
Ñapillaria tomentose Russia (Skiba 1998)
Saccocoelioides tarpazensis Venezuela (Diaz and Gonzalez 1990)
Transversotrema patialense (Whitfield et al. 1986)
**Urocleidoides reticulatus* Australia –post-quarantine (Evans and Lester 2001)

(r) Caudo (*Phalloceros caudimaculatus*)

No specific disease agents found

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

Virus

IPNV (Humphrey 1995b)
*Gourami iridovirus (Fraser et al. 1993, Go et al. 2005)
Iridovirus (Paperna et al. 2001)
*+Lymphocystis (Durham and Anderson 1981)

Bacteria

*+*Aeromonas hydrophila* (Fock et al. 2001)
*+*Edwardsiella tarda* (Dixon and Contreras 1992, Ling et al. 2001)

[#]*Mycobacterium* sp. (Santacana et al. 1982)
[#]*Nocardia* sp. (Paperna 1996)
*[+]*Vibrio anguillarum* (Fang et al. 2000)

Fungi

*[+]*Aphanomyces invadans* Thailand (Tonguthai 1985, Catap and Munday 1999)

Protozoa

Goussia trichogasteri (Szekely and Molnar 1992, Kim and Paperna 1993)
Trichodina heterodentata Philippines (Duncan 1977)
Valkampfia debilis (Lom and Dykova 1992)

Metazoa

Camallanus anabantis (Nimai 1999)
Transversotrema patialense Malaysia (Seng 1988)

(t) Oriental weatherloach (*Misgurnus anguillicaudatus*)

Virus

IPNV (covert infection Chou et al. 1993, OIE 2003)

Bacteria

*[+]*Flavobacterium columnare* (AQIS 1999)

Protozoa

**Piscinoodinium pillularis* (Langdon 1988)
*[+]*Trichodina heterodentata* Taiwan (Basson and Van As 1994)

Metazoa

Centrocestus complanatum (Lo et al. 1981, Paperna 1996).
*[+]*Clinostomum complanatum* Japan (Langdon 1988)
[#]*Diplostomum* sp. Japan (Miyamoto 1987)
Echinostoma cinetorchis Korea (Seo et al. 1984).
Echinostoma hortense Korea, Japan (Chai et al. 1985, Miyamoto 1987, Ryang 1990)
Gnathostoma nipponicum Japan, China (Ando et al. 1988, Sohn et al. 1993)
*[+]*Gyrodactylus macracanthus* ACT (Ergens 1975, Dove and Ernst 1998)
Gyrodactylus micracanthus (Ergens 1975)
Gyrodactylus monstruosus USSR (Gusev 1955)
Gyrodactylus misgurni China (Ling 1962)
Gyrodactylus strelkovi USSR (Ergens and Danilov 1980)
Massaliatrema misgurni China (Ohyama et al. 2001)
Metagonimus sp. Japan (Miyamoto 1987)
Paracaryophyllaeus gotoi Japan (Scholtz et al. 2001)

(u) Goldfish (*Carassius auratus*)

Virus

Black moor herpesvirus (Humphrey 1995b)
Goldfish iridovirus (Wolf 1988)
*[+]Haematopoietic necrosis herpesvirus of goldfish (CyHV-2)(Jung and Miyazaki 1995, Stephens et al. 2004)

*+Herpes-like virus (Humphrey 1995b)
Infectious spleen and kidney necrosis virus (He et al. 2002)
IPNV (Adair and Ferguson 1981)
Spring Viraemia of Carp (OIE 2003)

Bacteria

*+*Aeromonas salmonicida* atypical (Humphrey 1995b)
*+*Edwardsiella tarda* (Humphrey 1995b)
*+*Mycobacterium* sp. (Humphrey 1995b)
*+*Pseudomonas fluorescens* (Humphrey 1995b)
*+*Streptococcus* sp. (Humphrey 1995b)
*+*Vibrio cholerae* (non-O1) (Humphrey 1995b)
*+*Yersinia ruckeri* (Humphrey 1995b)

Fungi

*+*Aphanomyces invadans* (Chinabut and Roberts 1999)
Pythium undulatum (Alderman 1982)

Protozoa

Acanthamoeba sohi Korea on gills, pathogenic to mice (Im and Shin 2003)
*+*Chilodonella cyprini* (Humphrey 1995b)
*+*Chilodonella hexasticha* (Humphrey 1995b)
*+*Cryptobia* sp. (Humphrey 1995b)
*+*Eimeria* sp. (Humphrey 1995b)
Goussia carpelli (Lom and Dykova 1992)
#*Ichthyobodo* sp. (Humphrey 1995b, Thilakaratne et al. 2003)
#*Pleistophora* sp. (Lom and Dykova 1992)
*+Systemic amoebiasis (*Dermocystidium*-like) (Voelker et al. 1977, Humphrey 1995b)
#*Tetrahymena* sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Trichodina reticulata* (Dove and O'Donoghue 2005)
#*Trichodina* sp. (Humphrey 1995b, Thilakaratne et al. 2003)
Trypanoplasma borreli (Lom and Dykova 1992)
Trypanosoma carassii (Lom and Dykova 1992)
Trypanosoma danilewskyi (Islam and Woo 1991)
Vannella platypodia (Dykova et al. 1996)

Myxozoa

*+*Hoferellus carassii* (*Mitaspora cyprini*) (Lom and Dykova 1992)
Myxobolus carassii (Lom and Dykova 1992)
Myxobolus cultus Japan (Yokoyama et al. 1995)
Myxobolus diversus China, Hungary (Molnar and Szekely 2003)
#*Myxobolus* sp. (Humphrey 1995b)
Sphaerospora molnari (Lom and Dykova 1992)
Sphaerospora renicola (Lom and Dykova 1992)
#*Sphaerospora* sp. (Humphrey 1995b)

Metazoa

Argulus sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Bothriocephalus acheilognathi* (Mitchell and Hoffman 1980, Dove and Fletcher 2000)
Centrocestus sp. Sri Lanka (Thilakaratne et al. 2003)
*+*Dactylogyrus anchoratus* (Dove and Ernst 1998)

Dactylogyrus dulkeiti Czech Republic (Simkova et al. 2004)
Dactylogyrus extensus Sri Lanka (Thilakaratne et al. 2003)
Dactylogyrus formosus Czech Republic (Simkova et al. 2004)
Dactylogyrus inexpectatus Czech Republic (Simkova et al. 2004)
Dactylogyrus intermedius Czech Republic (Simkova et al. 2004)
Dactylogyrus vastator (Wootton 1989, Thilakaratne et al. 2003)
#*Dactylogyrus* sp. (Humphrey 1995b, Thilakaratne et al. 2003)
Gyrodactylus carassii (Malmerg 1957)
*+*Gyrodactylus kobayashii* (Jones et al. 1997)
Gyrodactylus shulmani China (Ling 1962)
Gyrodactylus sprostonae China (Ling 1962)
#*Gyrodactylus* sp. (Humphrey 1995b, Thilakaratne et al. 2003)
*+*Lernaea cyprinacea* (syn. *L. elegans*) (Humphrey 1995b)
#*Lernaea* sp. (Humphrey 1995b, Thilakaratne et al. 2003)
Philometroides sanguinea (Bauer 1991).

(v) Rosy barb (*Puntius conchonius*)

Virus
*Rosy Barb virus Australia - quarantine (Langdon 1990)

Bacteria
*+*Aeromonas hydrophila* India (Devashish et al. 1999)
**Edwardsiella ictaluri* Australia – quarantine (Humphrey et al. 1986)
#*Streptococcus* sp. Humphrey (1995b)

Fungi
*+*Aphanomyces invadans* Thailand (Tonguthai 1985, Roberts et al. 1986)

Protozoa
**Piscinoodinium pillulare* Malaysia (Shaharom-Harrison et al. 1990)

Metazoa
#*Gyrodactylus* sp. Philippines (Lumanlan et al. 1992)
Procamallanus spiculogubernaculus (Hine and Diggles 2005)
Pseudocapillaria margolisi India (De and Maity 1996)

(w) White cloud mountain minnow (*Tanichthys albonubes*)

Bacteria
#*Streptococcus* sp. Canada (Ferguson et al. 1994)

Protozoa
#*Trichodina* sp. Philippines (Lumanlan et al. 1992)

Metazoa
Transversotrema patialense (Whitfield et al. 1986)

5.4 Knowledge gaps

Despite little evidence of targeted research into the parasitology and disease agents of most of the species listed, published records of parasites and disease agents were found for 21 of the 23 species. Twenty of those 21 species were shown to harbour at least one disease agent alien to Australia. In addition, as the review progressed it became clear that each species could harbour a number of ubiquitous disease agents, which are well known and commonly described from ornamental fishes worldwide. Many of these ubiquitous agents cause significant disease. However, all these ubiquitous disease agents (with the exception of *Argulus foliaceus*) have already been recorded in Australia, many probably being introduced through importation of alien fish (Langdon 1988; Humphrey 1995a,b).

The organisms that are ubiquitous and common to many species of fish are listed in Table 5.1.

Table 5.1: Ubiquitous pathogens found in Australian freshwater fish.

Viruses	*+Lymphocystis Virus
Bacteria	*+*Aeromonas hydrophila* *+#*Flexibacter* spp *+#*Flavobacterium* spp. *+#*Mycobacterium* spp. *+#*Vibrio* spp.
Fungi	*+#*Aphanomyces* spp. *+#*Branchiomyces* spp. *+#*Pythium* spp. *+#*Saprolegnia* spp.
Protozoa	*+#*Amyloodinium* spp. *+*Ichthyobodo necator* *+*Ichthyophthirius multifiliis* *+#*Oodinium* spp. *+#*Piscinoodinium* spp. *+#*Tetrahymena* spp. *+#*Trichodina* spp. *+#*Trichodinella* spp.
Metazoa	*+#*Dactylogyrus* spp. *+#*Gyrodactylus* spp. Argulus foliaceus

Major knowledge gaps that became evident during the course of the review included the following:

1) There was a lack of knowledge of the parasitology and disease agents of ornamental fishes in their countries of origin. For most of the listed species, there was little evidence that there had ever been a thorough examination for

parasites undertaken by suitably qualified persons in their countries of origin. Indeed, for two of the species listed (Victoria Burton's haplochromis and one spot live bearer) no record of any specific disease agents could be found in the literature. This suggests that few, if any, studies of the disease status of these species has been done in their countries of origin. Furthermore, evidence of surveillance for viruses and bacteria, appeared virtually non-existent in most cases. This is not surprising, as although most of the serious diseases of finfish are viral or bacterial in nature, the resources and expertise required to conduct effective bacteriological and virological studies are unavailable to most of the poorly developed countries currently supplying ornamental fishes to the trade. In other countries, the expertise and resources to study these disease agents in fish may be available, but disease outbreaks due to bacteria or viruses are generally not investigated until there are significant economic or public health implications. This is also the case in Australia. It is not surprising, therefore, that Evans & Lester (2001) concluded that there are potentially large numbers of unknown and undescribed parasites being transported worldwide with the ornamental fish trade. Their observation may well hold for viruses and bacterial disease agents too.

2) Although Australia has the expertise to identify and monitor fish disease outbreaks in fish, the resources for extensive pro-active monitoring are lacking. Furthermore, there is a lack of knowledge of the parasitology and disease agents of Australian native fishes. Although a large amount of work has been done in this area (see review by Humphrey (1995a,b)), knowledge of the parasitology and disease agents, which naturally occur in Australian fishes, remains incomplete. For example, Dove & O'Donoghue (2005) studied the trichodinid ciliate ectoparasites of introduced and native fishes to determine which species have been introduced with alien fishes and to determine the extent to which these species have crossed into native fish populations. They found 21 putative species of *Trichodina* in 33 species of fish examined, and used a simple formula to estimate that the biodiversity of these parasites in Australian freshwater fish may approach 150 species. Their paper outlined how incomplete knowledge of natural parasite fauna of our freshwater fishes becomes a problem whenever new parasites and disease agents are discovered. The key question of whether the agent occurs naturally in wild fish populations, or has been introduced via alien species, often cannot be answered with any certainty due to a lack of baseline information. Furthermore, as pointed out by Dove and O'Donoghue (2005), thorough taxonomic studies are required to determine the true extent of species diversity of parasites of native fish populations, so that phenomena such as host switching between native and introduced species can be better recognised where and when it occurs.

3) There was extremely poor knowledge of the parasites and disease agents of introduced fishes in Australia and their impact on native fish populations. The parasite fauna and disease agents of introduced fishes in Australia has been virtually unstudied, except for the work done by Langdon (1988, 1990) and more recently, Evans & Lester (2001) and Dove and co-authors (i.e. Dove 1998; Dove & Ernst 1998; Dove & Fletcher 2000; Dove & O'Donoghue 2005). The paper by Rowland & Ingram (1991) discussed a number of parasites found on native fish species, including Murray cod, golden perch and silver perch, and suggested that at least one of the parasites found on native fishes (*Lernaea* sp.) was introduced by common carp. However generally speaking there appears to be a significant knowledge gap surrounding the parasites and disease agents of introduced fishes in Australia, which is surprising given the value of commercial and recreational fisheries and the current rapid expansion of aquaculture in this country.

5.5 Prioritisation of species in terms of their risk to fish health

Humphrey (1995a, b) undertook a most thorough assessment of the quarantine threat of diseases of aquatic animals, including ornamental fishes. His work clearly showed that ornamental fishes are recognised vectors of alien diseases of high quarantine significance, but indicated that the ornamental fish industry, apart from quarantine provisions, is essentially unregulated with regard to movements of fish, and potentially their diseases, around the country (Humphrey 1995a).

The risks of introduction of disease agents with ornamental fish is clear; however the extent of their threat to the health status of native fish and other aquatic organisms will vary depending on the type of disease agent, and its host. For example, many parasites have high host specificity (e.g., monogeneans), while others tend to have complex multi host lifecycles (e.g., digeneans, cestodes, nematodes), characteristics that tend to reduce the risk of transfer of these parasites to native species. Obviously for these species, the risk of transfer tends to increase when alien and native fish species are closely related. Thus the high level of endemicity of Australian fishes may assist in reduction of risks of transfer of some alien metazoan parasites from introduced fishes (Dove & Ernst 1998). However, many invasive metazoan parasite species have low host specificity (e.g., *Bothriocephalus acheilognathi*, *Camallanus cotti*), and viruses, bacteria and protozoa seldom exhibit high host specificity (Dove & O'Donoghue 2005). Thus the introduction of these types of disease agents could potentially threaten the health of native fishes and other aquatic fauna, regardless of the identity of the alien host vector.

Humphrey (1995a) recommended that ornamental fishes be divided into low and high-risk groups on the basis of their potential threat to Australia's aquatic environment and quarantine/trade status. Goldfish (*C. auratus*), guppies (including *Poecilia reticulata*) and gouramis (including *Trichogaster trichopterus*) were recognised as special cases for immediate inclusion in the high risk category, as all three species are recognised vectors of alien diseases of high quarantine importance, all are farmed in their countries of origin in open systems with direct access to natural waters, and large numbers are currently imported into Australia (Humphrey 1995a, b). The literature review done here reinforces the position of Humphrey (1995a) by showing that goldfish, guppies and gouramis harbour a number of very pathogenic disease agents which would almost certainly cause significant and irreversible damage to Australia's indigenous fish fauna, fisheries and aquaculture industries and adversely affect the countries trading status if they were introduced into wild fish populations. For example, three-spot gourami (*Trichogaster trichopterus*) is a known carrier of IPNV, which can cause epizootic mortalities in salmonids and marine fishes, and also iridoviruses which potentially threaten both native fish and amphibians (see below).

Recent disease outbreaks in farmed Murray cod (Lancaster et al. 2003) were caused by new iridoviruses, which are suspected to have been introduced into Australia by ornamental fish. There is currently no direct evidence of introduction of these iridoviruses into wild fish populations via ornamental fishes: however Go et al. (2005) showed that several species of diseased gouramis (subfamily Trichogastrinae of the family Osphronemidae) sampled from pet shops in Sydney harboured alien strains of iridovirus (namely a tropivirus related to dwarf gourami iridovirus (DGIV) which exhibited over 99.6% sequence homology with the iridovirus isolated from the diseased cultured Murray Cod (Go et al. 2005)). In experimental cohabitation trials, the virus isolated from diseased gouramis was then transmitted to captive Murray cod, causing mortalities of 36.6% within 28 days (Go et al. 2005). Furthermore, intraperitoneal injection of organ filtrates from infected gouramis caused 96.6% mortality of Murray cod within 28 days (Go et al. 2005). This information strongly suggests that gouramis can act as vectors of iridoviruses pathogenic to native fish. Hence populations of gouramis established in the wild may be reservoirs for alien iridoviruses which can cause mortalities in native fishes which are both economically important, and threatened in many parts of their range by habitat destruction and river flow alterations. Furthermore, some iridoviruses carried by amphibians (members of the Ranavirus group) are known to cause disease in fish (Moody & Owens 1994; Cullen et al. 1995). The close relatedness of tropiviruses and ranaviruses suggests that the converse may also occur (Daszak et al. 1999), suggesting viruses carried by gouramis may cause disease in frogs, many species of which are already endangered in Australia. This information has lead to Biosecurity Australia undertaking a re-assessment of the quarantine risk associated with imports of freshwater ornamental finfish with respect to iridoviruses (Biosecurity Australia 2005).

The present review confirmed that goldfish are host to a very large number of disease agents. Many of these have already been identified in goldfish in Australia, and some, such as *Aeromonas salmonicida*, have already been transferred to native fish species (Humphrey 1995b). However a number of significant viral, protozoan, myxozoan and metazoan parasites of goldfish remain alien to Australia at this time. In particular the viruses such as IPNV and Spring Viraemia of Carp are listed by the OIE and their introduction would have significant negative ramifications for Australia's trading status as well as potentially causing significant morbidity and mortality in native fishes and salmonids. For these reasons, goldfish must certainly be considered amongst the highest risk ornamental fish species imported into Australia. In fact, because of the high disease risk posed by this species, some countries have banned the importation of goldfish (Hine & Diggles 2005), instead relying on production by local producers to meet demand by hobbyists for this species.

It has been suggested by some authorities that guppies (*Poecilia reticulata*) may have introduced the iridovirus EHN virus which causes disease and mortalities in redfin perch and some native fishes. This is because iridoviruses isolated from *P. reticulata* entering Australia were closely related to EHN virus (Hedrick and McDowell 1995). The fact that guppies and other poeciliids (*Xiphophorus*) harbour a range of iridoviruses and nodaviruses suggests they deserve to be included in the highest risk category. Furthermore, the non-host specific, pathogenic, Asian nematode *Camallanus cotti,* has spread in Southeast Asia, Europe, North America, Hawaii and Australia with the trade in guppies (see Levsen & Berland 2002; Levsen & Jakobsen 2002). Examination of guppies imported into Korea showed 14.4% prevalence (Kim et al. 2002a), and in those entering Australia the prevalence was 48% (Evans & Lester 2001). *Camallanus cotti* caused 30% mortalities following introduction into an ornamental fish farm in Korea, where it infected 71% of the cultured fishes (Kim et al. 2002b). *Camallanus cotti* normally uses planktonic copepods as intermediate hosts, but if they are not present, it can infect directly, fish-to-fish (Levsen & Jakobsen 2002). After guppies were introduced into Hawaii for mosquito control, *C. cotti* jumped host into 5 native fish species, including an eleotrid (*Eleotris sandwicensis*) (see Font & Tate 1994; Font 1998), and many of Australia's freshwater gobies and gudgeons are members of the family eleotridae (Allen 1989). Langdon (1988) reported *C. cotti* as being present and causing disease in captive populations of sailfin mollies (*P. latipinna*), but it remains unclear whether this parasite has established in wild populations of poeciliids in Australia. The work done by Dove et al. (1997), Dove (1998), Dove & Fletcher (2000) suggests that it may have not yet done so, which is good news for many species of smaller native fishes, at least until more work is done on their parasite faunas, which may prove otherwise.

A significant parasite commonly found in poeciliids is the digenean *Centrocestus formosanus*, a gill trematode, which causes significant losses in juvenile tropical fish culture (Blazer & Gratzek 1985; Vogelbein & Overstreet 1988). This parasite occurred in *Poecilia* spp. and *Xiphophorus* spp. in Australia at prevalences up to 100% after clearing quarantine (Evans & Lester 2001). This parasite is virtually non host specific for fish second intermediate hosts, but is more specific for the first intermediate host, which is usually the snail *Melanoides tuberculata* (see Vogelbein and Overstreet 1988; Mitchell et al. 2005). *M. tuberculata*, a member of the family thiaridae, has been confirmed as being introduced into tropical Australia (http://www.environment.gov.au/ssd/new/watersnail.html), and there are also a number of other species of native thiarid snails which might also act as intermediate hosts for this parasite in Australia, which uses water birds (herons and egrets) and mammals as the final host (Mitchell et al. 2005). This complex lifecycle could therefore be completed in tropical wetlands in the northern parts of Australia. The introduction and establishment of this parasite in Australia would pose threats to the health of a wide variety of juvenile native fishes, as it has done in the USA where it threatens a number of endangered fish species (Mitchell et al. 2005).

This review therefore prioritises all three species groups described above as representing the highest disease risk to native aquatic fauna. Goldfish (*Carassius auratus*), gouramis (including *Trichogaster trichopterus*), and poeciliids (*Poecilia* spp, *Xiphophorus* spp.) imported from overseas all host significant exotic viruses and/or parasites which could adversely affect native fauna. The fact that all three of these high risk fish species have been released and have developed natural self sustaining populations reinforces the conclusion that there is also a similarly high risk of introduction and establishment of the diseases carried by these species.

Of the remaining species, we consider a second group should also be prioritised as representing a lesser, though still significant risk. This medium risk group includes fish which host one or two significant exotic disease agents with low host specificity, and/or parasites of zoonotic importance. They include Mozambique tilapia (*Oreochromis mossambicus*), oriental weatherloach (*Misgurnus anguillicaudatus*), and rosy barb (*Puntius conchonius*).

Mozambique tilapia is host to a variety of disease agents of concern, including iridoviruses and nodaviruses, *C. formosanus*, *B. acheilognathi*, and a number of alien protozoan and metazoan parasites. To date there has been little study of the disease agents present in populations of Mozambique tilapia established in Australia, and therefore the full extent of the impact of the establishment of wild populations of these fish remains undetermined.

The oriental weatherloach, is a known covert carrier of IPNV (OIE 2003). The establishment of this species has already introduced the monogenean *Gyrodactylus macracanthus* but that parasite has high host specificity and is unlikely to infect native fishes (Dove and Ernst 1998). However, the oriental weatherloach hosts a number of zoonotic helminth parasites (*Echinostoma hortense*, *Gnathostoma nipponicum*) the larvae of which infect a wide range of fishes and which cause disease in mammals and humans in Asia (Miyamoto 1987; Ryang 1990; Sohn et al. 1993). These parasites occur at high prevalences in wild weatherloach and probably also in cultured loach in their countries of origin. The presence of these parasites would not be detected in quarantine. The larval parasites survive a long time in the host and adult parasites could reduce the health of native wildlife and even humans if they ate undercooked weatherloach. The decision to stop importation of weatherloach into Australia (Dove & Ernst 1998) would therefore appear a good one, when the disease agents this species could potentially introduce into the country are considered.

Rosy barb was the final species identified as posing a medium risk. This was because it has been recognised as harbouring a birna-like virus called rosy barb virus which has previously been isolated from this species in quarantine (Langdon 1990). This species is also a known covert carrier of *Edwardsiella ictaluri*, an alien bacterium listed by the OIE (2003) because it causes epizootic mortalities in catfishes and a variety of other fish species. The introduction of this bacterium would have significant negative ramifications for Australia's trading status as well as potentially causing significant morbidity and mortality in salmonids and a variety of native fish species, many of which are likely to be susceptible to the pathogen. Closely related species in the genus *Barbus* are also known to carry other viruses, including IPNV (Ortega et al. 1993a, 1993b).

These examples show that diseases carried by the high and medium risk ornamental fish species listed above represent a significant threat to the ecology and sustainability of Australia's native aquatic fauna, in some cases potentially native waterbirds and mammals, and in the case of zoonotic agents, even to human health. The remaining species are considered to represent a lower risk of disease introduction to native aquatic fauna. Mostly this lower risk status has been based on the fact that most of the records found for the remaining species are either ubiquitous disease agents which already occur in Australia, or are parasites with complex lifecycles (nematodes, digeneans, cestodes) and/or high host specificity (monogeneans). Both these latter factors tend to reduce the risk of introduction of disease agents into native fish populations (Dove 1998; 2000; Dove & Ernst 1998). In particular, the establishment of alien monogenean populations on Australian native fishes via host-switching is considered less likely than for other parasitic groups due to the generally high host-specificity of monogeneans, combined with the phylogenetic dissimilarity of native and alien fishes (Dove & Ernst 1998). However, caution must be emphasised before discounting the disease threats posed by establishment of these lower risk fish species. This is because in most cases little if any research has been conducted on their disease status either in Australia or their countries of origin. Many fish could well harbour new disease agents that are presently not known to science (Evans & Lester 2001), and it is therefore impossible to estimate the full extent of the risk posed by these unknown disease agents, though they undoubtedly do pose some level of risk (Gaughan 2002).

5.6 Summary and recommendations

Many examples of deleterious impacts from disease agents introduced by alien ornamental fishes have been recorded both in Australia and overseas (Asburner 1976;

Whittington et al. 1987; Langdon 1988; Bauer 1991; Stewart 1991; Lumanlan et al. 1992; Arthington & McKenzie 1997; AQIS 1999; Torchin et al. 2002; Chong & Whittington 2005). For example, in Australia, significant disease agents such as the bacterium *Aeromonas salmonicida*, ciliates *Ichthyophthirius multifiliis*, *Trichodina* spp., *Chilodonella hexasticha*, and *C. cyprini*, and helminths *Gyrodactylus* spp. and *Bothriocephalus acheilognathi* have all been spread into native fish populations from alien fish released into the wild, most causing significant disease and ecological damage (Asburner 1976; Whittington et al. 1987; Langdon 1988, 1990; Roland & Ingram 1991; Humphrey & Ashburner 1993; Humphrey 1995a, 1995b; Dove et al. 1997; Dove & Ernst 1998; Dove 1998, 2000; Dove & Fletcher 2000; Dove & O'Donoghue 2005). In addition, some authorities suspect that Australia's first recorded finfish virus, the iridovirus EHN virus in redfin perch and various native fishes, may have been introduced by ornamental fish. Recent iridovirus outbreaks in farmed Murray cod are caused by another iridovirus, also probably introduced into Australia by ornamental fish. These examples show that diseases carried by ornamental fishes represent a significant threat to the ecology and sustainability of Australia's native aquatic fauna. The introduction of diseases via ornamental fish also has the potential to result in significant, irreversible, and economically detrimental effects on Australia's fisheries and aquaculture industries.

A review of the disease agents recorded in the scientific literature from a short list of 23 alien species that have established in Australia was undertaken with the aim of identifying; their potential for introduction of significant disease agents, gaps in the knowledge of their diseases, criteria for prioritising which species represent the biggest threat, and to detail practical approaches towards filling in knowledge gaps and mitigating threats posed by these species.

Despite little evidence of research into the parasitology and disease agents of most of the species listed, published records of parasites and disease agents were found for 21 of the 23 species. Twenty of those 21 species harboured disease agents alien to Australia. In addition, each species can harbour a number of ubiquitous disease agents, many of which can cause significant disease. However, nearly all these ubiquitous disease agents have already been recorded in Australia, many undoubtedly already present via importation with alien fish.

Major knowledge gaps which were evident included lack of knowledge of the parasitology and other disease agents (particularly viruses and bacteria) of ornamental fishes in their countries of origin, lack of knowledge of the parasitology and endemic disease agents of Australian native fishes, and extremely poor knowledge of the parasites and disease agents of introduced fishes in Australia and their impact on native fish populations. The latter appears to be a particularly significant knowledge gap given the value of commercial and recreational fisheries and the current rapid expansion of aquaculture in this country.

By reviewing the number and types of disease agents carried by each species on the shortlist, the following species were prioritised as representing the highest disease risk to native aquatic fauna: goldfish (*Carassius auratus*), gouramis (including *Trichogaster trichopterus*), and poeciliids (*Poecilia* spp., *Xiphophorus* spp.). All three host significant exotic viruses and/or large numbers of exotic parasites, which could adversely affect native aquatic fauna.

Other species were also prioritised as representing a lesser, though still significant risk. These medium risk species include Mozambique tilapia (*Oreochromis mossambicus*), oriental weatherloach (*Misgurnus anguillicaudatus*), and rosy barb (*Barbus conchonius*). All three of these species host significant exotic disease agents with low host specificity, and/or other parasites of zoonotic importance which could pose a threat not only to native fish, but also to the health of humans, waterbirds and/or other warm blooded native terrestrial animals.

The remaining species on the list were considered to represent a lower risk of disease introduction to native fauna, due to the increased likelihood of them harbouring parasites with high host specificity and/or complex lifecycles. Both these factors tend to reduce the risk of introduction and establishment of disease agents into native fish populations. However, caution must be emphasised before discounting the threat posed by establishment of these species, as in most cases little if any research has been conducted on their disease status either in Australia or their countries of origin, and even less on their potential to infect native fish species.

Possible ways of filling the current knowledge gaps were considered to include:

- increased surveillance of the parasites and disease agents of ornamental fish traded internationally;
- increased surveillance and taxonomic study of the parasites and disease agents of Australian native fishes in the wild; and
- increased surveillance, taxonomic and epidemiological study of the parasites and disease agents of introduced fishes.

Practical ways of mitigating the disease threat posed by these species were considered to include:

- increased public education to reduce the frequency of hobbyists releasing ornamental fish into the wild; and
- fostering studies to scan both native and alien fish populations in the wild to determine the presence/absence and distributional ranges of alien parasites and disease organisms;

- providing Biosecurity Australia with relevant new scientific information to support a review of current quarantine risk management measures when this information demonstrates that current risk management measures may not be effective.

There is much potential for the ornamental fish industry to play an important role in helping to implement these recommendations, particularly in relation to public awareness of the risks associated with the release of ornamental fish into the wild. Considerable research and surveillance and monitoring of diseases and parasites of ornamental fish is needed and this will require adequate funding to achieve. Finding the funds for such research will be the key to achieving this goal.

The industry is at the 'coalface' when it comes to detecting diseases in newly introduced fish and has practical experience in preventing and handling disease. It is in the interests of fish importers, breeders and distributers to minimise disease risk to their stocks. Therefore the industry could play an important co-operative role by helping in the set-up and implementation of disease monitoring systems and by encouraging the breeding within Australia of alien species with potentially high disease loadings. A pro-active role in disease monitoring and prevention would reduce the overall risk to the industry's economic base while providing an indirect benefit to native fish and other Australian freshwater resources by reducing the risk of disease transfer.