Fish fauna of the Vasse River and the colonisation by feral goldfish (*Carassius auratus*)

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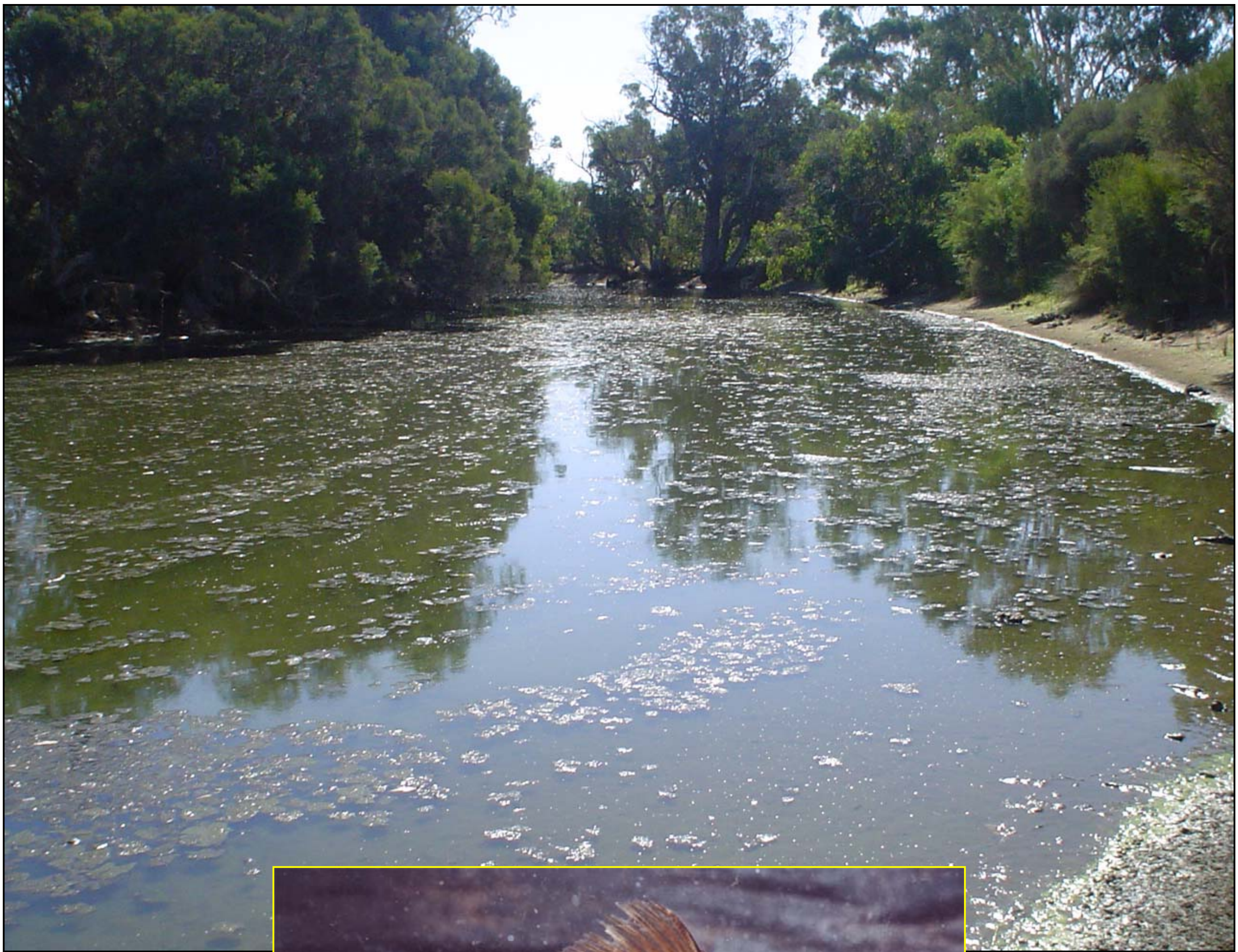

David Morgan & Stephen Beatty

Centre for Fish & Fisheries Research

MURDOCH UNIVERSITY

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Project summary

During December 2003 and March 2004 a total of 7895 fish from nine species were captured during a survey of the Vasse River, including two sites in the Vasse River Diversion Drain. Of the fish captured, four were native freshwater fishes that are endemic to the south-west, three were native estuarine species and two were introduced fishes. Two estuarine species dominated the native catches with the western hardyhead (*Leptatherina wallacei*) being captured at the most downstream sites and the Swan River goby (*Pseudogobius olorum*) being captured throughout the river aside from the upper-most headwater site. The endemic western pygmy perch (*Edelia vittata*) was also widely distributed in the river, however, it was captured in relatively low numbers aside from immediately downstream of the Diversion Drain at a site with more complex in-stream and riparian habitat. The western minnow (*Galaxias occidentalis*) and nightfish (*Bostockia porosa*) were only captured in relatively low numbers at two sites each in the lower Vasse River. This study also captured the rare mud minnow (*Galaxiella munda*) at the headwater site, which is the first record of this species in the Vasse River.

The Vasse River is generally heavily modified and two introduced feral species, the mosquitofish (*Gambusia holbrooki*) and goldfish (*Carassius auratus*) have become established and accounted for over 60% of all fish captures. These species were particularly dominant in more degraded reaches of the river, such as the Diversion Drain and the lower Vasse River. The goldfish were captured in the lower Vasse River, between the Diversion Drain and immediately below the Old Butter Factory slot-boards. This stretch of the river has essentially become a heavily silted, stagnant pool due to the restriction of flow from the Diversion Drain and the presence of slot-boards, which together prevent adequate flushing of the system and that is likely to have facilitated the establishment of the feral species, as well as exacerbating algal blooms.

It is suggested that the introduction of goldfish into the Vasse River is relatively recent and the dominance of juveniles born in October last year will result in a rapid increase in the population in the next few years. Growth rates of goldfish in the Vasse River far exceed those reported elsewhere with individuals attaining lengths of over 180 mm TL at the end of their first year, the age at which they also mature. Goldfish are known to be vectors for disease introduction, may prey on native fish and their eggs and larvae, reduce aquatic plant biomass and re-suspend nutrients further fuelling algal blooms. Furthermore, recent studies have demonstrated that significant growth of cyanobacteria is stimulated by the passage through goldfish intestines. Goldfish, which attained lengths of over 40 cm in the Vasse River, therefore have the potential to contribute to algal blooms.

It is recommended that flushing of the river could occur by removal of the slot-boards at the Old Butter Factory and diverting flows from the Diversion Drain back into the river, thus attempting to return environmental flows to a more natural regime. Riparian vegetation should also continue to occur in this stretch of the River with estuarine species able to tolerate the higher salinities expected to occur as the River returns to a more natural, estuarine system.

A goldfish eradication program should be implemented in the lower Vasse River. This program would also provide an excellent opportunity to gain further information on their biology and ecological impact in the system, particularly with regard to their role in algal blooms. An education program should also be implemented outlining the problems caused by releasing aquarium fish into wild aquatic systems.

Introduction

Threats to the native freshwater fishes of the south-west

The freshwater fish fauna of the south-west of Western Australia, although not rich in number, is highly unique with eight of the ten species being found nowhere else (Morgan *et al.* 1998). The uniqueness of the aquatic fauna is also reflected in the freshwater crayfish of the region with all 11 species being endemic (Austin and Knott 1996; Horwitz and Adams 2000).

Perhaps due to their small size, the native freshwater fishes are relatively poorly appreciated with none of the species, aside from the freshwater cobbler (*Tandanus bostocki*), providing angling opportunities. A number of introduced freshwater fish species have become established in this State and many have deleterious impacts on native species. Relatively large, predatory introduced species have been translocated into aquatic systems in this region for the purpose of angling, i.e. rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and redfin perch (*Perca fluviatilis*). These species are known to predate heavily on native freshwater fish and crayfish, particularly redfin perch (e.g. Morgan *et al.* 2002, in press). Another notable feral species, introduced for the purpose of mosquito control, is the mosquitofish (*Gambusia holbrooki*). This species originates from North America and, due to its widespread liberation, is now one of the most widely distributed freshwater fishes in the world. It is also an aggressive species that fin-nips native species (Gill *et al.* 1999) and attains very high densities via a highly effective live-bearing reproductive strategy which involves reaching maturity early in life and having an extended spawning period.

A number of aquarium species have also been released and have become established in wild aquatic systems in this region. Perhaps most notably, the goldfish (*Carassius auratus*) is found in a number of systems, particularly lakes and slow moving waterways, such as irrigation drains that traverse the Swan Coastal Plain (see Figure 16). This relatively large species is a known detrital feeder and may alter the benthic habitat of aquatic systems through its feeding behaviour. The impact of these introduced species on native aquatic species in this region is increasingly being recognised, but is poorly understood.

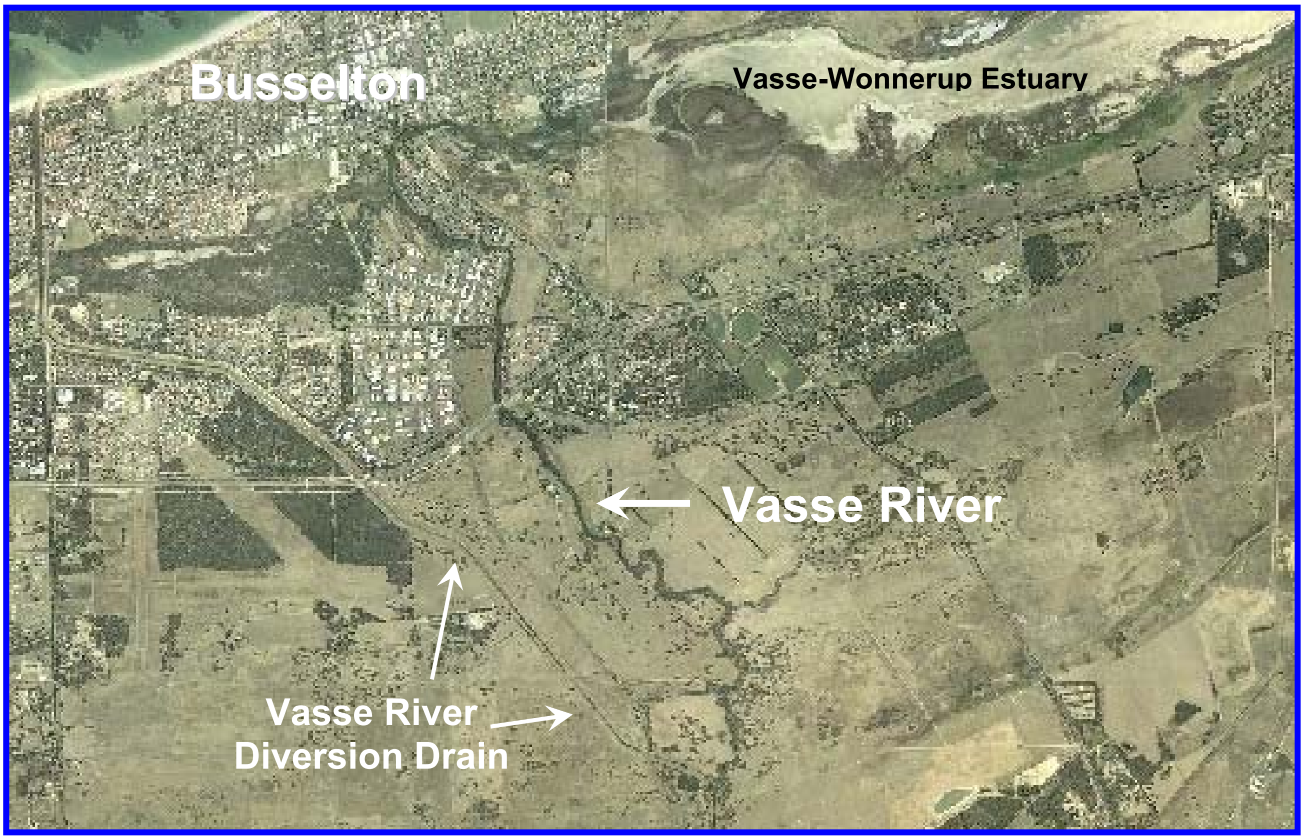
In addition to introduced fishes, there exist other considerable threats to this highly endemic fish fauna associated with habitat degradation (such as salinisation, eutrophication, and destruction of riparian vegetation) and barriers to fish migration (in particular dams, gauging weirs and drainage canals). For example, the alteration of rivers as they traverse the Swan Coastal Plain from the Darling Scarp for irrigation and flood control has involved: straightening of natural stream meanders; the formation of diversion drains; steepening of banks; placement of barriers in the form of slot-boards; and removal of native riparian vegetation and in-stream structures. These actions result in homogeneity of aquatic habitat that differ widely from the natural stream form and create a highly disturbed aquatic system that favours introduced aquatic species, often to the detriment of native species. Recent work has established that native fish species, such as the western pygmy perch (*Edelia vittata*), western minnow (*Galaxias occidentalis*) and the nightfish (*Bostockia porosa*), in these systems persist only in the limited areas of favourable habitat (such as deep pools with structure) whilst the numerically dominant introduced mosquitofish and goldfish have no such preference, being found in less diverse, 'typical' drain habitats (Morgan and Beatty 2003).

Introduced teleost species may have serious impacts on aquatic ecosystems including; habitat alteration; introduction of disease; competition for resources with native fish species; predation and agonistic impacts on native fish species. For example, predation on native fish and freshwater crayfish (by rainbow trout, brown trout and redfin perch) and fin-nipping native fish species (by mosquitofish) have been previously described (Gill *et al*. 1999, Morgan *et al*. 2002, Morgan and Beatty 2003). However, there has been a relative paucity of research into the impacts of these species on the overall aquatic ecosystems in this region. Virtually nothing is known on the impacts of goldfish in Australia.

The Vasse River

The Vasse River is approximately 45 km long encompassing a catchment of approximately 270 km^2, however approximately 60% of the catchment is cleared and heavily modified, with much of the flows diverted to drainage canals for flood mitigation (Pen 1997). Much of the Vasse-Wonnerup estuarine lagoon, which is roughly 1.5km wide and runs for 25km behind narrow coastal dunes covering an area of 1000ha is cleared and the hydrology has been largely modified by drainage and tidal barriers and is threatened by eutrophication with the system no longer functioning as an estuary (Jaensch and Lane 1993, Pen 1997). Regardless, the system still provides important habitat for waterbirds and is listed as a Ramsar Wetland of International Importance (Jaensch and 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 incorporated reshaping and revegetation of the bed and banks of the Lower Vasse River while also conducting Phoslock™ trials to reduce dissolved phosphorus and thereby attempt to reduced blue-green algal (cyanobacteria) blooms in the river (Goss and Greenop 2003). During this work, the reported sightings and capture of feral fish such as goldfish and mosquitofish in the Vasse River has increased considerably in recent years.

As part of a wider Vasse River rehabilitation program, there was thus a need for a comprehensive fish survey of the lower Vasse River to ascertain the distribution and abundances of endemic and introduced fishes. The lower Vasse River between the slot-boards at the Old Butter Factory and the Vasse River Diversion Drain, has effectively become a stagnant reservoir and the sampling regime was designed to determine what impact this has had on the fish fauna compared with upstream of this reach of the river and to a lesser extent the Vasse River Diversion Drain.



Aerial photograph of the lower Vasse River, including Busselton, the Vasse River Diversion Drain and the Vasse-Wonnerup Estuary.

This study aims to complement the above rehabilitation work via conducting a thorough assessment of the fish fauna of the lower Vasse River and formulate recommendations relating to environmental flows, habitat enhancement for native fish and feral species eradication. The results of the proposed study will act as a management template for similar potential river rehabilitation and fish fauna enhancement projects in this region. The aims of the project were to:

- Undertake a comprehensive fish faunal survey of the lower Vasse River to determine the distribution and abundance of fishes.
- Educate local volunteers in the identification of native and introduced fishes.
- Formulate an eradication program of introduced fishes in the lower Vasse River.
- Provide recommendations for further aquatic habitat enhancement to allow successful establishment of appropriate native fish species.

Materials and methods

Sampling sites and environmental variables

An initial sampling occasion occurred in December 2003 in the lower Vasse River. Four sites were selected as far downstream as immediately below the slot-boards at the Old Butter Factory and upstream to the Busselton Shire Offices (Figure 1). Due to the relatively high water levels at that time (as the slot-boards remained inserted at the Old Butter Factory), which reduces the effectiveness of the sampling methodologies, this was treated as an exploratory survey to determine the species present in this section of the river and to determine appropriate methodologies for the subsequent more intensive sampling occasion, in March, 2004.

The major sampling occasion in March involved two major methods: the first involved intensively sampling a total of seven sites distributed from below the Old Butter Factory slot-boards (sampled as part of the initial survey) to as far upstream as the waterpoint near Chapman Hill Rd, in the extreme upper catchment of the Vasse River (Figure 1). This sampling also included sites in the Vasse River Diversion Drain, and was designed to compare fish fauna in the lower Vasse River with that in the Diversion Drain and the more natural, less modified upper reaches. The second sampling method was designed to survey the distribution of goldfish and attempt to remove as many as possible from the lower Vasse River.

The water temperature and conductivity of each site was measured at the bottom of the water column at three locations. The latitude and longitude of each site was recorded with the use of a hand held GPS and maps of sampling sites created using the MapInfo™ program.

Sampling of fish fauna

Fish surveys

Sampling of fish as part of the broad survey of the river involved the use of 5 and 10 m seine nets (mesh widths 3 mm, fished to a depth of 1.5 m) and the use of a back-pack electrofisher (*Smith Root model 12-A*) which momentarily stuns the fish. Each fish was identified to species and abundances determined. The mean density (± 1 S.E.) of each species at each site was determined using the formula:

$$D = N / A$$

where D is the density of each fish species at each site, N is the number of fish captured at each site and A is the area sampled at each site.

Goldfish

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, an alternate method was used to capture as many goldfish as possible. This involved the use of a 240 volt, generator powered electrofisher deployed from a boat from ~500 m upstream of the Bussell Hwy Bridge to immediately downstream of the Old Butter Factory slot boards (Figure 2). 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 (see Figure 18).

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 guts 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 determine the frequency of occurrence of each prey category in the guts of goldfish and the relative contribution (by volume) of each prey category to their diet.

The number of translucent zones of the otoliths (ear bones) is commonly used to determine the age of fish as they are generally laid down annually as a consequence of seasonal variations in water temperature, day-length etc, in much the same way that trees develop growth rings. As there appeared to be distinct cohorts of goldfish present in our samples (see Figure 19), the otoliths of each goldfish in the sub-sample were removed 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 also for an introduced fish (e.g. Morgan *et al*. 1995, 2000, 2002)). A length-frequency distribution was produced separately for those goldfish captured in December and those electrofished during March, and was split for each year class, based on age from otoliths (see Figure 19).

The length of each individual was plotted against its age and a preliminary growth curve was fitted using a von Bertalanffy curve 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, specifically, North Lake, 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 and Discussion

Environmental variables and sampling sites

The sampling sites differed considerably in depth, morphology, flow rates, and instream and riparian vegetation (Figures 1 and 2). The four sites in the lower Vasse River including the Rotary Park site, the site near the Shire offices and the sites at the Strelley St and Bussell Hwy bridges, appeared to be broadly similar. This stretch of river is largely urbanised with a degraded riparian zone (although riparian vegetation regeneration has occurred by GeoCatch in some stretches) (Figure 2). It was typified by relatively deep water and has a heavily modified flow regime due to the slot-boards at the Old Butter Factory, which prevent flushing of this stretch of the river, coupled with the presence of the control valve at the Diversion Drain which generally is only fully-opened in winter. Elevated temperatures were recorded at these sites, particularly at the Bussell Hwy Bridge site where a significantly greater maximum mean temperature than any other site was recorded (29.6 ºC, Table 1, Figure 3). These sites also had moderately high conductivities with means up to 1910.7 µS/cm at the Bussell Hwy Bridge (Table 2). These elevated temperatures and conductivities were likely brought about by the low flow rates and lack of shading afforded by the sparse riparian zone in this section of the river. This modified section of the river also experiences severe cyanophyte blooms, one of which occurred during the March sampling occasion and GeoCatch was conducting *Phoslock*™ trials in an attempt to reduce the severity of the blooms.

The site immediately below (downstream) the valve connecting the above section of the river and the Vasse River Diversion Drain (Figures 1 and 2) differed from downstream sites in that it had a relatively narrow stream profile which was relatively shaded by remnant vegetation and also contained kikuyu grass that afforded instream habitat to native species (see *Fish Fauna of the Vasse River* section). It was likely that the considerable shading resulted in this site recording a significantly lower mean temperature (22.0 ºC) than all other sites aside from the Stuart Rd site in the upper catchment (Table 1, Figure 3). The conductivity was moderately high reflecting the proximity to the Diversion Drain, where the highest conductivities were recorded (see below) (Table 2).

The two sites in the Vasse River Diversion Drain (Figures 1 and 2) were typical of irrigation drains of the region in that they have a heavily modified streamline (effectively a trench) that had extremely homogenous habitat and limited riparian or instream vegetation (see Morgan and Beatty, 2003) (Figure 2). A lack of shading typified these sites and resulted in the relatively high temperatures being recorded at the site above the Vasse River Diversion Drain valve (26.9 ºC compared to the mean of 22.0 ºC at the above mentioned shaded site immediately below the valve 25.6 ºC) (Table 1, Figure 3). These sites also had elevated conductivities due to evapo-concentration of the still, shallow water and the Vasse River Diversion Drain site had significantly greater conductivity ($P \leq 0.01$) than any other site (2993 µS/cm) (Table 2).

Much of the upper Vasse River was dry during the March sampling occasion (Figure 2), however, the Stuart Rd site (Figure 1), which is a fire-fighting waterpoint, would connect during winter. The upper reaches of the Vasse River is a stream that passes through State Forrest and agricultural land and, for the most part, the stream has a degree of natural remnant riparian vegetation affording heavy shading and heterogenous instream habitat (Figure 2). The Stuart Rd site therefore had considerable riparian vegetation and the lowest recorded mean temperatures of any site sampled (19.9 ºC) (Table 1, Figure 3). This site was also significantly fresher than all others sampled with a mean conductivity of 357.3 µS/cm (Table 2).

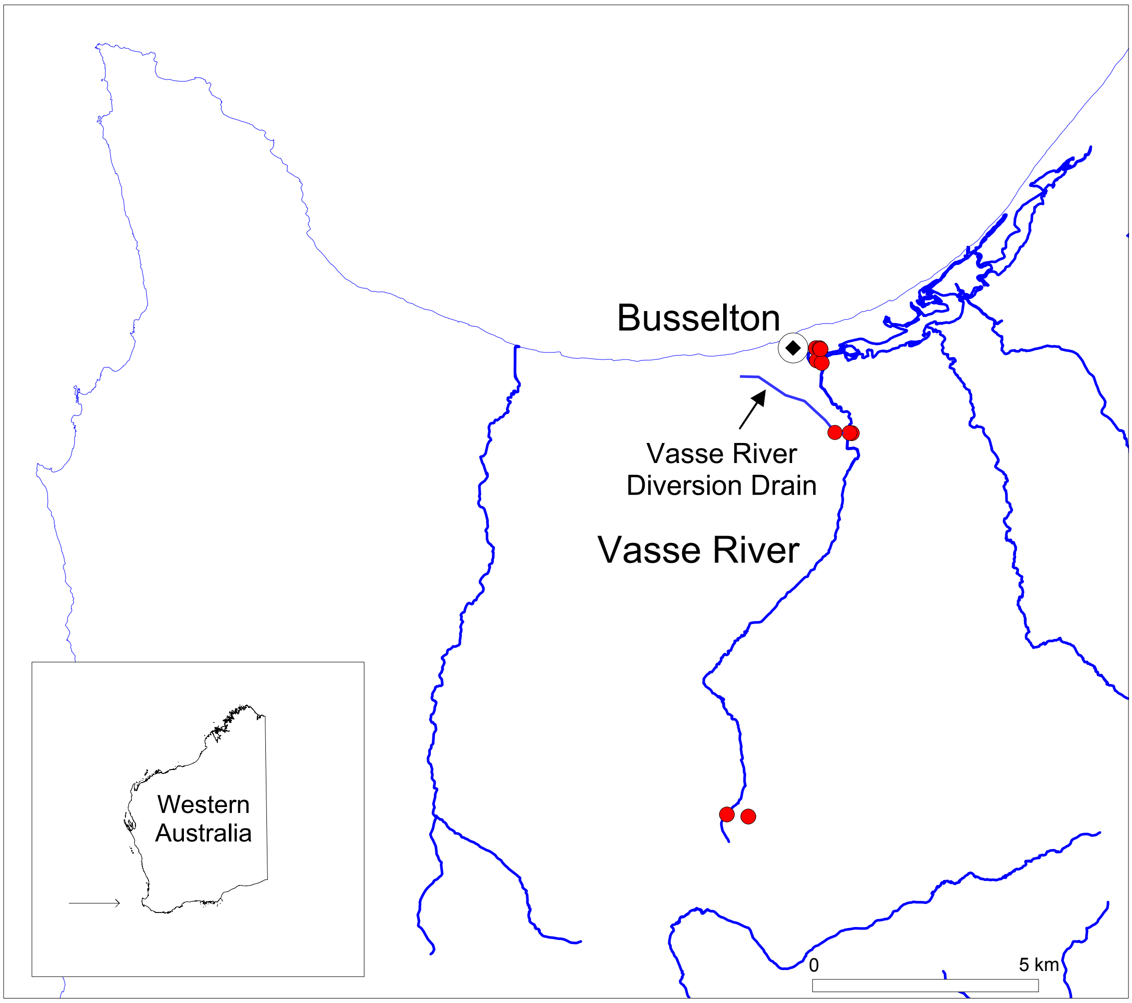


Figure 1 Sites sampled for fish in the Vasse River and in the Vasse River Diversion Drain.

Figure 2 A-D. Seine netting and electrofishing at slot boards at Old Butter Factory; E. Strelley St Bridge; F-G. Electrofishing upstream of Bussell Hwy Bridge; H. Junction of Vasse River and Diversion Drain; I. Diversion Drain; J. Upper Vasse River waterpoint where mud minnows were captured. N.B. Lack of riparian vegetation in the lower Vasse River and Diversion Drain sites.

Table 1 Mean temperatures at each sampling site in the Vasse River in March 2003 (++ Rotary Park recorded in December). Significant differences between sites (ANOVAs) are shown: ns = not significantly different, * = $P \leq 0.05$, ** = $P \leq 0.01$.

			Increasing distance upstream →						
	Sites		Rotary Park ++	Strelley St Bridge	Bussell Hwy Bridge	Below Vasse Diversion Drain valve	Above Vasse Diversion Drain valve	Vasse Diversion Drain	Stuart Rd
		Temperatures (±1 S.E)	**23.9 (±0.35)**	**25.3 (±0.62)**	**29.6 (±0.29)**	**22.0 (±0.33)**	**26.9 (±0.45)**	**25.6 (±0.08)**	**19.9 (±0.07)**
Increasing distance upstream ↓	Rotary Park ++	**23.9 (±0.35)**	-						
	Strelley St Bridge	**25.3 (±0.62)**	ns	-					
	Bussell Hwy Bridge	**29.6 (±0.29)**	**	**	-				
	Below Diversion Drain valve	**22.0 (±0.33)**	*	**	**	-			
	Vasse Diversion Drain above valve	**26.9 (±0.45)**	**	ns	**	**	-		
	Vasse Diversion Drain	**25.6 (±0.08)**	ns	ns	**	**	ns	-	
	Stuart Rd	**19.9 (±0.07)**	**	**	**	*	**	**	-

Table 2 Mean conductivity at each sampling site in the Vasse River in March 2003 (++ Rotary Park recorded in December). Significant differences between sites (ANOVAs) are shown: n = not significantly different, * = $P \leq 0.05$, ** = $P \leq 0.01$.

			Increasing distance upstream →						
	Sites		Rotary Park ++	Strelley St Bridge	Bussell Hwy Bridge	Below Vasse Diversion Drain valve	Above Vasse Diversion Drain valve	Vasse Diversion Drain	Chapman Hill Rd
		Conductivity (µS/cm)	**797.3 (±3.56)**	**1651 (±176.78)**	**1910.7 (54.12)**	**1474.3 (±51.79)**	**1548.7 (±27.35)**	**2993 (±10.89)**	**357.3 (±1.47)**
	Rotary Park ++	**797.3 (±3.56)**	-						
	Strelley St Bridge	**1651 (±176.78)**	**	-					
Increasing distance upstream ↓	Bussell Hwy Bridge	**1910. 7 (54.12)**	**	*	-				
	Below Diversion Drain valve	**1474.3 (±51.79)**	**	n	**	-			
	Vasse Diversion Drain above valve	**1548.7 (±27.35)**	**	n	**	n	-		
	Vasse Diversion Drain	**2993 (±10.89)**	**	**	**	**	**	-	
	Stuart Rd	**357.3 (±1.47)**	**	**	**	**	**	**	-

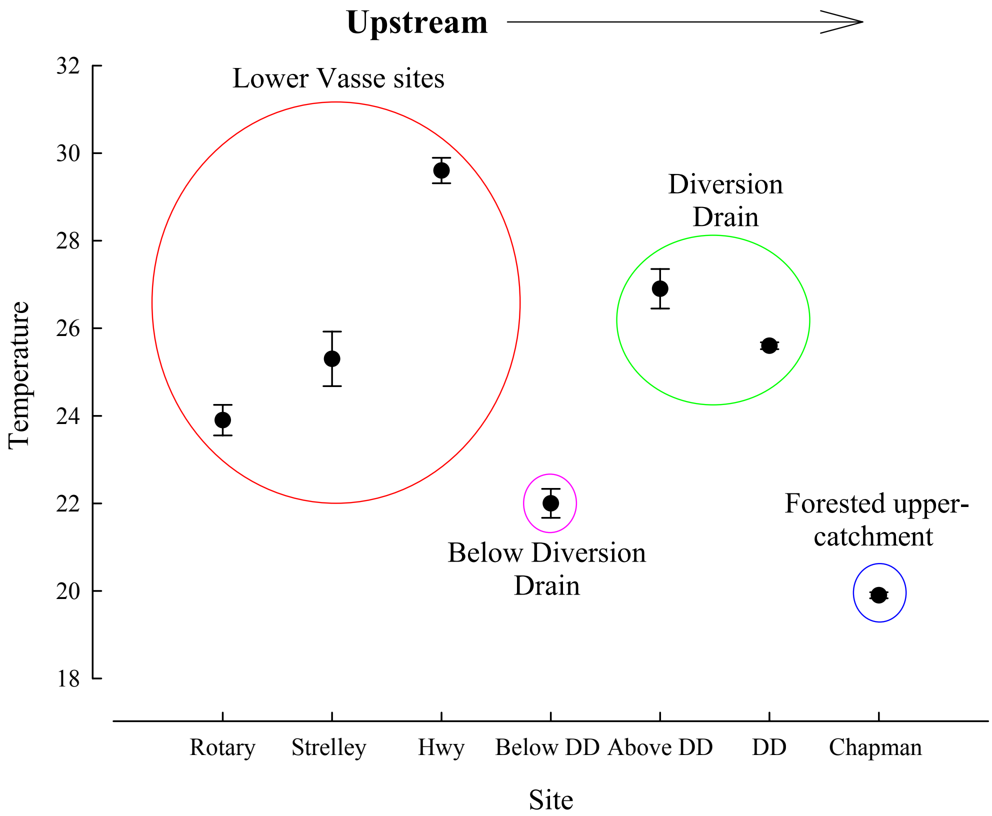


Figure 3 Mean temperatures (±1 S.E.) of the sites sampled in the Vasse River. Circles broadly group sites based on habitat types. (DD = Diversion Drain).

Fish fauna of the Vasse River

A total of 7895 fish were captured during the study (Figure 4), the majority of which were the feral mosquitofish with 4731 captured from all sites aside from immediately above the Old Butter Factory slot-boards and the upstream-most site at Stuart Rd and represented ~60% of total captures with a total mean density of 1.09/m^2 (Table 3, Figure 4). The next most abundant species captured was the estuarine western hardyhead (*Leptatherina wallacei*) with 1980 captured (0.45/m^2, ~25% of captures) at the three most downstream sites (Table 3, Figure 5). The Swan River goby (*Pseudogobius olorm*), a species also commonly caught in estuarine habitats, was also captured in relatively high abundances (661, 0.15/m^2, ~8% of captures) and was captured at the most number of sites of any species (all except the upstream-most site at the Stuart Rd site) (Table 3, Figure 5). A total of 378 western pygmy perch was captured at five sites (0.09/m^2, 5% of captures) (Table 3, Figure 5). Ninety-one goldfish were captured in the lower Vasse River at a total mean density of 0.02/m^2 and represented 0.01% of all captures (Table 3, Figure 5, see also section below on goldfish for detailed description on their distribution).

Western minnows were only recorded at two sites with a total of 39 captured above and below the Diversion Drain valve (Table 3, Figures 2, 4, 5-11). Nightfish were also in low abundance and only a total of seven were captured at two sites: downstream of the Old Butter Factory slot-boards and at below the Diversion Drain valve (Table 3, Figure Figures 2, 4, 5-11). The restricted mud minnow was also captured during the survey, a species that has not previously been recorded in the Vasse River catchment and is therefore of considerable note, at the upstream site at Stuart Rd (Table 3, Figures 2, 4, 5-11). This species is listed as *RESTRICTED* on the Australian Society for Fish Biology's List of Threatened Fishes and through degradation of habitats on the Swan Coastal Plain, now has a severely fragmented distribution.

The five most downstream sites, i.e. above and below the Old Butter Factory slot-boards, Rotary Park, Shire Offices and Strelley St Bridge (Figures 1 and 2), were numerically dominated by estuarine species including the western hardyhead and Swan River goby and the two feral species captured in the Vasse River, the mosquitofish and goldfish (Figures 5 - 11). As mentioned, these sites have been heavily modified and largely lacked instream habitat with the river essentially being a widened dam lacking: a natural flow regime (due to slot-boards at the Old Butter Factory and attenuated flows at the Diversion Drain valve), established riparian vegetation zone (dominated by parkland with some remnant riparian zone at the Shire Office and Strelley St Bridge and rehabilitation having occurred on the eastern bank of the river) or heterogenous instream habitat (Figure 2).

These highly disturbed sites therefore appeared to provide ideal habitats for the feral species. The predictable numerical dominance of estuarine species (with three large sea mullet also only captured at Rotary Park) at these downstream sites was due to the relatively close proximity to the ocean. It should also be noted that low numbers of the endemic western pygmy perch were recorded at most of these sites and nightfish were recorded below the Old Butter Factory slot-boards and therefore the potential exists for enhancement of these native species by continued riparian habitat rehabilitation and restoration of natural flow regimes (see Conclusions and Recommendations). Their capture here suggests that the slot-boards act as an impediment to the movement of natives through the river.

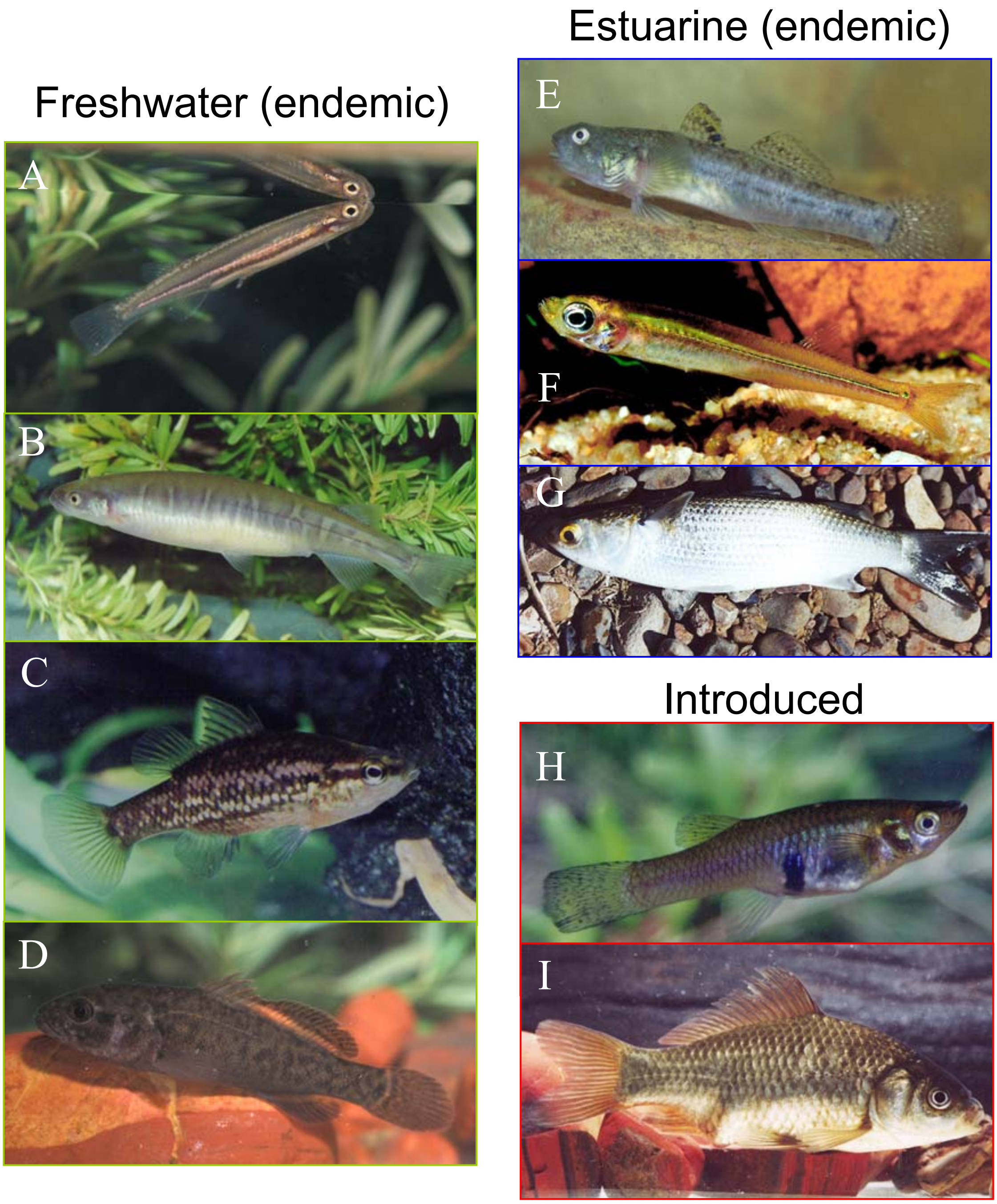


Figure 4 The fishes captured in the Vasse River.
Freshwater endemic fishes: A. Mud minnow (*Galaxiella munda*); B. Western minnow (*Galaxias occidentalis*); C. Western pygmy perch (*Edelia vittata*) and; D. Nightfish (*Bostockia porosa*).
Estuarine fishes: E. Swan River goby (*Pseudogobius olorum*); F. Western hardyhead (*Leptatherina wallacei*) and; G. sea mullet (*Mugil cephalus*).
Introduced fish: H. Mosquitofish (*Gambusia holbrooki*) and; I. Goldfish (*Carassius auratus*).

Table 3 Sites sampled, abundance and relative density of fish captured in the Vasse River during the study.

Sampling details				**Species density per m² (total number in parenthesis)**									
Site	**Date**	**Coordinates**	**Area sampled (per m²)**	Western pygmy perch	Nightfish	Western minnow	Mud minnow	Swan River goby	Western hardyhead	Sea mullet	Mosquitofish	Goldfish	**Total**
Below Old Butter Factory slot-boards	9-Dec	S 33.6532 E 115.35	200	0.010 (2)				0.375 (75)	6.900 (1380)		0.050 (10)		7.335 (1467)
Below Old Butter Factory slot-boards	25-Mar	S 33.6532 E115.35	2500	0.003 (8)	0.002 (6)			0.024 (60)			0.200 (10)	0.014 (35)	0.0476 (119)
Above Butter Factory slot-boards	9-Dec	S 33.6528 E 115.3496	300	0.053 (16)				0.183 (55)	1.000 (300)			0.120 (36)	1.357 (407)
Rotary park	9-Dec	S 33.6528 E 115.3478	270					0.111 (30)	1.111 (300)	0.011 (3)	0.222 (60)		1.456 (393)
Shire Offices	9-Dec	S 33.6577 E 115.3482	140	0.064 (9)				0.179 (25)			1.071 (150)	0.036 (5)	1.35 (189)
Strelley St Bridge	23-Mar	S 33.6587 E 115.3507	200	0.015 (3)				0.400 (80)			5.750 (1150)		6.165 (1233)
Below Vasse River Diversion Drain valve	24-Mar	S 33.6868 E 115.3651	54	6.296 (340)	0.019 (1)	0.111 (6)		0.389 (21)			6.685 (361)		13.5 (729)
Above Vasse River Diversion Drain valve	24-Mar	S 33.6867 E 115.364	200			0.165 (33)		0.225 (45)			2.500 (500)		2.89 (578)
Vasse River Diversion Drain	24-Mar	S 33.6861 E 115.3163	420					0.643 (270)			4.762 (2000)	0.036 (15)	5.440 (2285)
Stuart Rd waterpoint	25-Mar	S 33.8399 E 115.3154	40				0.125 (5)						0.125 (5)
Total mean density			**4324 m²**	**0.08743**	**0.002**	**0.009**	**0.001**	**0.153**	**0.458**	**0.0007**	**1.094**	**0.021**	**1.826**
Total number				**78**	**7**	**39**	**5**	**661**	**1980**	**3**	**4731**	**91**	**7895**

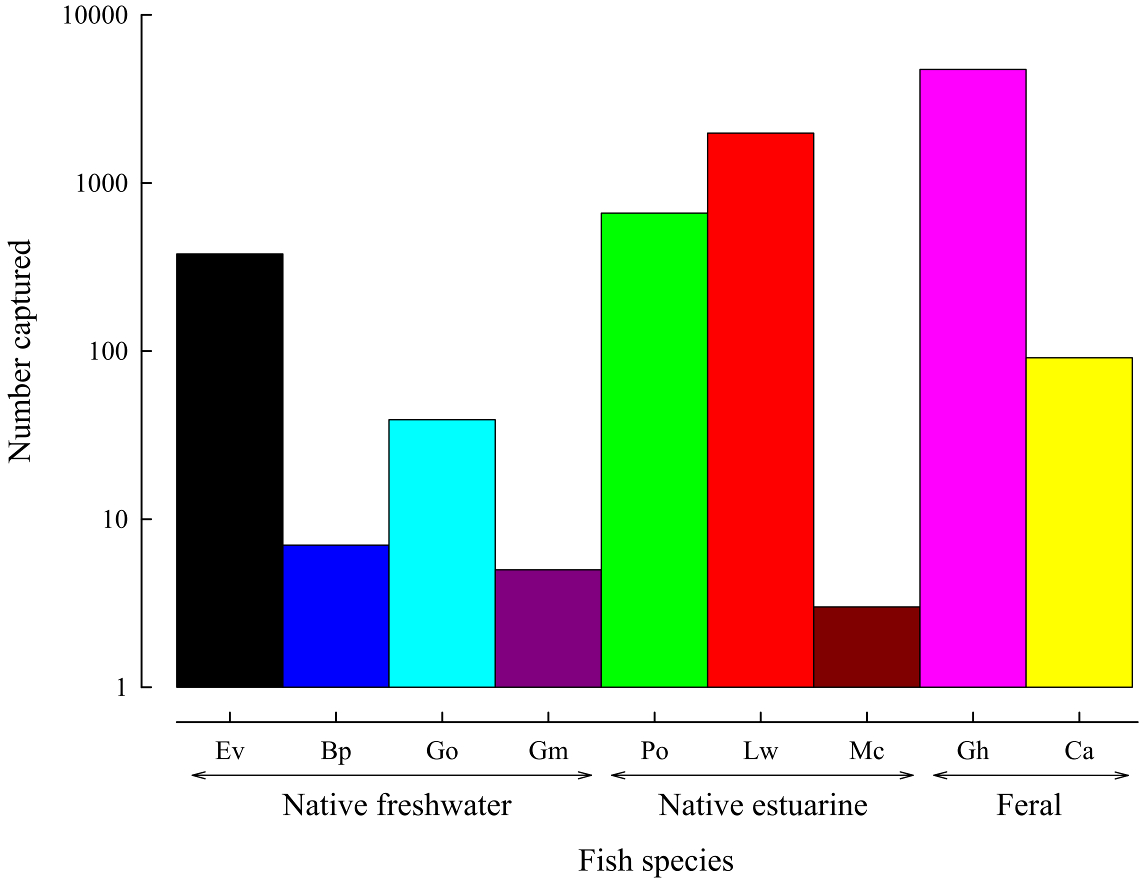


Figure 5 Total number of each fish species captured in the Vasse River during the study. Ev = western pygmy perch, Bp = nightfish, Go = western minnow, Gm = mud minnow, Po = Swan River goby, Lw = western hardyhead, Mc = sea mullet, Gh = mosquitofish and Ca = goldfish.

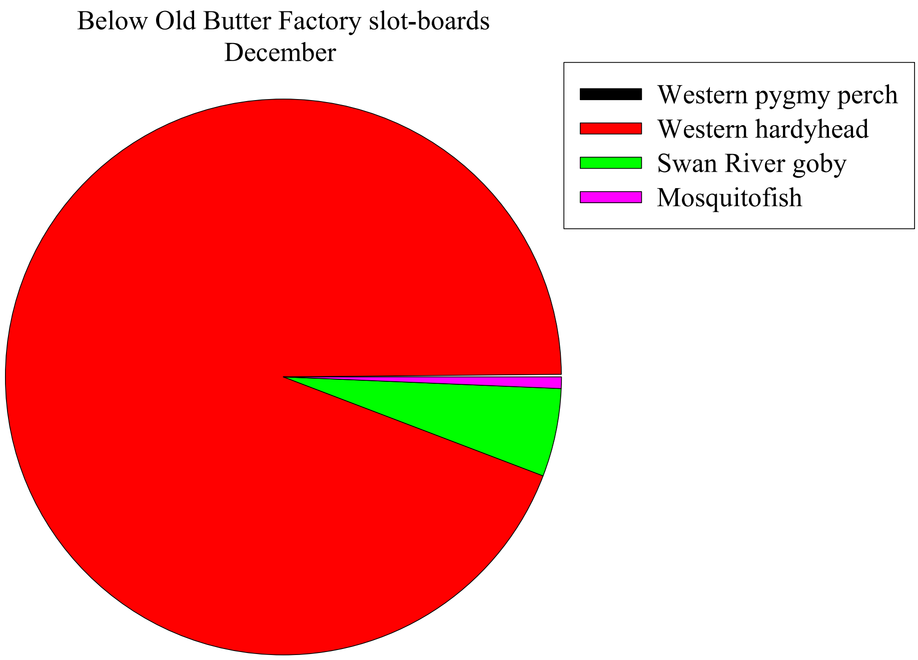


Figure 6 Proportional densities of the fishes captured below the Old Butter Factory slot-boards in the Vasse River in December, 2003.

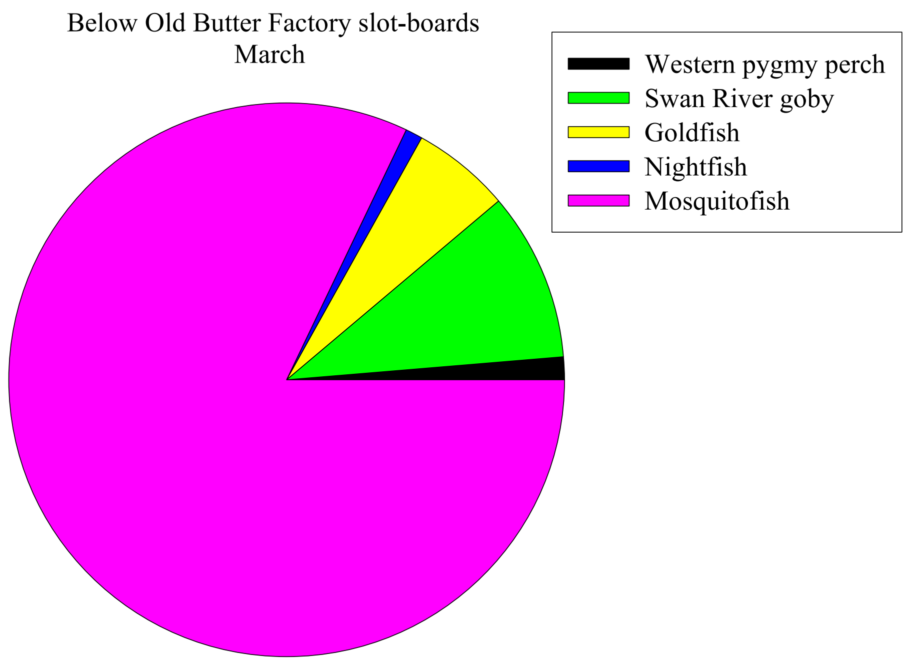


Figure 7 Proportional densities of the fishes captured below the Old Butter Factory slot-boards in the Vasse River in March, 2004.

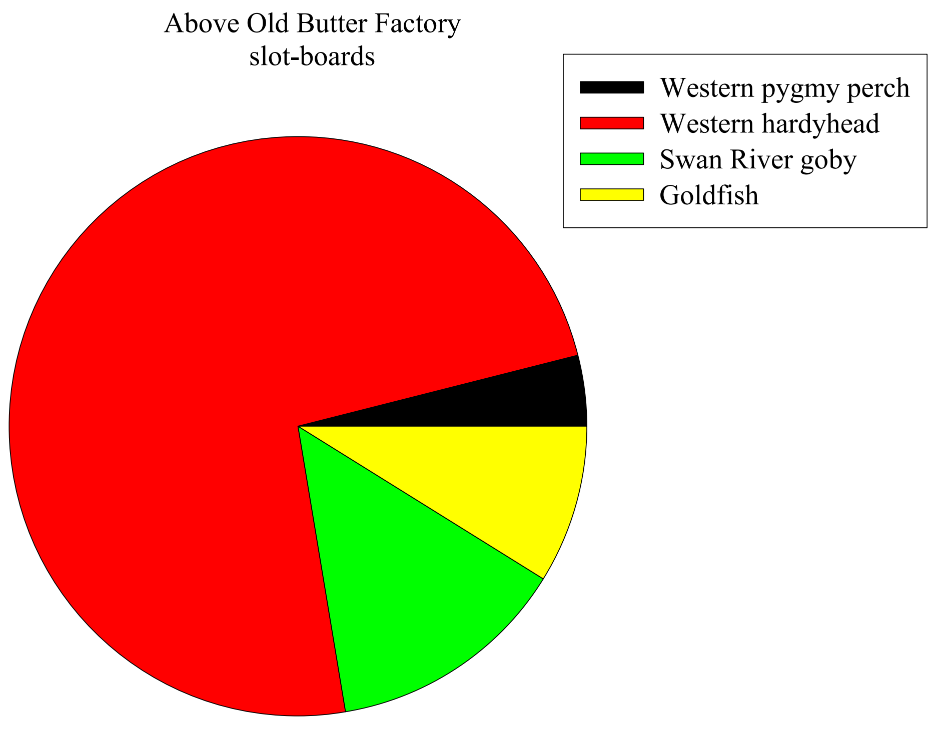


Figure 8 Proportional densities of the fishes captured above the Old Butter Factory slot-boards in the Vasse River in March, 2004.

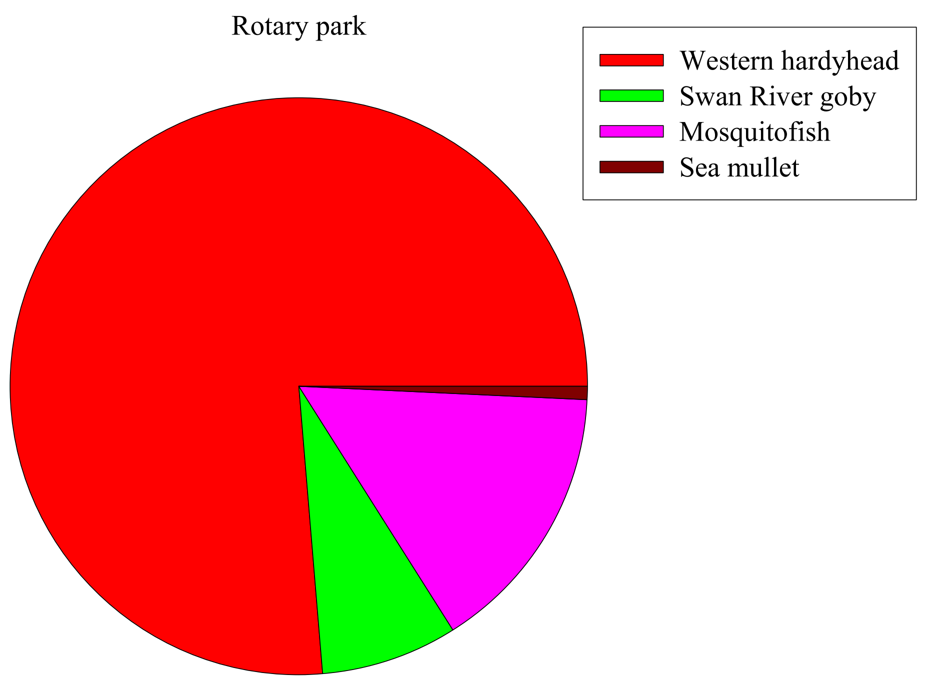


Figure 9 Proportional densities of the fishes captured at Rotary Park in the Vasse River in March, 2004.

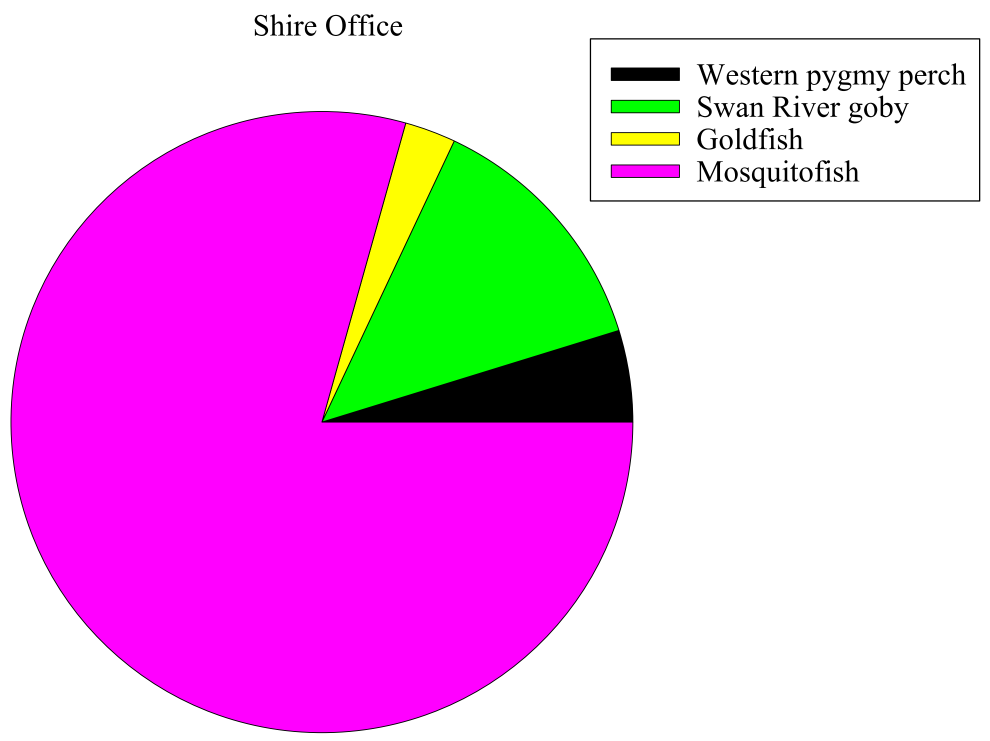


Figure 10 Proportional densities of the fishes captured at the Shire office site in the Vasse River in March, 2004.

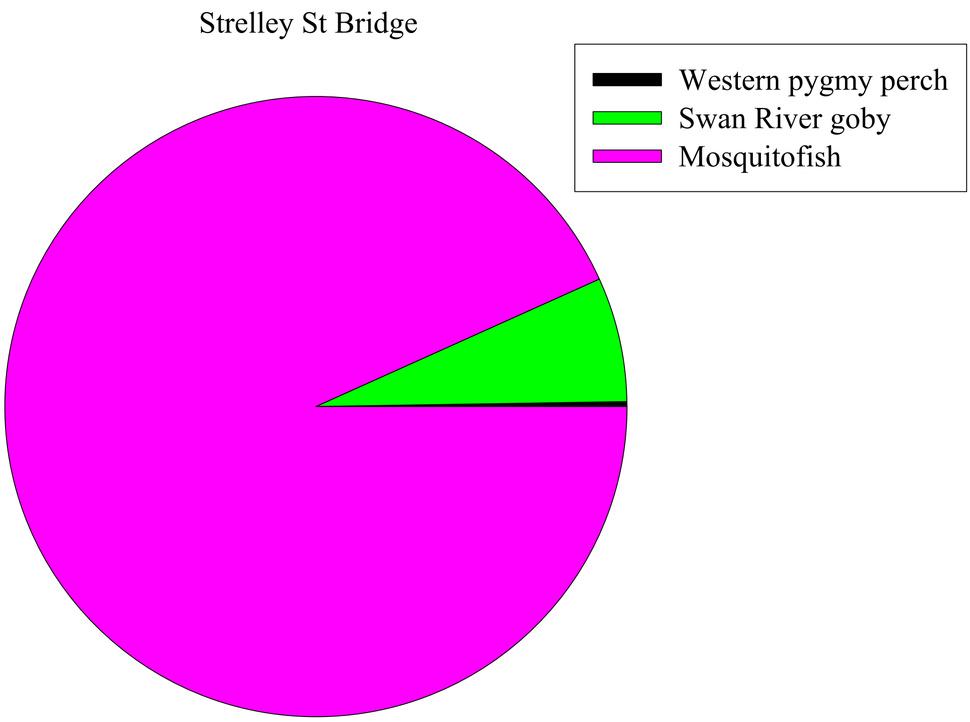


Figure 11 Proportional densities of the fishes captured at the Strelley St Bridge in the Vasse River in March, 2004.

The site immediately below the Vasse River Diversion Drain valve appeared more favourable for the native western pygmy perch where it was far more dominant than at any other site (Table 3, Figures 2, 3 and 12). The relatively high flows (with the river reduced to a narrow streamline downstream of the Diversion Drain valve), high degree of shading due to the presence of some remnant riparian trees and relatively complex habitat created by the thick grass are elements of habitat that typically favour native species. Although the mosquitofish was still a dominant species at this site, the faster flow and cooler water (Table 1, Figure 4) are conditions least suited to this species (which is often associated with warm, still or slow moving water-bodies) and the complex habitat would provide protection to native species from this aggressive feral species (see Gill *et al.* 1999; Morgan and Beatty, 2003).

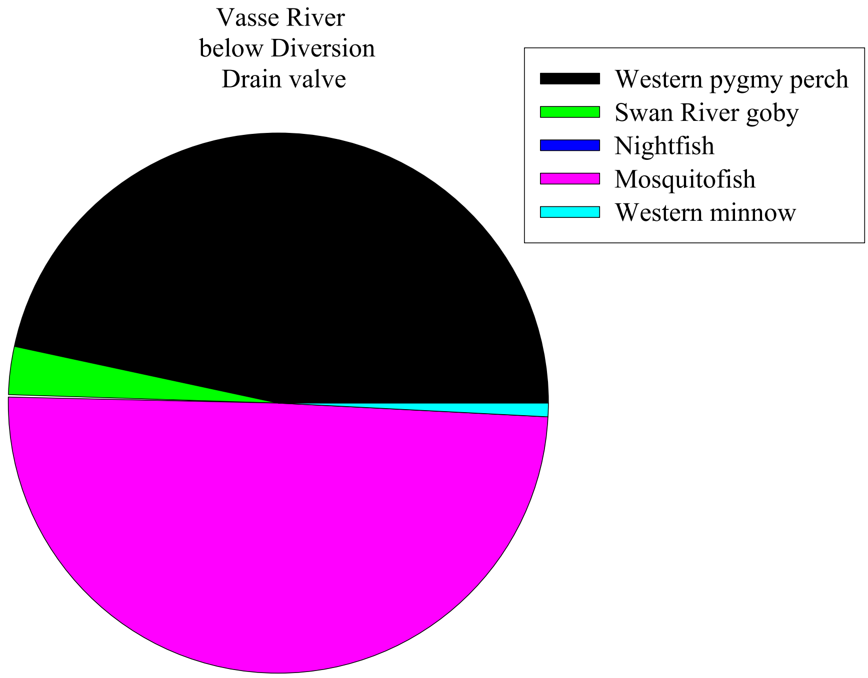


Figure 12 Proportional densities of the fishes captured in the Vasse River immediately downstream of the Diversion Drain valve in March, 2004.

The fish fauna recorded in the two sites in the Vasse River Diversion Drain (Figures 1 and 2) were typical of that associated with irrigation drains in this region in that large numbers of the feral mosquitofish were recorded at both sites (Table 3, Figures 13 and 14). The Swan River goby was also present in relatively large numbers at both these sites as were goldfish at the Vasse River Diversion Drain site and the native western minnow at the site above the Diversion Drain valve (Figures 13 and 14). As mentioned, the Vasse River Diversion Drain is typical of irrigation drains on the Swan Coastal Plain in that it lacks diverse instream habitat or riparian vegetation and has relatively slow-flowing, warm water that is highly suited to mosquitofish (Figures 2 and 3). However, the western minnow is a fast swimming species often found in shallow waterbodies (including irrigation drains, see Morgan and Beatty, 2003) and the Swan River goby is a benthic species and these are probably less prone to attack by mosquitofish compared to other native species, such as the western pygmy perch, which feed throughout the water column and have reduced swimming ability (Gill *et al.* 1999). Therefore, despite the high densities of mosquitofish, the former two native species are able to co-exist in these drains. However, in order to enhance the abundance and richness of native species in the Diversion Drain, in-stream and riparian habitat rehabilitation would be required (see Conclusions and Recommendations section and Morgan and Beatty *et al.* 2003).

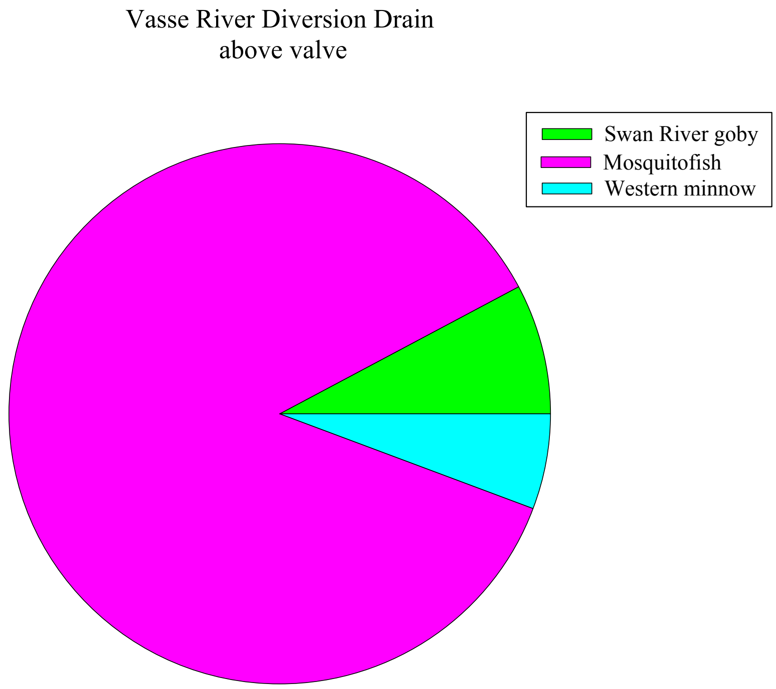


Figure 13 Proportional densities of the fishes captured in the Vasse River immediately upstream of the Diversion Drain valve in March, 2004.

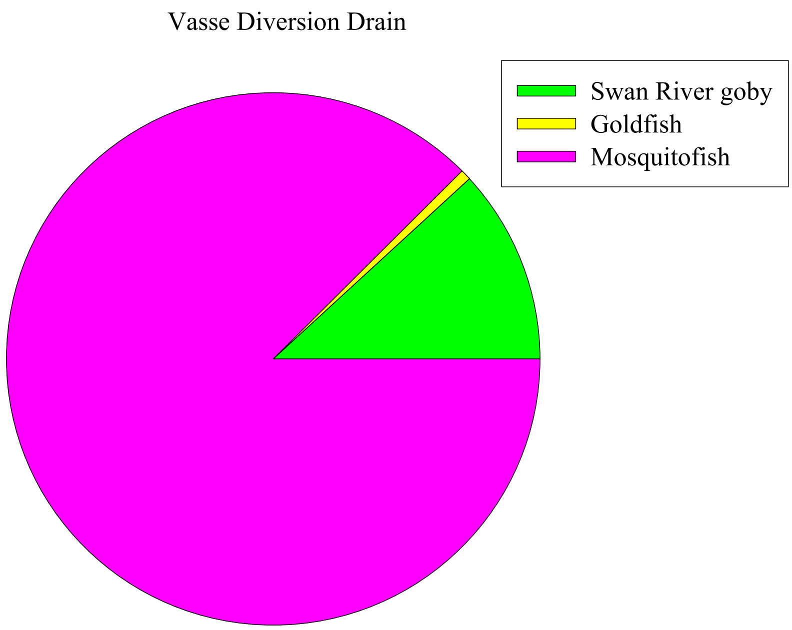


Figure 14 Proportional densities of the fishes captured in the Vasse River Diversion Drain site in March, 2004.

The forested, upper catchment was the most undisturbed section of the Vasse River and the rare mud minnow was the only species captured at the Stuart Rd waterpoint site (Table 3, Figures 2, 4 and 14). As mentioned, only the upper-catchment of the Vasse River is unregulated with limited forested (State Forest) areas. The extreme headwaters therefore provide a refuge for the mud minnow and this study is the first known recording in the Vasse River, an important expansion of this restricted species, previously found as far north as the adjacent Margaret River catchment (aside from a disjunct population in the Moore River) (Morgan *et al.* 1998).

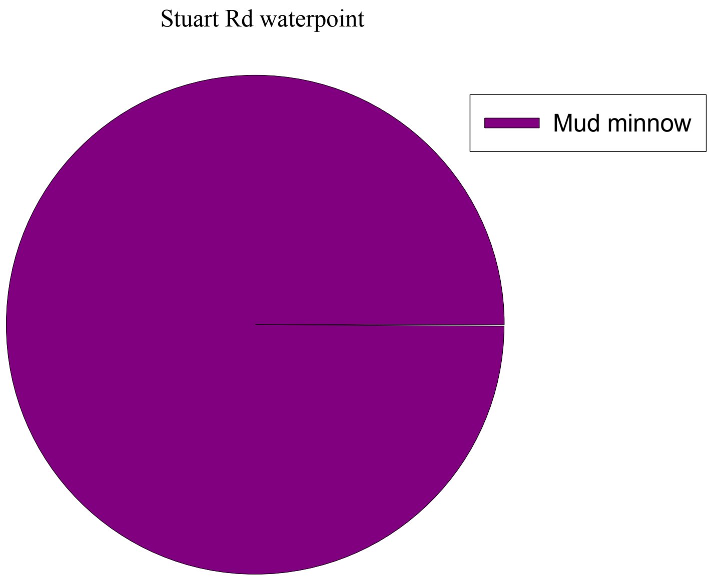


Figure 15 Proportional densities of the fishes captured in the Vasse River at the upstream site on Stuart Rd in March, 2004.

Freshwater crayfish

It should also be noted that this study represents the first known record of the introduced yabbie (*Cherax destructor*) in the Vasse River. We captured yabbies at four sites in the Vasse River: the Diversion Drain, the Vasse River site below the Diversion Drain, Rotary Park and above the Old Butter Factory Boards (Figure 1). This species was introduced from eastern Australia into the farm dams of south-western W.A. in the 1930's and has recently invaded many wild aquatic systems including: the Arrowsmith, Hill, Avon, Canning, Murray, Harvey, Vasse, Blackwood, Warren, Kalgan, Gairdner, Fitzgerald and Phillips rivers (Morgan and Beatty, unpublished data). This species has a wide tolerance of extreme environmental conditions (particularly low oxygen) and is found in both temporary and permanent aquatic systems. It has an invasive life-history strategy including an extended spawning period, early age at first maturity and rapid growth rate and has the potential to out compete native freshwater crayfish species and alter aquatic ecosystem functioning and its presence in the Vasse River is thus of considerable concern (Beatty *et al.* unpublished data).

The other freshwater crayfish captured was the endemic gilgie (*Cherax quinquecarinatus*), which also inhabits a wide variety of temporary and permanent aquatic systems in this region (Austin and Knott 1996), and was captured co-existing with yabbies in the Diversion Drain sites (Figure 1). Both these species are able to tolerate the relatively extreme conditions in irrigation drains and are able to burrow to escape drought and provide shelter (see also Morgan and Beatty 2003).

Goldfish

Distribution in Western Australia

Goldfish are relatively widespread throughout the Swan Coastal Plain, from the Moore River in the north to the Vasse River in the south and they have also been captured in the arid interior north of Kalgoorlie and south of Norseman (Figure 16). Their presence here is the result of either deliberate releases or from the escape of ornamental ponds during flooding. The sites that goldfish are captured are usually disturbed and are often eutrophic.

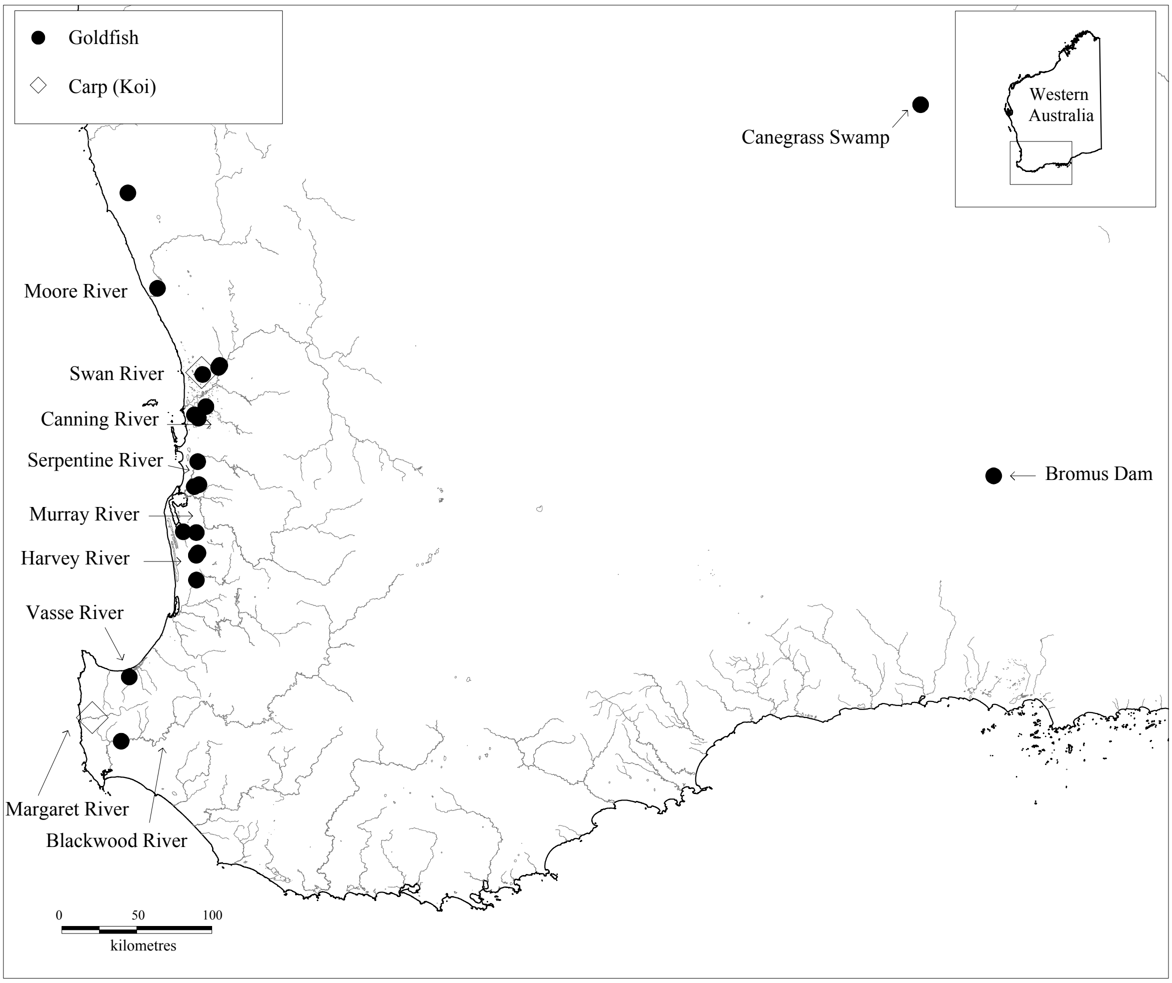


Figure 16 The known distribution of feral (wild) populations of goldfish (*Carassius auratus*) and carp (*Cyprinus carpio*) in Western Australia (from Morgan *et al*. in press).

Goldfish or carp? Identification

Goldfish, due to their sometimes mottled, bright orange coloration and large sizes attained in the wild are often mistaken as carp (*Cyprinus carpio*), a species that is relatively uncommon in wild rivers of Western Australia (see Figure 16). These species are readily distinguished by the absence a barbels ('whiskers') on the chin of carp, a feature that is absent for goldfish. In the wild, the offspring of these feral cyprinids very quickly lose their bright coloration, probably within one or two generations and become gold in colour, hence the name goldfish (see Figure 17). The loss of the bright orange coloration is most likely a consequence of the brightly coloured individuals being more conspicuous to predators, and thus represents natural selection towards the golden colour.

Figure 17 Vasse River goldfish showing a brightly coloured specimen (38 cm TL, >5 years old) and a gold 'naturally' coloured fish (34 cm TL, 3 year old).

Distribution of goldfish in the Vasse River

Within the Vasse River goldfish were only captured in the lower Vasse River and not in the Diversion Drain or upper catchment (Table 3, Figure 18). Large numbers of juveniles were captured around the Old Butter Factory slot-boards, while the larger individuals were found more upstream in loose schools in the close vicinity (usually just upstream) of structures such as bridges or snags. The captures in Figure 18 are a result of electrofishing the length of the lower Vasse River. Single dots represent single captures while the total numbers captured when more than one was present is given in the yellow circles. The distribution of goldfish in the Vasse-Wonnerup estuary needs to be assessed as part of the eradication program (see Summary and recommendations). Population demographics and diets are outlined below.

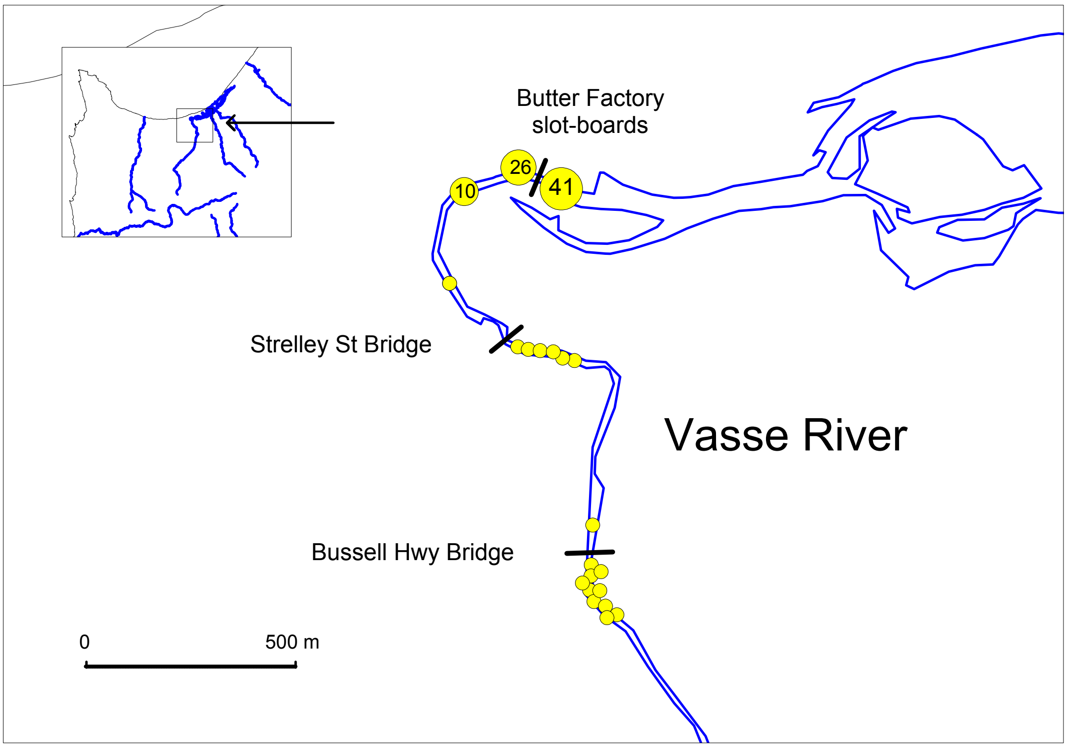


Figure 18 The location (and number) of goldfish (*Carassius auratus*) captured in the Vasse River during March 2003 and December 2004.

Population structure and growth of goldfish in the Vasse River

Analysis of length-frequency histograms and utilising the number of translucent zones of 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 the Vasse River at the time of sampling is dominated by the cohort born in the spring of 2003 (Figures 19 and 20). However, two older and larger fish, over 400 mm TL, were captured.

The fitting of a growth curve to these data revealed that, in the Vasse River, the asymptotic length (L_∞) of the population is 368 mm TL, the growth coefficient (K) is 0.06 and the hypothesized age at which their length would be zero (t_0) was 0.66 months (Figure 20). Thus, based on the growth curve of this population, at the end of their first year of life goldfish in the Vasse River would attain an approximate length of 185 mm TL, while at two and three years of age they would be approximately 280 and 325 mm TL, respectively (Figure 20). N.B. The largest fish were not included in analyses as one was kept for display in the Busselton community and the other had unreadable otoliths. The fact that otoliths of this large fish was unreadable may have been due to them spending part of their life in captivity where delineation of translucent zones would not occur as when exposed to seasonal variations in the wild, suggesting that this may have been one of the original fish released into the Vasse River.

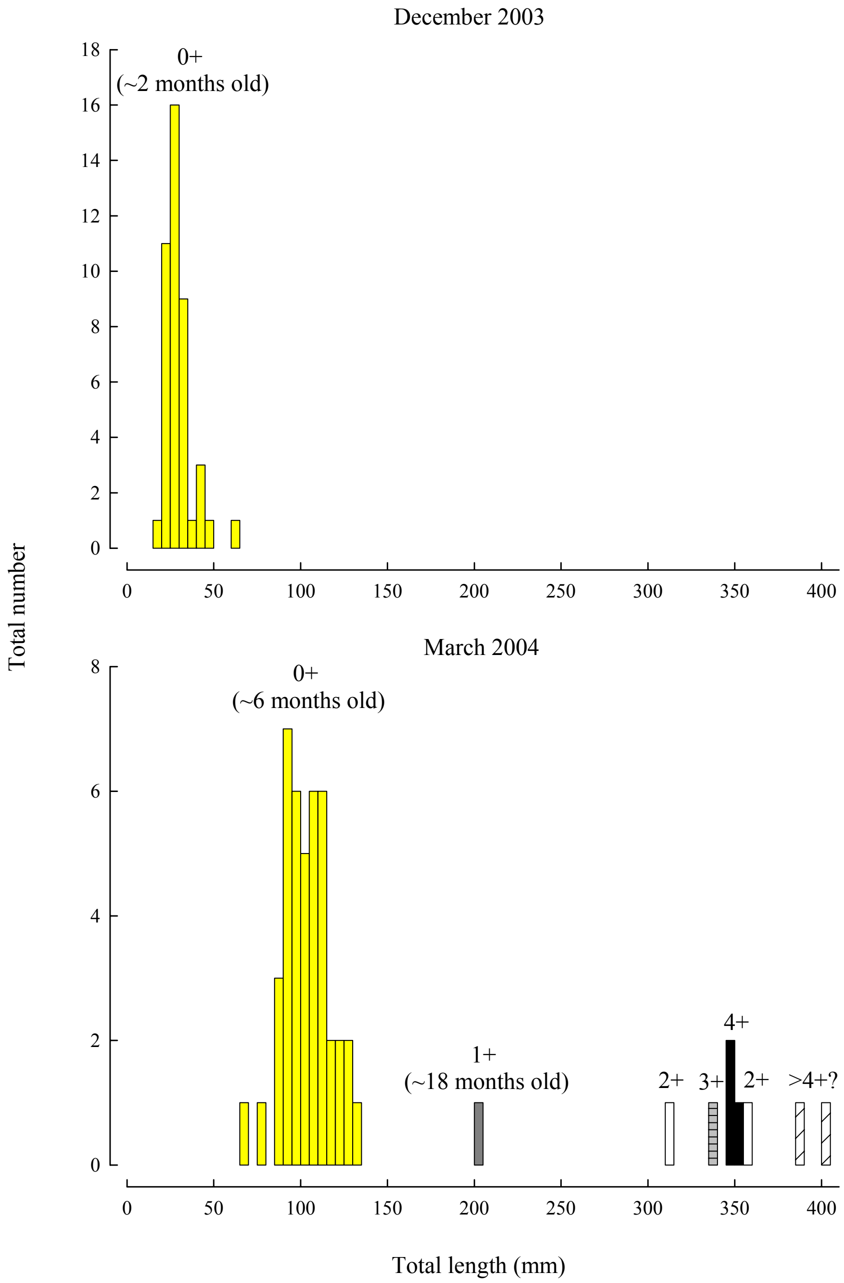


Figure 19 Length-frequency histograms of goldfish (*Carassius auratus*) captured in the Vasse River during March 2003 and December 2004. N.B. approximate age classes, based on the number of translucent zones on the otoliths, are included.

The age and growth data presented here (Figures 19 and 20), while appearing to provide a good estimate of length versus age, requires validation before it can be accepted. Thus, more older fish are required from throughout the year so that changes in the otoliths translucent/opaque zones can be verified as annuli (i.e. marginal increment analysis). Generally, sexes are also plotted separately. Further eradication of goldfish would provide an excellent opportunity to examine the biology and ecological impact of this species, a study that would be the first of its kind on this species in Australia.

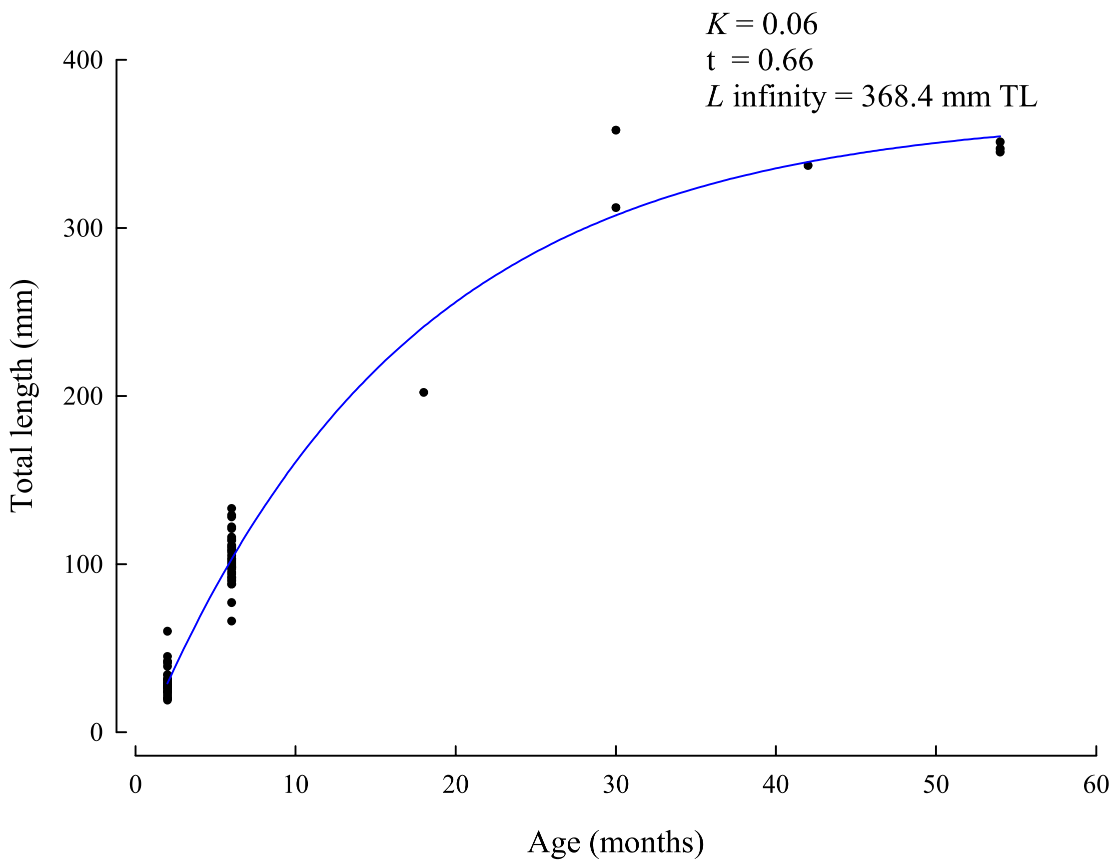


Figure 20 Length at age of goldfish captured during in the Vasse River including the von Bertalanffy growth curve. N.B. approximate age classes were based on the number of translucent zones on the otoliths and October 1st was assigned as the birth date.

The only previous age and growth study on wild goldfish populations in Australia was by Mitchell (1979) who used scales to age fish from South Australia. In terms of comparisons with the Vasse River population, 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 found one fish living for over 10 years that weighed over 2 kg.

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 may spawn at the end of their first year of life. The numerical dominance of the 2003 year class, all of which had lost any orange coloration, and their potential to breed during 2004 may lead to a rapid population increase during 2005 and beyond. The persistence of orange coloration in the two largest individuals, together with the unreadable otoliths perhaps as a result of living in captivity, suggests that they may have been either the original stock introduced into the Vasse River or they are first or possibly second generation – their age however is not known, hindering an estimation of year of introduction. These larger fish weighed approximately 1600 g (Figure 21).

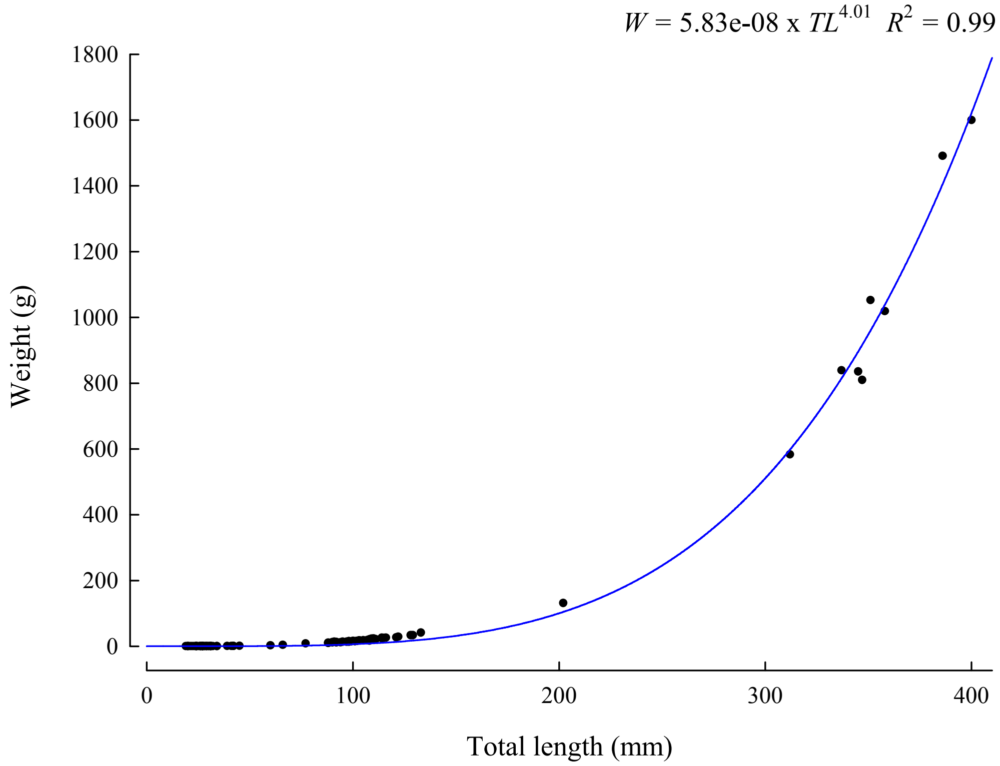


Figure 21 Relationship between the total length and wet weight of goldfish (*Carassius auratus*) captured in the Vasse River.

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 also contained diatoms, nematodes, anisopteran larvae, coleopteran larvae and dipteran larvae. Also consumed were mosquitofish, green algae and some terrestrial insects.

Kolmakov and 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 grew better than in controls. The process of cyanobacteria stimulation is not known, however the authors considered that passing through the goldfish guts 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 (S. Grigo, Department of Environment, Southwest Region Phytoplankton Ecology Unit, Vasse River sampling results 2003-2004).

The above findings of the diets of the goldfish in the Vasse River, together with the fact that they can stimulate significant growth in blue-green algae, and that the goldfish population in the Vasse River may be in its infancy and set to boom over the next few years, 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. Furthermore, the vigorous bottom sucking 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 that may coincide with the initial introduction of goldfish. An increase in algae also provides this feral species with an abundance of a food source that they can utilise from a very young age.

Feral goldfish also 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 also compete with native fishes for food and space and by growing to a much larger size than all but one of the south-west's native freshwater fishes, 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 also 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. It is recommended that a detailed dietary study of goldfish in the Vasse River be implemented and that it is based on both seasonal and ontogenetic changes in diet.

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 (e.g. Morgan 2003). 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).

The implications for the activation of cyanobacteria blooms after passing through fish digestive tracts are huge when considering not only the widespread distribution of goldfish in Western Australia, but that there are large numbers of other feral fishes that consume phytoplankton. Specifically, apart from populations of goldfish, feral populations of tilapia (*Oreochromis mossambicus*), one-spot livebearers (*Phalloceros caudimaculatus*), swordtails (*Xiphophorus helleri*) and carp have become established here (Morgan *et al*. in press), and as all are detritivores they may all have the ability to stimulate cyanobacteria growth. Furthermore, native species such as sea mullet and Swan River gobies are known to consume detritus and may also contribute to algal blooms. The control of such blooms may be aided with eradication programs of feral detritivorous fishes.

Summary and Recommendations

- The Vasse River catchment has been heavily cleared and its flow regime modified by drain construction and instream barriers. Much of the riparian zone is also relatively degraded.
- The lower reach between the Diversion Drain and the Old Butter Factory has essentially become an elongated reservoir due to the insertion of slot-boards and presence of a valve at the Diversion Drain and is the site of cyanobacteria blooms.
- The Vasse River houses seven native species of fishes, however, is dominated by the feral mosquitofish and also contains a feral population of goldfish found downstream of the Diversion Drain.
- Goldfish are known carriers of disease and impact on ecosystem structure and functioning, including enhancing algal blooms via their feeding behaviour.
- The goldfish population is likely to have been established relatively recently (~5 years) and, due to the numerical dominance of a cohort of juveniles, it is expected that the population will increase rapidly in coming years, should no management actions (i.e. eradication program) be undertaken.
- It is recommended that the lower Vasse River be returned to a more natural flow regime via the removal of the slot-boards at the Old Butter Factory and opening of the valve at the Diversion Drain for longer periods. The riparian re-vegetation program should be expanded.
- An ongoing goldfish eradication program, run initially over three years, should be implemented and should form the basis of a study examining their biology and ecological impact. Studies should include examining the extent to which the growth of the dominant cyanobacteria species in the Vasse River is stimulated after passing through goldfish digestive tracts.
- The eradication program should involve an annual intensive capture effort prior to the onset of the spawning period (i.e. September).
- Eradication efforts should focus on areas of high goldfish densities as outlined in this study i.e. upstream and downstream of the Old Butter Factory, upstream of the Strelley St and Bussell Hwy bridges.
- The eradication program should involve the use of gill net (large mesh width to prevent the capture of native freshwater species), seine nets and electrofishing.

- All goldfish captured should be retained for the above-mentioned biological and ecological studies.
- The success of the eradication program should be evaluated after three years by comparison of relative abundances of goldfish in the lower Vasse River at that time with the relative abundances documented in this study.
- An education program should be instigated detailing: the native and feral fishes found in the Vasse River; the problems associated with the release of aquarium fishes into wild aquatic systems; the goldfish eradication program. This should involve a poster being displayed at Rotary Park and brochures being produced which should be distributed by GeoCatch and the Department of Fisheries, Busselton.

Acknowledgements

This project would not have been possible without funding from Fishcare WA (Department of Fisheries WA) and support from the Geographe Catchment Council. We would like to thank Gilbert Stokman and Annaleisha Sullivan for initiating the project and generating public support for the project, including volunteers. The volunteers during sampling included Dane Hordacre, Michael Burgess (Department of Fisheries Busselton), John McKinney, Veronica Piper, Ric Scott and Sue Elsecot. Thanks also to the kind people that pointed out to the Department of Transport that our boat, which was pictured in the local rag, was unregistered, woops!

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