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Feral Goldfish (*Carassius auratus*) in Western Australia: a case study from the Vasse River

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Abstract

Minimal information is available with regard to impacts of wild populations of Goldfish; despite being one of the most widely introduced freshwater fishes of the world, and arguably the most popular ornamental fish species. During a control programme for a population of feral Goldfish in the Vasse River, Western Australia, aspects of population demographics and diet were examined. A relatively high growth rate was found with fish, on average, attaining ~ 180 mm TL at the end of their first year of life, a period that coincided with first maturity. Goldfish were relatively long-lived with the oldest fish recorded being in its 11th year of life. The diet was dominated by detritus that was largely comprised of blue-green algae. The potential of this species to exacerbate algal blooms within nutrient enriched environments is discussed.

Keywords: feral goldfish, *Carassius auratus*, Vasse River, Western Australia,

Introduction

The establishment of introduced fishes outside their natural range is often facilitated by a wide tolerance to environmental regimes, maximisation of reproductive potential, high genetic diversity and tendency for good dispersal mechanisms (r-strategists) (Stauffer 1984). An expression of a broad diet (*e.g.* omnivory) and the ability to tolerate degraded habitats also enables exotic species to exist and thrive in foreign environments. Within Australia, examples of omnivorous fish species that are highly adaptable to a wide range of environmental conditions include some of the poeciliids, cichlids and cyprinids; groups that are all traditional aquarium species but are naturally absent from the country (see Morgan *et al*. 2004). While the ecological impacts of some members of these groups are well understood, there is little information with regard to one of the most widely introduced freshwater fishes of the world, *i.e.* Goldfish (*Carassius auratus*). As arguably the most popular and well known ornamental fish species, it is not surprising that feral populations of Goldfish have been reported from almost every state of Australia (McKay 1984, Koehn & MacKenzie 2004) and indeed are now found throughout much of the world (*e.g.* Fuller *et al.* 1999, Gido & Brown 1999, Skelton 2001). It is also established in almost every state of the United States and is thought to be the first foreign fish species introduced into that country (*e.g.* Fuller *et al*. 1999). Goldfish have been implicated with the introductions of parasites to South Africa and Australia (Fletcher & Whittington 1998, Mouton *et al*. 2001, Hassan, Morgan, Beatty & Lymbery unpublished data) and with the decline of a number of native fishes in the U.S. (Deacon *et al*. 1964, Moyle 1976).

Within Western Australia, Goldfish are generally restricted to the south-western corner of the state in the vicinity of major population centres where they appear to be most successful in modified or degraded waters (Morgan *et al*. 2004). The only previous biological study (growth and feeding) of wild Goldfish populations in Australia was conducted by Mitchell (1979) who used scales to age fish from South Australia, while Izci (2001) determined growth rates and age and sex compositions for a wild population of Goldfish in Lake Eğirdir, Turkey. The main aim of this study was to implement an ongoing control programme for Goldfish in the highly nutrient enriched Vasse River and thereby reduce the biomass of the species. Secondary aims were to examine the distributions, habitat associations, age compositions and growth and diet of Goldfish and to develop an understanding of factors contributing to its success in this and other nutrient enriched waterbodies.

Methods

Study site

The Vasse River, in south-western Australia, is ~ 45 km long with a catchment of approximately 270 km^2. About 60% of the catchment is cleared and heavily modified, with much of the natural flows diverted to drainage canals for flood mitigation (Pen 1997). Much of the Vasse-Wonnerup estuarine lagoon, which is roughly 1.5 km wide and 25 km long, stretches behind narrow coastal dunes covering an area of 1000 ha, is cleared with the hydrology having been largely modified by drainage and tidal barriers and is threatened by eutrophication with the system no longer functioning as an estuary (Jaensch & Lane 1993, Pen 1997). Regardless, the system still provides important habitat for waterbirds and is

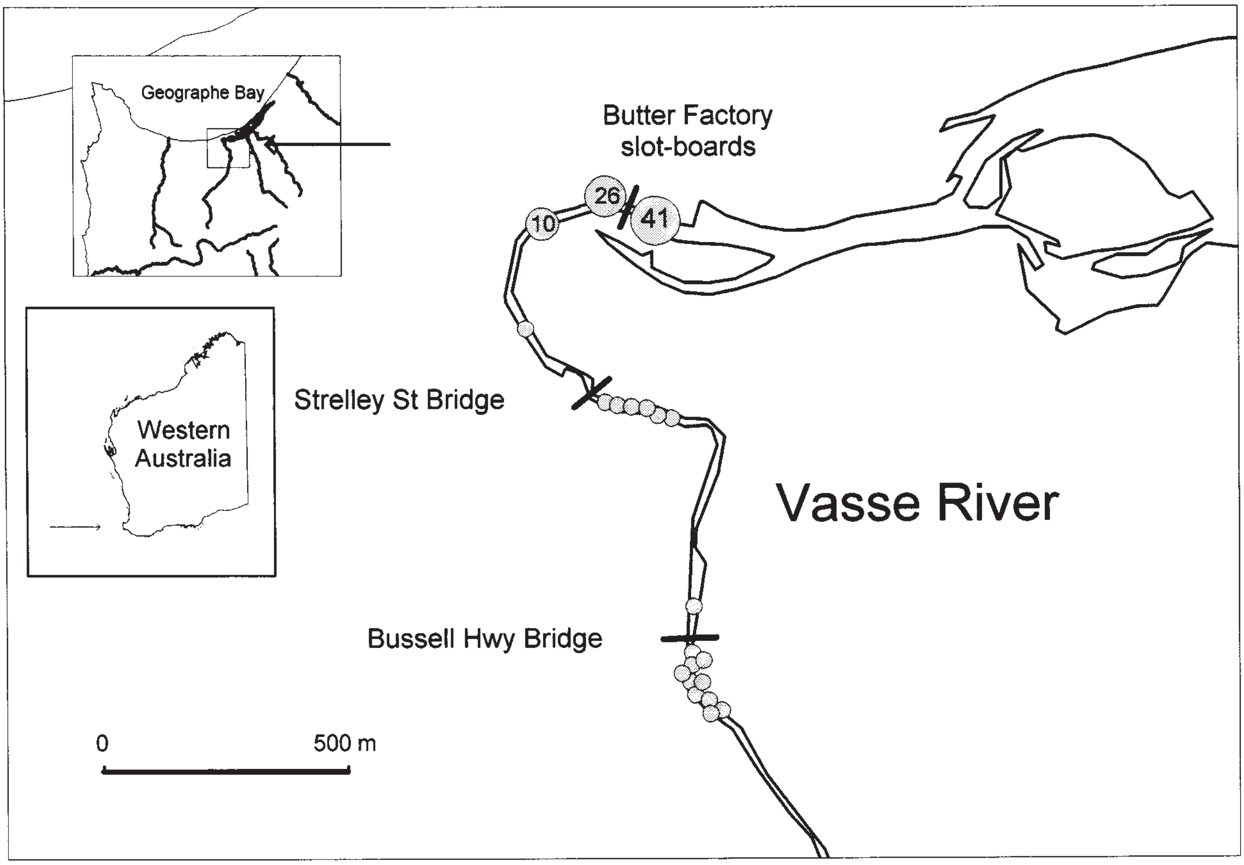

Figure 1. The location (and number) of Goldfish (*Carassius auratus*) captured in the Vasse River during March 2003 and December 2004. N.B. Catch locations remained consistent in subsequent years.

listed as a Ramsar Wetland of International Importance (Jaensch & Lane 1993, Pen 1997). In appreciation of the importance of natural stream morphology and riparian vegetation in creating healthy stream ecosystems, the Lower Vasse River Cleanup Program, coordinated by the Geographe Catchment Council, has undertaken reshaping and revegetation of the bed and banks of the Lower Vasse River while and conducting Phoslock™ trials to reduce dissolved phosphorus and thereby attempt to reduced blue-green algal (cyanobacteria) blooms in the river (Goss & Greenop 2003). During these works, the reported sightings and capture of feral fish such as Goldfish in the Vasse River has increased considerably in recent years.

Capture techniques

The distribution of feral Goldfish within the Vasse River was determined in December 2003 and March 2004, and goldfish removal events (for population control [see below]) occurred during March 2005, May 2006 and September 2006. Although sites were sampled throughout the catchment, Goldfish were restricted to the lower Vasse River (see Figure 1). As the lower Vasse River is a large body of water relative to upstream reaches due to slot board insertion and the Vasse River Diversion Drain, a number of methods were employed to capture as many Goldfish as possible. This initially involved the use of gill nets, seine nets and a back-pack electrofisher (a device that momentarily stuns fish). However, the subsequent Goldfish captures were achieved utilising a 240 volt, generator-powered electrofisher deployed from a boat. The entire stretch of the river from ~ 500 m upstream of the Bussell Highway Bridge to immediately downstream of the Old Butter Factory slot-boards was electrofished at least twice on each sampling occasion with the exception of December 2003 (see Figure 1). Key Goldfish habitats were revisited on each sampling occasion (see results). The latitude and longitude of each Goldfish capture was recorded using a GPS and a map of the distribution of Goldfish captures was produced using the MapInfo™ program.

Biological techniques

Each Goldfish captured was placed immediately in an ice slurry and, upon return to the laboratory, measured to the nearest 1 mm total length (TL) and weighed to the nearest 1 mg. A length-weight relationship was produced via testing a number of models and the one that provided the greatest R^2 value adopted as the best fit of the data. The stomach contents of a sub-sample of 20 Goldfish from a wide size range were removed and the contents classified into a number of prey categories. The frequency of occurrence and points method (Ball 1961, Hynes 1950) was used to food items in the stomachs of Goldfish and the relative contribution (by volume) of each prey category to their diet.

For age determination, the otoliths of each Goldfish in all larger fish and the majority of the apparent juvenile (0+) fish were removed, immersed in methyl salicylate and viewed though a dissecting microscope using reflected light. The number of translucent zones was counted and it was assumed that these corresponded to year classes (while not specifically validated, this technique has been validated for the majority of native freshwater fishes in south-western Australia and for an introduced fish in the region (*e.g.* Morgan *et al.* 1995, 2000, 2002)). A length-frequency distribution was produced separately for those Goldfish captured on each sampling occasion.

The length of each individual Goldfish was plotted against its age and a growth curve fitted using a von Bertalanffy growth equation with October 1 as an estimated birth date. This estimate was made from the small size of individuals captured in December and from the capture of larval (newly-hatched) Goldfish in other parts of south-western Australia during early spring. The von Bertalanffy growth curve is $L_t = L_\infty[1-E^{-K(t-t_0)}]$, where L_t is the length at age t (years), L_∞ is the asymptotic length of the population, K is the growth coefficient and t_0 is the hypothetical age at which the fish would have zero length.

Results

Distribution, population structure and growth of Goldfish in the Vasse River

Goldfish were only captured in the lower sections of the Vasse River and none were captured in the Diversion Drain or upper catchment. Large numbers of juveniles were captured around the Old Butter Factory slot-boards and other structures such as bridges, while the larger individuals were usually found in the close vicinity (usually just upstream) of structures such as bridges or around snags (Fig. 1).

Analysis of length-frequency histograms and the number of translucent zones on the otoliths as an estimate of age (*e.g.* one zone = 1 year old, two zones = 2 year old etc.) revealed that the population of Goldfish in 2003 and 2004 in the Vasse River at the time of sampling was dominated by the cohort born in the spring of 2003 (Fig. 2). However, two older and larger fish, over 400 mm TL, were captured. During March 2005, a total of 105 Goldfish were captured. Approximately 76% of these belonged to the 0+ age class, *i.e.* they were in their first year of life. The remaining fish varied in age with the oldest being in their sixth year of life (*i.e.* 5+). During sampling in May 2006, 55 Goldfish were captured, with 84% belonging to the 0+ age class, one fish of 11 years, and another two older than 7 years. The majority of fish were captured at the Strelley Street Bridge (31, all 0+), while 15 were captured at the Vasse Bridge, six near the Bussell Highway Bridge and two at the Butter Factory slot-boards. During September 2006 no Goldfish were captured in the study area main channel. This, together with large reductions in our captures at the Bussell Highway Bridge and at Butter Factory, suggests that the control programme may have been successful in reducing the population; however, four Goldfish were captured in a wetland (New River Wetland) adjacent

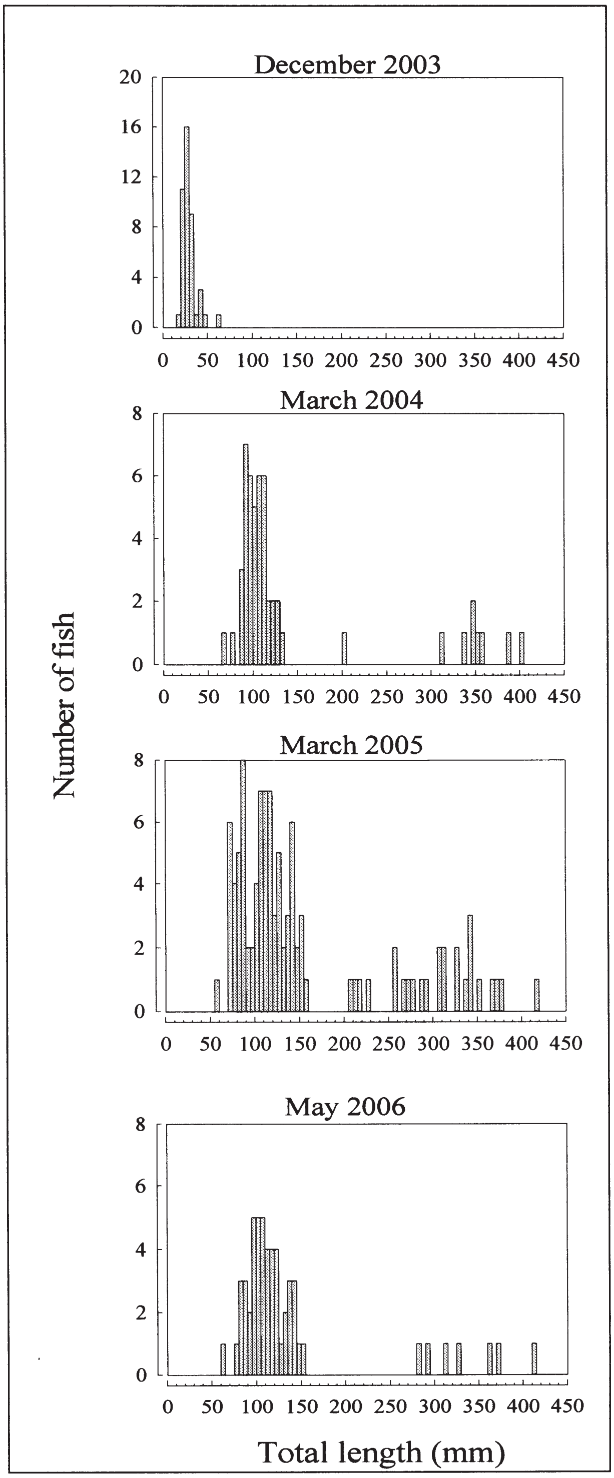

Figure 2. Length-frequency histograms of Goldfish captured in the Vasse River during December 2003, March 2004, March 2005 and May 2006.

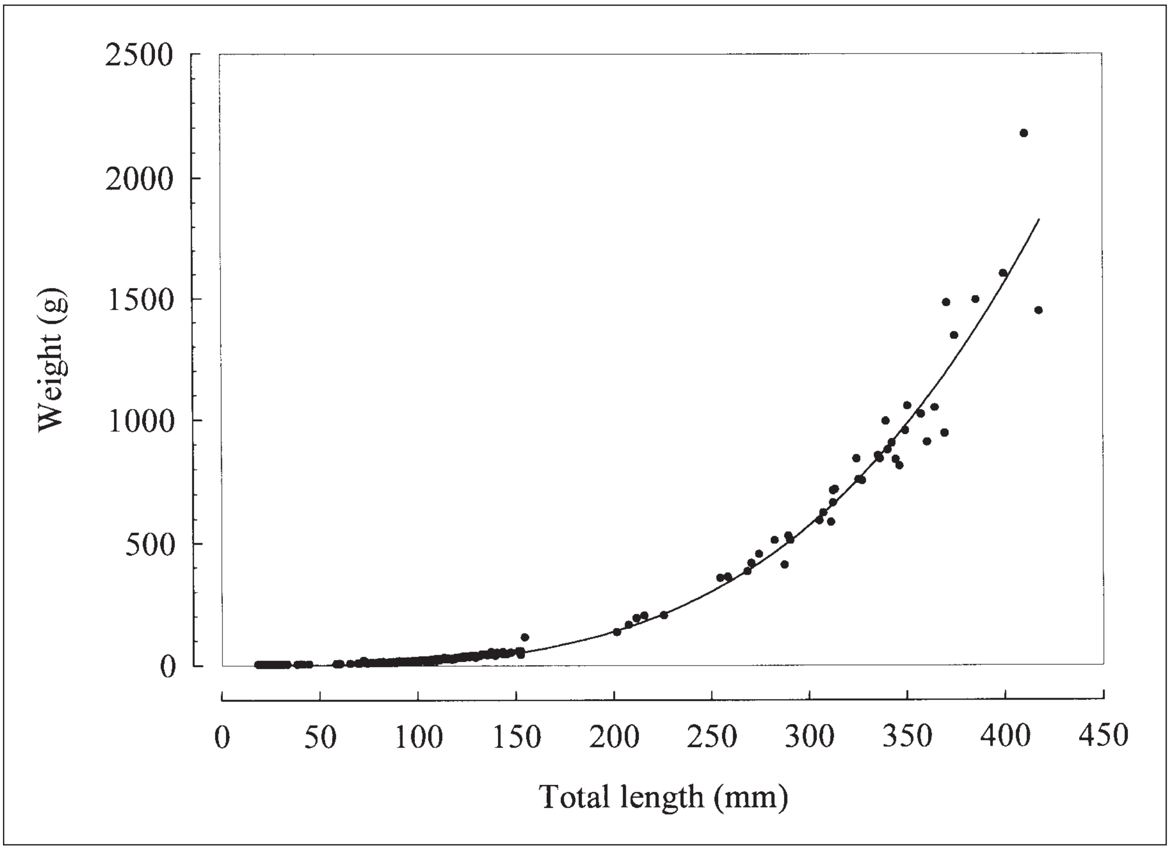

Figure 3. Length-weight relationships of the Goldfish captured in the Vasse River during December 2003, March 2004, March 2005 and May 2006. In the given equation, W = weight (g) and TL = total length (mm) of the fish.

and connected to the main channel. This wetland has only seasonal connectivity to the main channel and thus management actions should be undertaken to ensure that it does not act as a recruitment source of Goldfish.

The length-weight relationship for Goldfish in the Vasse River is:

$W = 1.168(10^{-6})(TL^{3.5077})$, where W = the wet weight (g) of the fish and TL = the total length (mm) of the fish (Fig. 3).

The von Bertalanffy growth equation is $L_t = 374.26[1-e^{-0.651(t-0.0163)}]$, where L_t is the approximate length at age t (in years). von Bertalanffy variables are: K = 0.651, t_0 = 0.0163 and $L\infty$ = 374.26. Based on this equation, Goldfish at age 1 year in the Vasse River attain approximately 177 mm TL, whereas at ages 2, 3, 4, 5 and 6 they reach ~ 271, 321, 346, 356 and 367 mm TL, respectively (Fig. 4).

The largest fish captured was 411 mm TL and weighed approximately 2.2 kg and was in its eighth year of life. The higher proportion of larger fish captured during 2005 was probably a result of the lower water levels encountered due to removal of the slot boards at the Old Butter Factory which are usually inserted to artificially maintain water levels.

Many of the larger fish had gonads that had clearly spawned and are classed as 'spent'. Examination of some of the 0+ cohort (6 month old fish) revealed that gonadal development was commencing and that they would have spawned at the end of their first year of life.

Diets and ecological impact of Goldfish in the Vasse River

The stomach contents of 20 Goldfish (28–386 mm TL) examined from the Vasse River were dominated by detritus that was largely comprised of cyanobacteria (blue-green algae), but additionally contained diatoms, nematodes, anisopteran larvae, coleopteran larvae, dipteran larvae, eastern mosquitofish, green algae and some terrestrial insects.

Community engagement

An approach identified by Koehn & MacKenzie (2004) as important in the management of feral fishes includes not only the recognition of pest species by managerial and government organisations but it is important to engage the scientific and community sectors in all aspects of the process. The recognition of feral Goldfish populations as a threat to ecosystem health in the Vasse River, at least, has been accepted, largely as a result of the involvement of managerial organisations such as Geocatch, Fisheries WA, the Vasse-Wonnerup LCDC, combined with community participation and wide local media coverage.

Discussion

The age and growth analyses of Goldfish in the Vasse River demonstrated substantial growth rates compared to populations elsewhere. The only previous age and

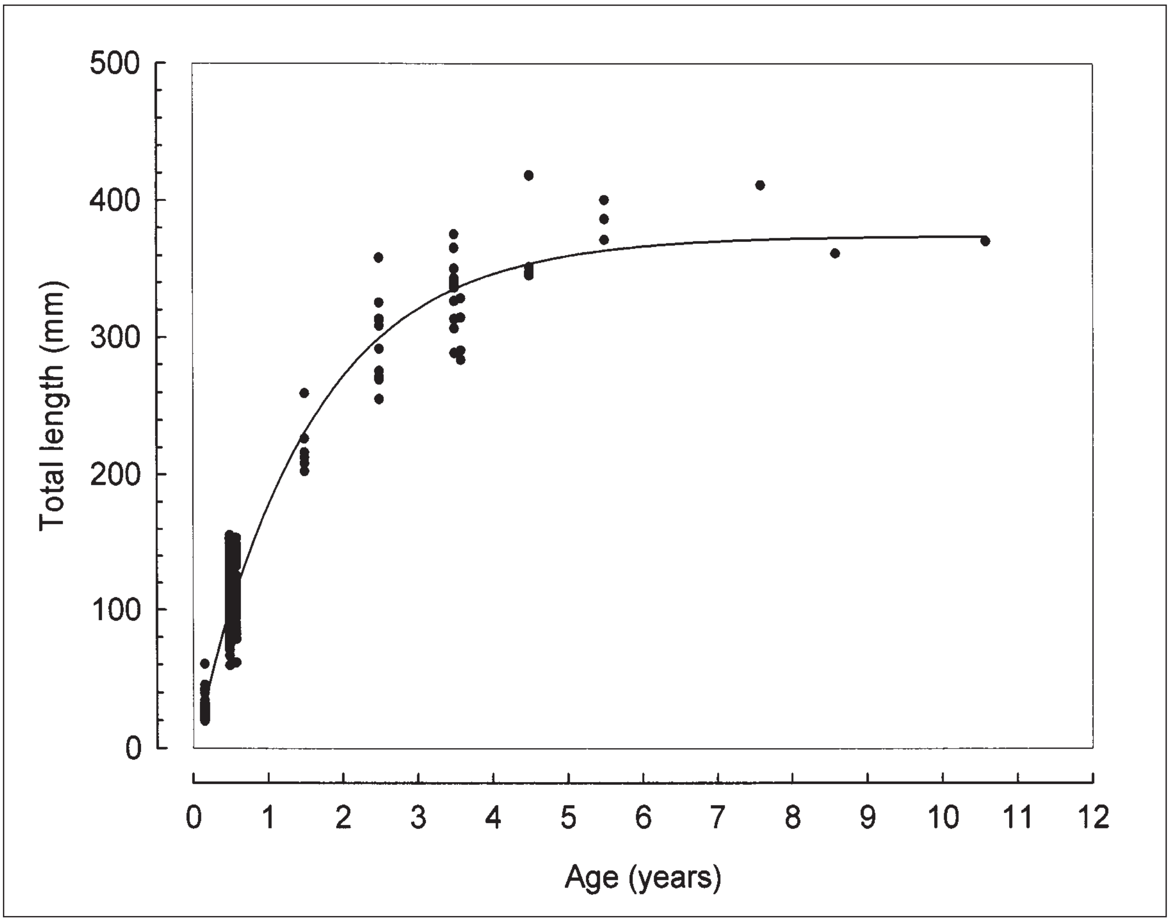

Figure 4. Total length at age of Goldfish captured during the study in the Vasse River including the von Bertalanffy growth curve. N.B. approximate age classes were based on the number of translucent zones on the otoliths and October 1 was assigned as the birth date. K = 0.651, t_0 = 0.0163, L∞ = 374.26.

growth study on wild Goldfish populations in Australia was by Mitchell (1979) who used scales to age fish from South Australia. The growth rates here substantially exceed those in Mitchell's study and are similar but higher to those published by Izci (2001) for a wild population of Goldfish in Turkey. Mitchell (1979) found one fish living for over 10 years that weighed over 2 kg. From the length-weight relationship in the Vasse River it is predicted that Goldfish would attain 2 kg at 447 mm TL.

Kolmakov & Gladyshev (2003) demonstrated that significant growth of the cyanobacteria *Microcystis aeruginosa* is stimulated by the passage through Goldfish intestines, while other cyanobacteria such as *Anabaena flos-aquae* and *Planktothrix agardhii* that were passed through Goldfish guts exhibited greater growth compared to the controls. The process of cyanobacteria stimulation is not known, however the authors considered that the passing through the Goldfish gut may give nutrient enrichment or that mechanical re-agglutination of cells from colonies may occur. *Microcystis* sp. and *Anabaena* sp. are known to cause algal blooms in the Vasse River. The above findings of the diets of the Goldfish in the Vasse River, together with the fact that they are known to stimulate significant growth in blue-green algae, is cause for concern in a system that is currently exposed to severe algal blooms during spring, summer and autumn (see Paice 2001). Thus, a substantial increase in Goldfish biomass could become a major factor attributing to algal blooms in the Vasse River and indeed within nutrient enriched environments elsewhere. Furthermore, the vigorous bottom feeding methods of Goldfish resuspends nutrients making them available to algae. Within the Vasse River algal blooms have lead to a number of fish kills since 1997 (Paice 2001), a period after the initial introduction of Goldfish, noting that during 2006 we captured a 10 year old fish. An increase in algae provides this feral species with an abundance of a food source that they can utilise from a very young age. The high growth levels found in Goldfish within the Vasse system may be a combination of the high degree of food availability and warmer conditions provided by the diversion of flows around this system creating a lentic rather that lotic environment.

Feral Goldfish have the potential to prey on the eggs, larvae and adults of native fishes and have been known to cause declines in native fish populations in the U.S. (*e.g.* Deacon *et al.* 1964). Goldfish compete with native fishes for food and space and by growing to a much larger size than all but one of the native freshwater fishes in the region, they would escape predation from a young age (probably by a few months old they would attain lengths larger than can be consumed by native fishes). Goldfish, as a benthic generalist/herbivore, has been shown to cause increased turbidity and deplete aquatic vegetation (Richardson *et al*. 1995). A reduction in aquatic vegetation reduces habitat and potential spawning sites for native fishes.

Very little is known of the parasites infecting freshwater fishes in Western Australia; however it is acknowledged that non-native parasites may use introduced fishes as vectors to infect native fishes. Goldfish are known carriers of a number of serious diseases and have been implicated with the introduction of several fish pathogens in South Africa (Mouton *et al*. 2001) and at least one monogenean trematode in Australia (Fletcher and Whittington 1998). Screening of parasites and diseases within captive populations of Goldfish is crucial in the detection of potentially harmful organisms.

The implications for the activation of cyanobacteria blooms after passing through fish digestive tracts are serious when considering the widespread distribution of Goldfish throughout the world, where they are predominantly associated with urban areas. A number of other fishes that have been introduced throughout the world, including within Australia, consume phytoplankton and thus have the potential to stimulate cyanobacteria growth in nutrient enriched environments. Specifically, feral populations of Tilapia (*Oreochromis mossambicus*), One-spot Livebearers (*Phalloceros caudimaculatus*), Swordtails (*Xiphophorus helleri*) and Carp (*Cyprinus carpio*) are not only established within Western Australia (Morgan *et al*. 2004), but most of these species have been introduced throughout the world. The control of algal blooms may be aided with eradication programs of feral detritivorous fishes inhabiting nutrient enriched environments worldwide.

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