Assessment of the distribution and population viability of the Pearl Cichlid in the Swan River Catchment, Western Australia

Report to: Swan River Trust

Prepared by: Freshwater Fish Group & Fish Health Unit, Centre for Fish & Fisheries Research; Centre for Fish and Fisheries Research; Murdoch University

S Beatty, D Morgan, G Sarre,
A Cottingham, A Buckland

Centre for Fish & Fisheries Research
Murdoch University

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Authors:

S Beatty, D Morgan, G Sarre, A Cottingham, A Buckland
Centre for Fish & Fisheries Research Murdoch University

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Freshwater Fish Group & Fish Health Unit
Centre for Fish & Fisheries Research

Murdoch
UNIVERSITY

Summary and recommendations

The Pearl Cichlid *Geophagus brasiliensis* (which is native to eastern South America) was first reported in Bennett Brook in February 2006 by Ben de Haan (North Metro Catchment Group Inc.) who visually observed what he believed to be a cichlid species. The senior authors were notified and subsequently initially captured and identified the species in the system on 15th of February 2006. Subsequent monitoring programs have been periodically undertaken and confirmed that the species was self-maintaining and is able to tolerate high salinities. There is thus the potential for the species to invade many tributaries and the main channel of the region's largest river basin, the Swan River. However, little information existed on the biology and ecology of the species within Bennett Brook and this information is crucial in understanding its pattern of recruitment, ecological impact, and potential for control or eradication. The current study involved monthly sampling of fishes within Bennett Brook and Lanius Drain (a major storm water drain that flows into Bennett Brook) between January and June 2010. Numerous other sites within the Swan River catchment were also sampled to determine whether the species had spread to other sections of the river. The report provides information on the distribution, biology and ecology of the Pearl Cichlid.

Despite widespread sampling, the Pearl Cichlid was not recorded within the Swan River or any of the major tributaries near the established population within Bennett Brook. Within Bennett Brook and Lanius Drain the species was shown to be sympatric with three native freshwater fishes, one other introduced species, and two native and one introduced freshwater crayfish species. The population of Pearl Cichlid within the Bennett Brook system was found to have traits typical of an invasive, r-strategist species, and key findings included:

- The monthly presence of gravid, spawning and spent mature fish and consistent presence of new recruits (20-40 mm Total Length TL) suggested the species underwent a protracted breeding period (January to June 2010).
- However, no very small juveniles (<20 mm TL) were recorded from Lanius Drain or Bennett Brook, nor was there evidence of nesting and, as a downstream re-colonisation of breeding adults and larger new recruits was recorded monthly, this suggests successful breeding almost certainly only occurred within the Altone Park wetlands.
- The majority of the population matured at the end of their first year of life at an average size of ~91 and 82 mm TL for females and males, respectively, determined via logistic regression for the length at which 50% of males and females were found to be mature.
- A relatively high growth rate was recorded up to a maximum size of ~250 mm TL. Pearl Cichlids attained sizes larger than native freshwater fishes in the system by the end of their second year of life.

- The largest fish recorded were found to be in their fourth year of life, and these represented the oldest fish recorded during the study.
- Although previous limited data suggested considerable piscivory in larger individuals (n=2), stomach content analysis in the present study revealed their diet to be omnivorous; dominated by benthic food items including vegetation, invertebrates (adults and larvae) such as insects and decapods.

Together, the above traits would have allowed the species to rapidly establish in the Bennett Brook environment and would similarly allow it to colonise a number of other systems within this region should it be introduced or migrate to them.

A key finding of the current study is that the overwhelming evidence suggests that the smallest juveniles (new recruits) appear to be entering Bennett Brook via the Lanius Drain and that the wetlands in Altone Park that drain into Lanius Drain are the key spawning habitat for the species. It is unclear why this is the case but is probably due to the higher temperature regime in the lentic wetland compared to lotic downstream habitats. If this is the sole spawning habitat for the species in the system, the control or eradication of the species would be more feasible than if the species was reproducing within Bennett Brook. It is also noteworthy that a wide size range of fish moved downstream each month.

Key recommendations of the study include:

- Monthly sampling should continue until December 2011 in order to add to the data presented here that will provide a complete examination of the biology and ecology of the Pearl Cichlid within Bennett Brook (e.g. confirm overall breeding period) and monitor the prevailing environmental conditions within the Bennett Brook system.
- Altone Park wetlands should be sampled in summer and autumn 2010-2011 in order to confirm this as the breeding habitat of the species (e.g. by recording juvenile and larval fish and comparing with the results of the current study).
- The temperature tolerance of this species (including minimum temperatures required for breeding) should be determined to better identify conditions required for recruitment.
- Feasibility studies examining control options for the species be undertaken to re-visit the potential to either eradicate the Altone Park wetland population, or prevent the ongoing downstream movement of the species into Lanius Drain, Bennett Brook and potentially the Swan River.

Contents

Background

The Pearl Cichlid (also known as the Pearl Eartheater) *Geophagus brasiliensis* is a popular aquarium species due to its attractiveness and ease of maintaining in captivity. Native to the coastal drainages of eastern and southern Brazil and Uruguay, the species has been introduced into wild systems of the USA, Taiwan, Philippines and Australia where feral populations have become established (Axelrod 1993, Fuller *et al.* 1999, Liang *et al.* 2006, Fishbase 2010). Sightings of the Pearl Cichlid in Bennett Brook were first reported in February 2006 by Ben de Haan (North Metro Catchment Group Inc.) to the two senior authors who subsequently investigated, captured and confirmed the species identification to be *G. brasiliensis*. In December 2009, the species was reported by a member of the public in the Swan River near the confluence of Bennett Brook in Guildford (Fishmarket Reserve) (Figure 1). A survey was conducted by the Department of Fisheries and the authors (Murdoch University) who recorded the species in Altone Park Wetlands, Lanius Drain (downstream of Altone Park), and in Bennett Brook both upstream and downstream (as far as Grogan Swamp) of the confluence of the Drain. An additional survey was conducted in 2008 and this detected the species at an additional downstream site within Grogan Swamp (Figure 1). Although first reported in 2006, the species has anecdotally existed in the system for more than ten years (pers comm. W.A. Cichlid Society). Notably, the species was not recorded in a previous survey by Bamford *et al.* (1998).

The Pearl Cichlid has the potential to colonise both the Swan River Estuary and its major tributaries due to its flexible feeding mode (Lazzaro 1991), ability to exist in both lentic and lotic habitats (Mazzoni and Iglesias-Rios 2002) and high tolerance of environmental variables such as salinity (de Graaf and Coutes 2010). It has previously been shown to recruit successfully at salinities of up to 14 (Mazzoni & Inglesias-Rios 2002); salinities which occur on average for eight months in the upper section of the Swan River Estuary. Depending on its biology and ecology within these ecosystems, it has the potential to severely impact the aquatic ecosystems in this iconic catchment.

As typical of many feral species invasions, the habitat within Bennett Brook is highly degraded relative to its original condition with more than 50% of its catchment in the Gnangara Pine Plantation and Whiteman Park, and the remainder cleared for residential, rural and industrial purposes. It generally has a riparian vegetation condition classified as poor or very poor with permanent flow that contributes 1.8% of the total flow into the Swan River (Shepherd & Siemon 1999). It is likely that the rate of conditional change in Bennett Brook has been proportional to the rate of human activities in its catchment over the past ~100 years. However, many introductions of aquatic species have occurred recently; as has been demonstrated for other aquarium releases in south-western Australia (Morgan et al. 2004).

There is a need for a greater understanding of the invasiveness of this species and the ecological threat that it poses. This information can be generated by assessing Pearl Cichlid distribution, biology (including patterns of reproduction and growth rates) and ecology (via dietary analysis), leading to an indication of the overall potential impact of the species and the feasibility of strategic control programs.

Aims

Through intensive fish-outs during monthly sampling events, the study was designed to remove large numbers of the species from Bennett Brook and use these individuals in the analysis of their reproductive biology, growth rates and dietary composition in this system and compare to populations elsewhere, if available.

The project therefore aimed to reduce the abundance of the species (contributing to the recovery the aquatic ecosystem of Bennett Brook) while simultaneously gathering the necessary information to understand their viability and ecological impact on the freshwater systems in which they are currently established and also the estuarine ecosystem of the Swan River into which they may establish. This information is required for the possible development and implementation of a cost-effective strategic control program of the species to protect the broader Swan River ecosystem from invasion by this species.

The specific aims of this study were to:

(i) Map the distribution of the Pearl Cichlid in the Swan River and tributaries adjacent to the known established population in Bennett Brook.
(ii) Determine the biology and ecology of the species within Bennett Brook and any other detected populations: including growth rates, reproductive biology (patterns of recruitment, gonadal development, length/age at first maturity) and diet.
(iii) Identify likely current and future Pearl Cichlid population viability and ecological impacts.
(iv) Prioritise sites where control measures may be most effective in controlling the spread of this species.

Methods

Sampling protocol

In order to determine the biology and ecology of the Pearl Cichlid in the Bennett Brook system, monthly sampling occurred at two sites in Lanius Drain and one in Bennett Brook between January and June 2010 (Figures 1, 2). This sampling involved the use of a back-pack electrofisher in order to obtain large numbers of Pearl Cichlids and also to allow a qualitative (i.e. presence/absence) and quantitative (i.e. mean density by determining numbers of each species within the area of stream sampled) assessment of the freshwater fish community at each site on each occasion. Each fish captured was identified and all native fish returned immediately to the site of capture. All Pearl Cichlids were retained and immediately placed in an ice slurry for later processing in the laboratory. Three replicate areas of stream were sampled on each occasion at each site in order for the mean density of each species to be determined. The mean densities of all freshwater fishes and crayfishes recorded at each site in the Bennett Brook and Lanius Drain were determined on each sampling occasions using the equation $D = N/A$, where D = density of the species, N = number captured and A = area sampled (m^2). Physicochemical parameters of water quality (temperature (°C), pH, dissolved oxygen (% and ppm), NaCl concentration (ppt), total dissolved solids (ppt) and conductivity (µS/cm)) were measured using an Oakton™ PCD650 waterproof portable multimeter at three locations at both Lanius Drain (immediately below Lord St) and Bennett Brook (Valley Brook Rd) on each sampling occasion and a mean and standard error (SE) determined.

In order to determine the wider distribution of the Pearl Cichlid in the Swan River catchment, sampling occurred in the lower section of Helena River (~500 m upstream of the Swan River confluence) in February 2010. A comprehensive fish survey also recently occurred in the Ellen Brook and Brockman River (a total of 16 sites in November 2009 and February 2010) as part of another study (Beatty *et al*. 2010). Additionally, sampling for Pearl Cichlids was undertaken in April and May, 2010 at a total of twelve sites in the nearshore shallow waters of the upper Swan River Estuary adjacent to the Bennett Brook and Helena River confluences (Figure 3). Each of these latter sites were sampled using a 21.5 m seine net, which consisted of a 1.5 m wide bunt of 3 mm mesh and two 10 m long wings (each comprising 4 m of 3 mm mesh and 6 m of 9 mm mesh). This net, which swept an area of 116 m^2, was laid parallel to the bank and then hauled onto the shore. All fish captured were then identified to species and counted. In the case of large catches, i.e., >100 individuals of the same species, numbers were estimated. All native fish were then returned to the water alive. In the case that any exotic fish species were encountered, including Pearl Cichlids, an ice slurry was on hand for euthanising.

Salinity, dissolved oxygen and temperature were recorded in the mid water at three sites in each region using a YSI (Yellow Springs Instrument) meter (Model # 556 MPS) and mean estimates (± 1 S.E.) for each sampling occasion were calculated.

Distribution, population structure and recruitment

In order to determine the spatial and temporal pattern in the distribution and density of Pearl Cichlid in the Bennett Brook system, its mean density (±1SE) at each site in each month was plotted. All Pearl Cichlids retained were measured to the nearest 1 mm total length (TL, i.e. from tip of snout to rear of longest lobe of caudal fin) and standard length (SL, i.e. from tip of snout to rear end of the last vertebra (that is, it excludes the tail)). In order to determine whether there was a spatial difference in population structure within the Bennett Brook system (e.g. whether there were spatial patterns of juvenile fish abundance that may indicate key spawning sites), length-frequency histograms were plotted separately based on site of capture, i.e. within Lanius Drain above and below Lord St and the downstream site in Bennett Brook.

Pearl Cichlid (*Geophagus brasiliensis*)

Figure 1: Sampling areas in the current study in Bennett Brook and the Swan River. GoogleMaps.

Figure 2: Sampling in the Lanius drain above (top) and below (middle) Lord St and in Bennett Brook adjacent to Valley Brook Rd in April, 2010. N.B. note the barrier upstream in the top photo in Lanius Drain above Lord St.

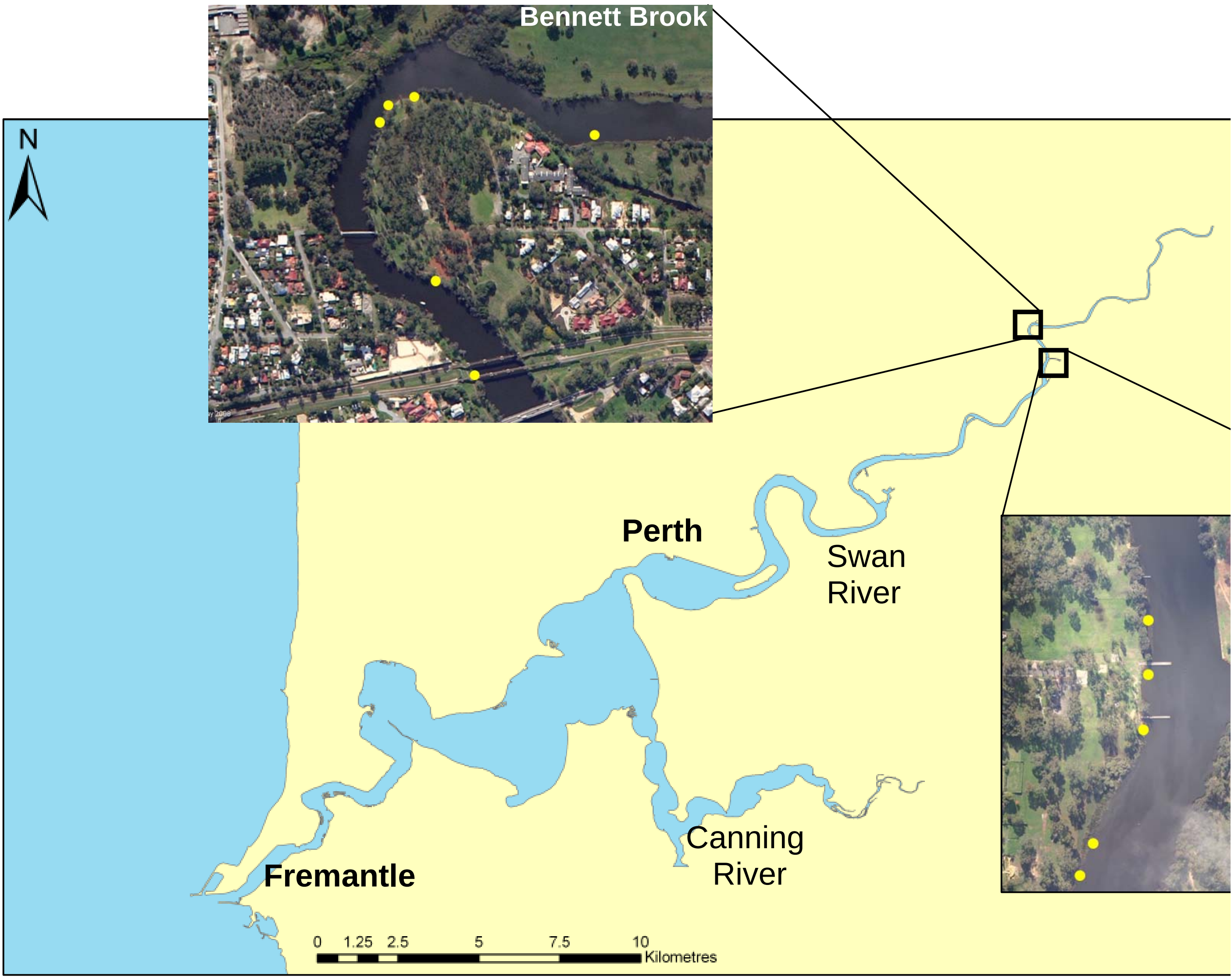

Figure 3: Sites sampled with (21 m seine net) in the Swan River at the confluence of Bennett Brook (top) and Helena River (bottom) in April and May 2010.

Reproductive biology

Subsamples of up to 75 Pearl Cichlids were dissected each month for analysis of reproductive development from the Bennett Brook system (including Lanius Drain). The sex of each fish was determined by removal and examination of the gonad under a dissecting microscope. Each gonad was initially macroscopically assigned to one of six developmental stages: I/II (virgin or maturing), III (developing), IV (developed), V (gravid), VI (spawning), VII (spent). A random sample of a range of female gonads stages were fixed in Bouin's solution, dehydrated in alcohol, and sectioned (at 6 µm) after being embedded in paraffin wax. These sections were examined microscopically to verify the macroscopically assigned stages. Gonad stages were then plotted over months for females and males to examine trends in reproductive development.

In order to provide information on the temporal pattern of Pearl Cichlid reproduction, the monthly gonadosomatic index (GSI) was determined for immature (stages I/II) and mature (stages III-VII) females and males using the formula GSI = $(W_1/W_2)\times100$, where W_1 = wet weight of the gonad, and W_2 = wet weight of the fish.

The length at first maturity was determined for female and male Pearl Cichlids in the Bennett Brook system. This was achieved by assigning maturity status, i.e. mature stages III-VII or immature stages I-II, to fishes in January to April (prior to and during peak spawning period, see results). Logistic regression analysis, using bootstrapping of 1000 random samples, was undertaken on the percentage of mature females and males in 5 mm TL increments. The logistic equation is:

$$P_L = \frac{1}{[1 + e^{-\ln 19(L-L50)/(L95-L50)}]}$$

where P_L is the proportion of Pearl Cichlids with mature gonads between January and April at TL interval *L*, and *L*50 and *L*95 are the lengths at which 50% and 95% of the population mature.

Growth

Fish used in the growth analysis were measured to the nearest 1 mm TL and standard length (SL) and weighed to the nearest 0.01 g. A length-weight relationship was produced via testing a number of models and fitting the one that provided the greatest R^2 value. For age and growth determination, the otoliths of a subsample of up to 112 fish per month were removed, immersed in glycerol and viewed through a dissecting microscope using reflected light. A seasonal climate in south-western Australia results in the otoliths of most freshwater fishes (both native and introduced) having clearly discernable annuli (translucent zones) laid down each year. To validate that these 'rings' are produced annually, marginal increments, i.e. the distance from the outer edge of the translucent zone to the outer edge of the otolith, were measured. For otoliths with only one translucent zone, the marginal increment was calculated as a percentage of the distance of the nucleus and the outer edge of the translucent zone. Marginal increments of otoliths with two or more translucent zones were calculated as the percentage distance between the outer edges of the two outer zones.

Although a protracted spawning period was recorded throughout the sampling period, the birth date was assumed to be January 1st; based on the prevalence of spent mature fish from this month onwards. This assigned birth date may be adjusted once a full year of data is collected.

Dietary analysis

Stomachs were removed from 30 individuals in both summer (January) and autumn (April 2010) and their contents examined under a dissecting microscope. Items were identified to the highest possible taxa and allocated to one of 14 prey categories. Diets were analysed using the frequency of occurrence and percentage overall volumetric contribution to the diets of each category. The frequency of occurrence is the proportion of stomachs that contained the prey item and the volumetric contribution is the proportion that each prey contributes to the overall stomach content of all fish or those in specified categories (Hynes 1950, Hyslop 1980). In order to determine whether there were seasonal or ontogenetic changes in dietary composition, these analyses occurred separately for season (summer and autumn) and three size classes (<50, 50-150, >150 mm TL) .

In order to determine the level of similarities among different size classes and seasons, the volumetric data were square-root transformed and a Bray Curtis similarity matrix constructed in the PRIMER v6 statistical package (Clarke and Gorley 2006). Non-metric multidimensional scaling (MDS) was used to create an ordination to display patterns in similarity between the three *a priori* designated size classes, i.e. <50 mm, 50-150 mm, >150 mm. The significance of differences in the dietary composition between the three size classes and two seasons was examined via constructing a ranked similarity matrix from the original similarity matrix and undertaking a two-way crossed analysis of similarity (ANOSIM) (Clarke and Gorley 2006). ANOSIM is a non-parametric test that utilises a permutation procedure. This calculates a test statistic, R, which is a measure of the average rank similarities of replicates within the *a priori* designated groups compared with the average rank similarity of all replicates among these groups. An R value of 0 indicates that there are no differences between *a priori* groups, i.e. season or size classes, and an R value of 1 indicates that within each *a priori* designated group, all replicates are more similar to each other than they are to any other replicate from a different group. The contribution of each prey item to the similarity within or dissimilarity among size classes or seasons was determined using SIMPER (PRIMER v6, Clarke and Gorley 2006).

Results and discussion

Physicochemical variables

The Pearl Cichlid is a tropical species and water temperatures within its native habitats range from 11-12^{o}C to 27-28^{o}C at the southern end of its distribution, to 30-37^{o}C in the Amazon River system (Rantin and Petersen 1985). Therefore, although one would expect it to favour the warmer conditions, it can also tolerate temperature regimes more typical of cooler (or Mediterranean) climatic regions. During the current study, temperature ranged from 29.3°C in January (Lanius Drain) to 13.8°C in June (Bennett Brook) and declined steadily from January to June 2010 within both Lanius Drain and Bennett Brook (Figure 4). The water temperature was invariably more than 2°C warmer (and up to 4.2°C in January) within the drain site *cf* with Bennett Brook. Therefore, the drain site and the generally warmer conditions provided by the lentic environments of the Altone Park wetlands immediately upstream would favour the species compared to the cooler conditions further downstream in Bennett Brook. The temperature tolerance of the species was investigated by Rantin and Petersen (1985) and they found the species actually had a relatively low thermal tolerance when compared to other species studied at that time. However, they found the lower lethal temperature limit varied depending on the temperature of acclimatisation and this ranged from 8°C (acclimatised at 12.5°C) to 17.8°C (when acclimatised at 32.5°C). Not unexpectedly, its upper thermal tolerance was relatively high ranging from 32.9°C (when acclimatised at 12.5°C) to 38.5°C (when acclimatised at 32.5°C). Although winter temperatures within the Bennett Brook system may fall to a level that results in some degree of seasonal mortality, this has not prevented the population from becoming established in Bennett Brook, however the population is possibly being maintained in Bennett Brook via transportation in the perennial flows in Lanius Drain from Altone Park.

Both sites were fresh throughout the sampling period with conductivity, TDS and NACL being similar between the Lanius Drain and Bennett Brook and there was a general declining trend between January and June probably due to rainfall reducing the effects of evaporative concentration of salts that would occur during dry periods (Figure 4). Dissolved oxygen was invariably greater in Lanius Drain than further downstream within Bennett Brook. Pearl Cichlids have a minimum mean dissolved oxygen saturation tolerance of just 10.6% (Webb 2008) and therefore would be well above this lower tolerance level at least within the drain and stream systems. The seasonal dissolved oxygen level of the Altone Park wetlands requires determination to enhance the understanding of the environmental tolerances of this population of Pearl Cichlid.

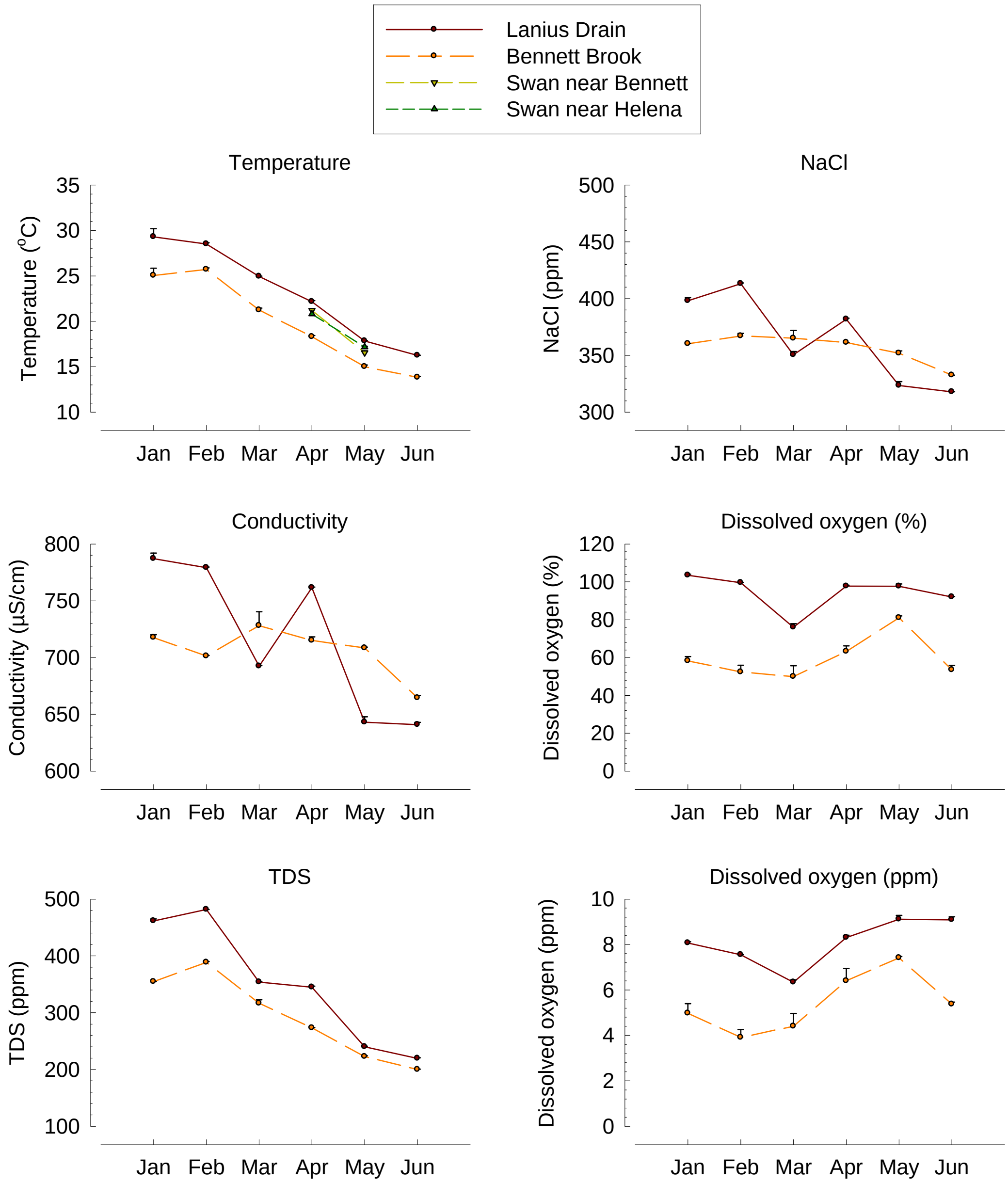

Figure 4: Environmental variables within Lanius Drain and Bennett Brook during the sampling period. Also shown is the temperature in the Swan River sites in April and May 2010.

Fish community structure

A total of 35645 fish and decapods were recorded from Bennett Brook between January and June 2010 (Table 1). Of these, 2097 were Pearl Cichlid or 9.5% of the 22139 fish captured. The dominant species in terms of abundance was another feral species the Eastern Mosquitofish with 19027 individuals of this species recorded (85.9% of fish). Therefore, native fishes contributed less than 5% of the fishes in this system.

In Lanius Drain, the Western Minnow *Galaxias occidentalis* was the only native fish recorded along with large numbers of the Pearl Cichlid, Eastern Mosquitofish, the eastern Australian Yabbie *Cherax destructor*, the endemic freshwater crayfish the Gilgie *Cherax quinquecarinatus* and a single Smooth Marron *Cherax cainii*. Below Lord St within Lanius Drain, the majority of Pearl Cichlids were captured along with Eastern Mosquitofish and three species of native freshwater fish including the Western Minnow, Western Pygmy Perch *Nannoperca vittata* and Nightfish *Bostockia porosa*. At that site the estuarine Swan River Goby *Pseudogobius olorum* was also found as well as the three above mentioned freshwater crayfishes and the South-west Freshwater Shrimp *Palaemonetes australis* (Table 1).

The downstream site in Bennett Brook housed the same fish species as the lower Lanius Drain site, however, contained far fewer Pearl Cichlids and a far greater number of Eastern Mosquitofish, Western Minnows and Western Pygmy Perch. The latter site also only housed one freshwater crayfish species, the Gilgie and large numbers of South-west Freshwater Shrimp (Table 1).

Therefore native freshwater fishes continue to be present in both Lanius Drain and Bennett Brook with their numbers being far less than that of the Peal Cichlid within Lanius Drain, but were more common than the Pearl Cichlid within Bennett Brook. The Eastern Mosquitofish was dominant in abundance at all sites. Despite being small (<60 mm), the North American Eastern Mosquitofish is another classic example of an r-strategist invasive species (see similar discussion on Pearl Cichlid in the Reproductive biology section below) and rapidly proliferates in new environments (being a live-bearer with a young age at first maturity). The species is extremely aggressive, often de-finning native fishes such as Western Pygmy Perch (Gill *et al.* 1999). The loss of all or parts of the caudal fin results in a reduced swimming ability that increases the vulnerability to attack and may result in death of the individual (Gill *et al.* 1999). The impact of Eastern Mosquitofish can be greatly reduced in most complex habitats that offer shelter for native fishes (Gill *et al.* 1999).

Sampling in the Swan River during April and May 2010 did not record the Pearl Cichlid and captures were dominated by shrimp, along with a only a few (<10 individuals per seine sample) estuarine species including Western Hardyhead *Leptatherina wallacei*, Swan River Goby, Black Bream *Acanthopagrus butcheri*, and Yellowtail Trumpeter *Amniataba caudavittata*.

Patterns in distribution and population structure of Pearl Cichlid

Densities of Pearl Cichlid were consistently much greater in the upstream tributary sites (Lanius Drain) compared with the site in Bennett Brook itself, suggesting that recruitment to the population was occurring from upstream of these systems (Figure 5). The March and April sampling event recorded much greater densities of Pearl Cichlid compared with January or February and both those samples occurred after the major rainfall event (and flooding) that occurred on March 23rd (Figure 5). It is likely that the rate of downstream colonisation from the Altone Park wetlands relates to level of flow and the flushing of fish downstream. Although the precise relationship between flow and downstream movement requires determination by more intensive monitoring of downstream recruitment and flow events, the perennial flow from Altone Park into Bennett Brook via Lanius Drain facilitates the continual recruitment of Pearl Cichlids into Bennett Brook (see following sections for justification).

A Pearl Cichlid being captured from Lanius Drain in May 2010

Table 1 Total captures of freshwater fish, estuarine fish, and freshwater decapods at the sites sampled between January and June 2010 in Lanius Drain and Bennett Brook. Species codes: Gb = *Geophagus brasiliensis*, Go = *Galaxias occidentalis*, Nv = *Nannoperca vittata*, Bp = *Bostockia porosa*, Gh = *Gambusia holbrooki*, Ca = *Carrasius auratus*, Po = *Pseudogobius olorum*, Cc = *Cherax cainii*, Cq = *Cherax quinquencarinatus*, Cd = *Cherax destructor*, Pa = *Palaemonetes australis.* Feral animals indicated in red.

	Freshwater fishes						Estuarine fishes	Freshwater decapods			
Site	Gb	Go	Nv	Bp	Gh	Ca	Po	Cc	Cq	Cd	Pa
Lanius Drain Upstream	912	124	0	0	2875	0	0	1	8	299	0
Lanius Drain Downstream	1040	33	59	34	4564	5	22	3	13	20	60
Bennett Brook	145	477	208	1	11588	6	46	0	42	0	13060
Total	**2097**	**634**	**267**	**35**	**19027**	**11**	**68**	**4**	**63**	**319**	**13120**

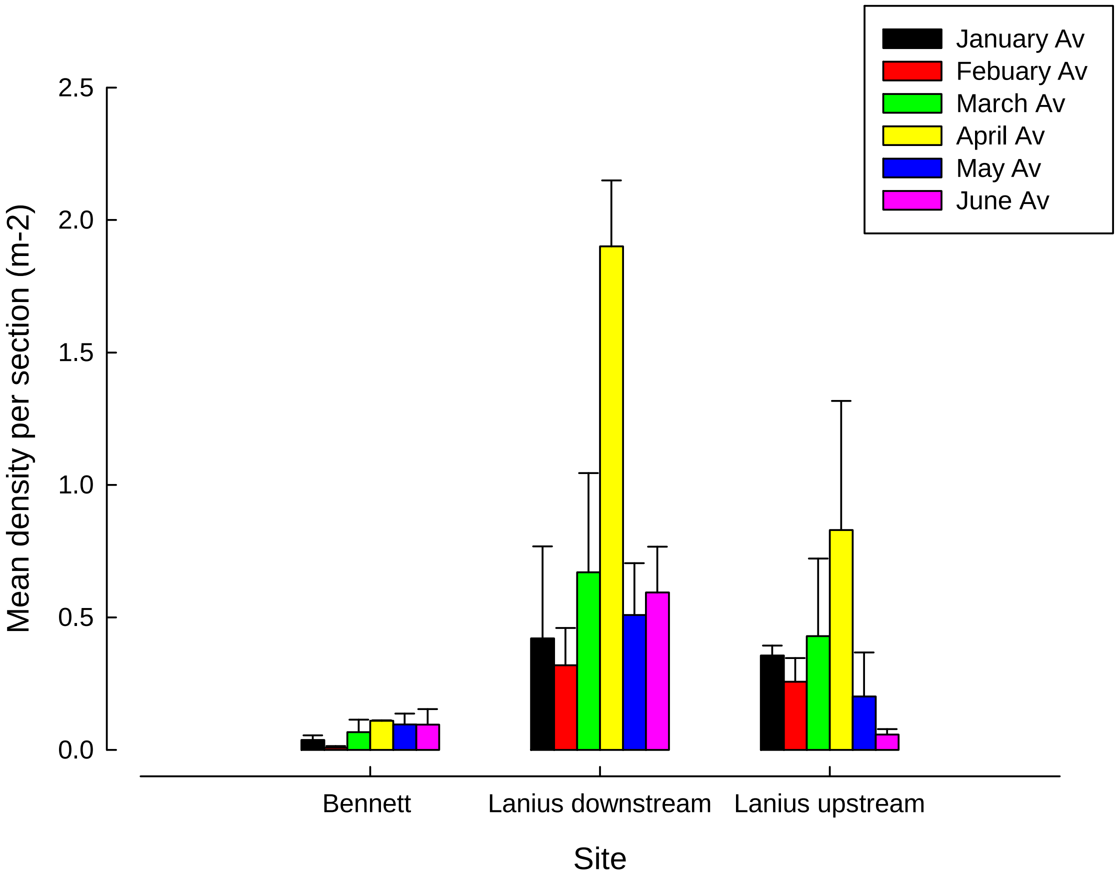

Figure 5: Mean (±1SE) densities of the Pearl Cichlid at sites within the Bennett Brook system sampled between January and June 2010.

The length-frequency distribution of Pearl Cichlids within the Bennett Brook system revealed a wide size range that represented a number of cohorts (see growth section below). Fish of lengths between 40-70 mm (0+ and 1+, see growth section) dominated the population in all months (see growth section for percentage of cohorts). New recruits (<40 mm TL) were present in all months (Figure 6) suggesting a protracted recruitment period of juveniles to the population that was occurring from at least January through to June. However, there were no small juveniles <20 mm TL that we would expect to be present should spawning and recruitment be occurring in these riverine systems. Therefore, as discussed below and in subsequent sections, the weight of evidence suggests that the Altone Park wetlands rather than Bennett Brook or Lanius Drain was the major (possibly only) spawning site. The greatest abundances of new recruits were detected in April, May and June suggesting that either spawning peaked prior to April (see Growth section for assigned birth date) and extended to at least May and/or an immigration recruitment of juveniles was occurring from the Altone Park wetlands during this period.

Intensive electrofishing, removing the vast majority of fish, occurred monthly in Lanius Drain both above and below Lord St. Although a variable recolonisation rate occurred between months (possibly related to the levels of flow), a wide size range of fish occurred in each month sampled and, therefore we did not record a clear reduction in Pearl Cichlid densities over the sampling period.

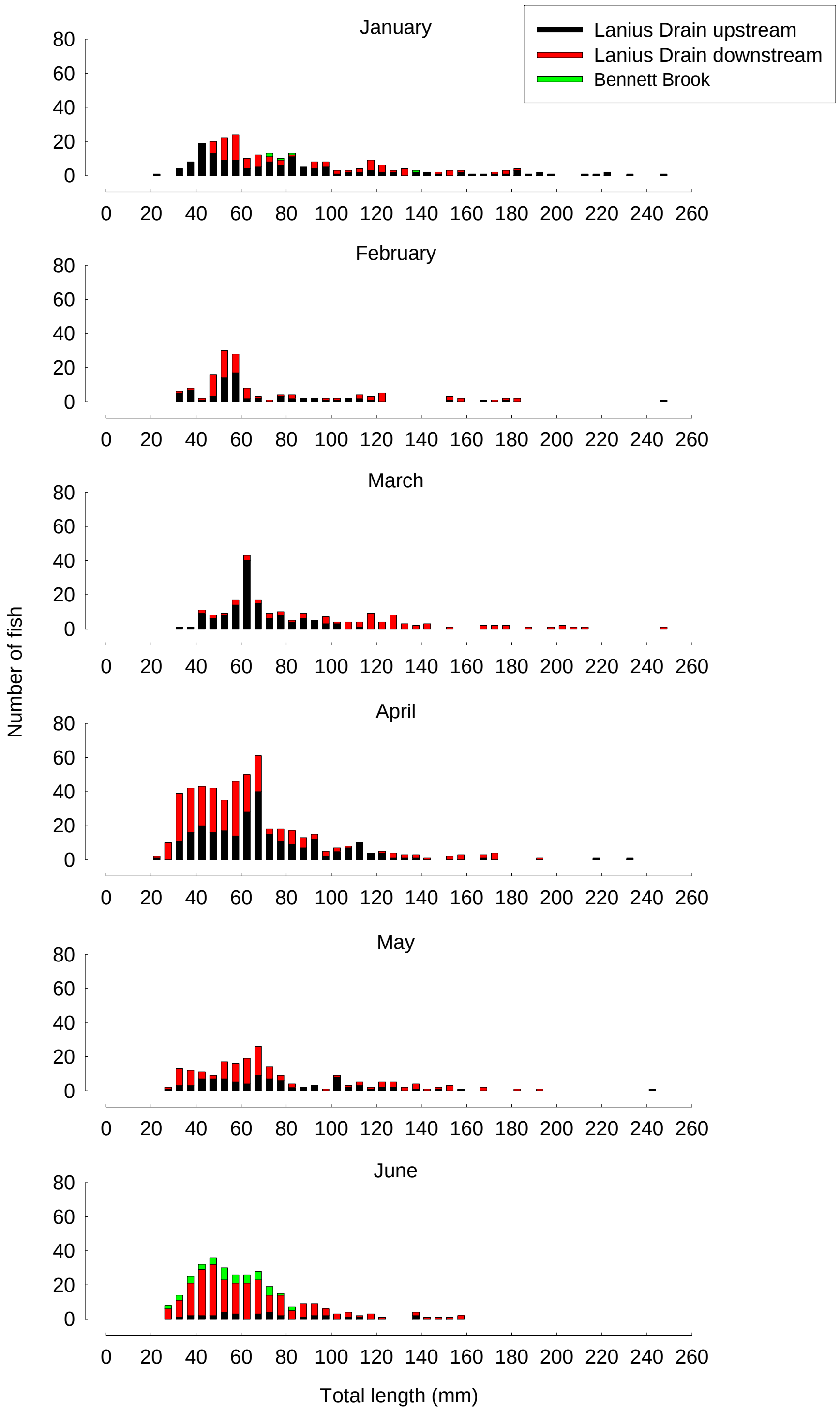

Figure 6: Length-frequency distributions of the Pearl Cichlids within Bennett Brook and Lanius Drain system between January and July 2010.

Recolonisation of Lanius Drain above Lord St by fish from further downstream would not be possible due to the considerable steps between each drain section. Recruitment therefore could not occur from downstream sources or within the drain itself and thus must have arisen from a downstream directional movement from the Altone Park wetlands in each month. In the site below Lord St, there is a similar downstream barrier (a waterfall) that would prevent upstream recolonisation following each electrofishing sampling and therefore, as with the drain site immediately upstream, monthly recolonisation and recruitment to the population appears much more likely to be from the Altone Park wetlands rather than *in situ* recruitment or upstream immigration from Bennett Brook itself.

Reproductive biology

Of the 371 fish that were dissected and that could be sexed, a sex ratio of 0.81F:1M was recorded. The temporal pattern in gonadal stages suggested that reproductively active (spawning stage VI and/or spent stage VII) fish were present throughout the sampling period (Figure 7). Females of spawning stage VI were present from January to May with reproductive activity appearing to reduce in June (Figure 7). It must be again noted that these gravid, spawning and spent fish were recruited from Altone Park wetlands each month where they probably underwent this gonadal development. Although the trends in gonadal development suggest that it is possible that spawning did occur within Lanius Drain or Bennett Brook, no evidence of subsequent successful recruitment within these systems was found during the current sampling such would have been evidenced by the presence of small juveniles <20 mm TL.

The temporal pattern of GSI of females also supports a protracted spawning period as a general decline was observed between April and June (Figure 8). Additional sampling over an entire year is required to determine when the onset of the breeding period occurs, however, given the presence of new recruits (<40 mm TL) in January (Figure 6), it is likely to be in late spring/early summer. The male GSI was less clear although it peaked in May before declining in June suggesting that spawning continued up until at least that period (Figure 8).

The lengths at which 50% and 95% of females and males matured in the Bennett Brook system were found to be 91.4 and 111.4 mm TL for females, and 81.9 and 118.3 mm TL for males, respectively (Figure 9). Based on the age and growth relationship (see Growth section below), the majority of the female and male population matured at the end of their first year of life.

This relatively rapid attainment of maturity and short generation time is typically a trait of what are known as r-strategists that are often rapid colonisers of new and variable habitats (Pianka 1970, Beatty *et al*. 2005). Furthermore, protracted breeding in more stable environments by r-strategists can also allow large recruitment potential (Pianka 1970). The degree of seasonality of reproduction in fishes in temperate environments is believed to be related mainly to variability in temperature, photoperiod and food availability (McKaye 1984, Payne 1986). *Geophagus brasiliensis* has previously been demonstrated to be phenotypically flexible in terms of its reproductive biology, being associated with the level of environmental stability (Mazzoni and Iglesias-Rios 2002). In South America, a protracted breeding period was recorded in the river population compared to a restricted spring/summer breeding period in a lagoon and the greater reproductive investment in the former population was attributed to that environment being more unstable environmentally and therefore the species was maximising the chances of a successful spawning event (Mazzoni and Iglesias-Rios 2002). This contrasts with the findings of the present study where the protracted breeding appears to occur in a lake system with a lack of (at least successful) breeding occurring in the stream. However, there may be numerous other contrasting habitat differences (such as river size, discharge regimes, climatic zone) between the systems in the current study and those within South America. Nonetheless, this reproductive variability is again typical of an r-strategist that will maximise its chances of population viability by altering its reproductive strategy.

There is some confusion as to the mode of reproduction of the Pearl Cichlid with Wimberger (1991) stating that the species is a substrate spawner with the breeding pair spawning on a cleaned (often elevated) surface and then the female guards and fans the eggs that hatch after five days. However, Linde *et al*. (2008) (citing Keenleyside 1991) state that the species is a mouthbrooder. As mentioned, no signs of nests were observed within Lanius Drain or Bennett Brook and although the mouths of all fish captured were examined, we did not observe this mouth-brooding behaviour in Bennett Brook during the current study.

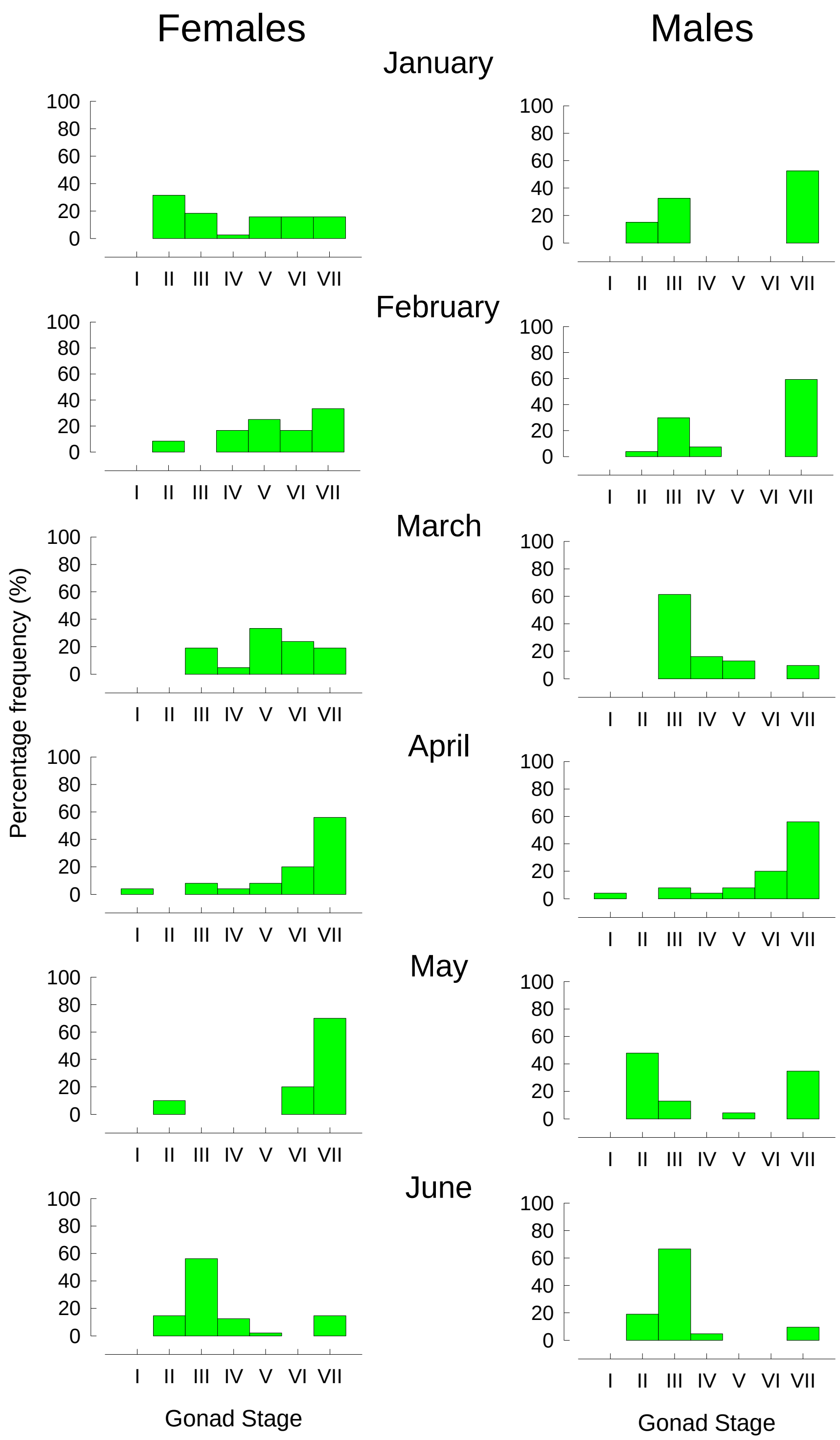

Figure 7: Temporal pattern of percentages gonadal stage frequency for female and male Pearl Cichlids during the study. N.B. for comparative purposes of spawning activity, fish <50 mm TL (that were invariably stage I) were excluded.

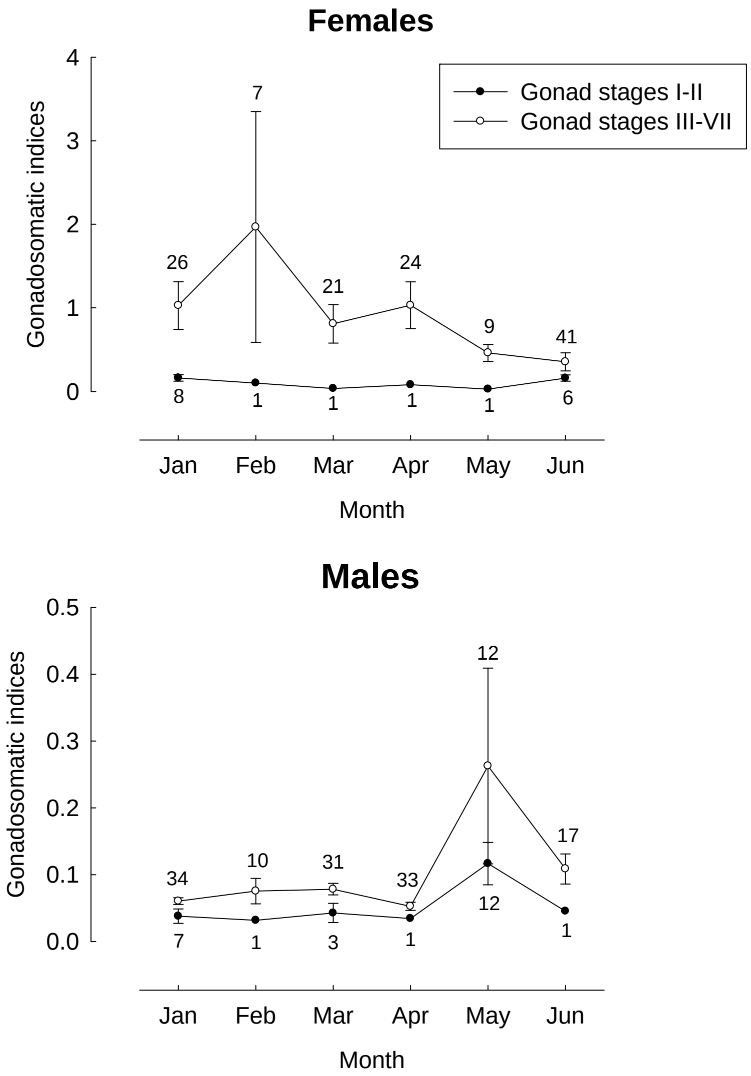

Figure 8: Gonadosomatic indices of female and male Pearl Cichlids in the Bennett Brook system between January and July 2010.

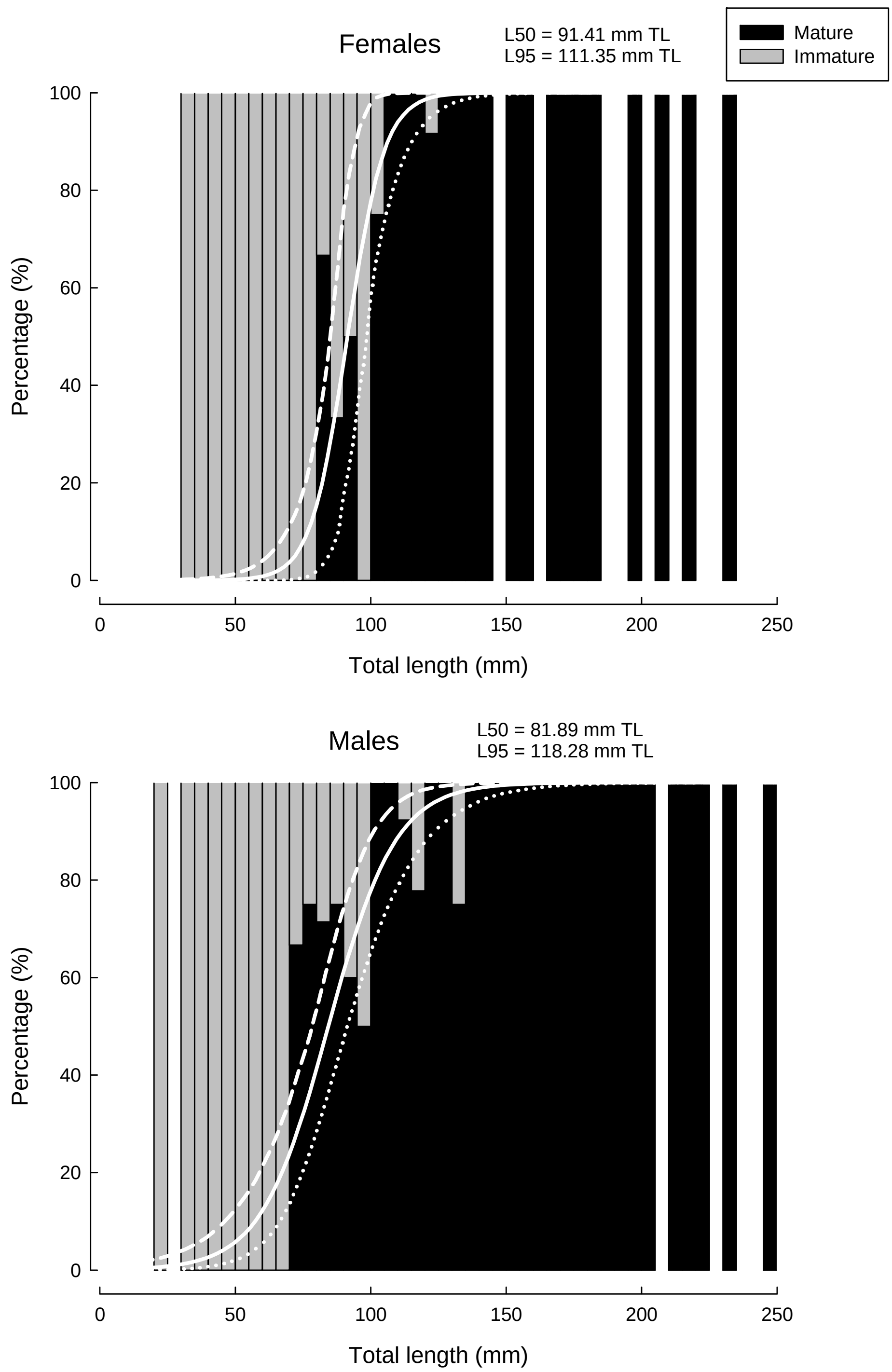

Figure 9: Percentage contributions of immature (i.e., gonad stages I/II) and maturing/mature (i.e., stages III–VII) female and male Pearl Cichlids, in sequential 2 mm TL intervals, during January to April. N.B., the logistic curve and accompanying 95% confidence limits are shown.

Growth

Of the 437 Pearl Cichlids that were aged during this study, approximately 23.1, 30.2, 29.7 and 16.2 % belonged to the 0+, 1+, 2+ and 3+ age classes, respectively. The von Bertalanffy growth curve parameters for both sexes, derived from length at age at capture data, which assumes a birth date of January 1st, are given in Table 2. The considerably higher growth coefficient (K) for the females, i.e. 0.1497 vs 0.0463, reflects the fact that growth for this sex approaches an asymptote earlier than the males, *cf* 350.64 vs 1024.32 mm (Table 2, Figure 10). The fairly unrealistic asymptotic length of the males may reflect the relative recent introduction of the species to the system, of which a similar scenario occurred with the introduction of Redfin Perch *Perca fluviatilis* into Big Brook Dam in the Warren River catchment of south-western Australia (Morgan *et al*. 2002). Alternatively, high mortality rate of larger fish may occur. Either of these scenarios may result in the 'straightening' (i.e. a reduced curvature) of the model (as only a small reduction in growth rate was recorded with age) and therefore the asymptote has occurred at a very large size.

The species has a reported maximum size of 280 mm TL although are commonly found to be ~90 mm TL in their natural range (Kullander 2003). Therefore, the length-frequency distribution of the population recorded in the current study is consistent with that size distribution, although the maximum size in this study was slightly less than previously recorded within its natural range (Figure 6). Although anecdotal evidence suggests that the population may have been introduced into Altone Park over a decade ago, the population within Bennett Brook may be short lived, with the oldest individuals only in their fourth year of life. Alternatively, it may suggest that the control efforts within the brook have been successful in eliminating individuals, particularly those of large total length which more readily succumb to electro-shocking due to a greater body surface area.

During this study, males were found to grow marginally faster than females, and attain, on average, lengths of 80.9, 123.6, 164.3 and 203.2 mm TL at the end of their 1st, 2nd, 3rd and 4th year of life. Females, on average, attained lengths of 82.1, 119.4, 151.6 and 179.2 mm TL at ages one, two, three and four. The wide size range of the various age classes is likely to be a reflection of the protracted spawning period for the population in Bennett Brook. For example, female fish in their fourth year of life range from between 135 and 230 mm TL, while males in this age class ranged from 150 to 245 mm TL. By their third year of life, Pearl Cichlids have attained lengths larger than any of the small native fishes that are endemic to the region (e.g. Pen & Potter 1990, 1991b, 1991c, Morgan *et al.* 1998, 2000).

Table 2 von Bertalanffy growth curve parameters for Pearl Cichlid.

Sex	L_∞	K	t_0
Females	350.64	0.1497	-0.781
Males	1024.32	0.0463	-0.778

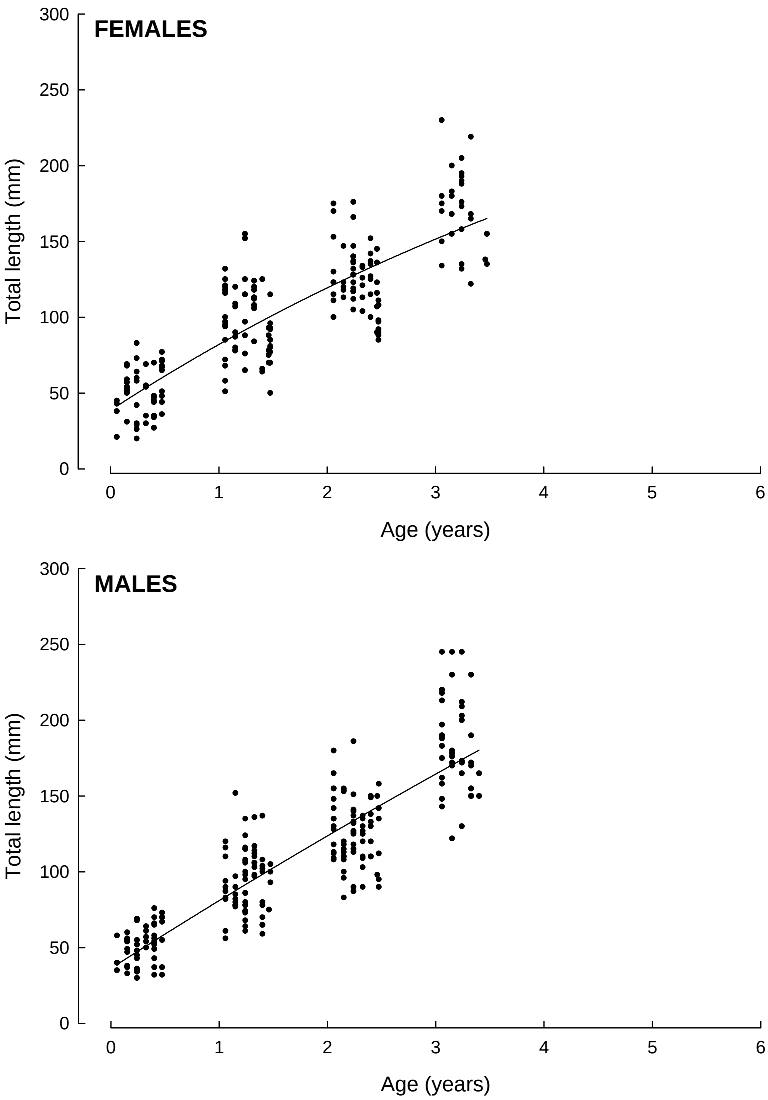

Figure 10: von Bertalanffy growth curves for female and male Pearl Cichlids in the Bennett Brook system.

Dietary analysis

Vegetation and detrital material generally dominated the diet in terms of frequency of occurrence (e.g. found in 100% of guts in January and >58% of the guts of all three size categories in April) (Tables 3A, B). Volumetrically, vegetation and detrital material was more dominant in the diets of fish in January (contributing 85, 78 and 67% of the overall volume of the <50 mm, 50-150 mm and >150 mm TL fish, respectively) compared to April (contributing to 13, 47 and 41% of the overall volume of the <50 mm, 50-150 mm and >150 mm TL fish, respectively) (Tables 3A, B). Chironomid larvae and coleopteran larvae and adults were also common in all size categories in January with terrestrial insects also contributing to the diets of larger fish (>50 mm TL) in that month. Freshwater crayfish (the native Gilgie) was also recorded in fish >150 mm in April (Table 3A). In April, chironomid larvae, odonatan larvae and coleopteran larvae were present in all size categories with coleopteran adults and freshwater crayfish (both the native Gilgie and introduced Yabbie) only being found in the two larger size categories of fish (Table 3B). Cladocerans and the freshwater limpet Ancylidae also contributed considerably to the <50 mm fish in April (Table 3B).

ANOSIM revealed a significant difference in the overall diets between summer and autumn (Global R=0.358, p=0.001). SIMPER analysis revealed that much of this difference (29%) was due to more vegetation/detritus in the January *cf* April guts and 17% of the difference due to greater volume of chironomid larve in the April *cf* January guts. The MDS ordination plot suggested an ontogenetic shift in dietary composition (Figure 11) and an overall slight but significant difference between size categories was confirmed by ANOSIM (Global R=0.191, p=0.001). Pair-wise tests revealed significant differences between the diets of the <50 mm fish and the larger two categories; however no difference between those larger groups (Table 4).

Table 3A Percentage contribution (% volume) and percentage occurrence of the different food items in the stomachs of Pearl Cichlid in the Bennett Brook system in January 2010.

	< 50 mm (n=9)		50-150 mm (n=13)		>150 mm (n=8)	
Prey Type	% volume (±1S.E.)	% occurrence	% volume (±1S.E.)	% occurrence	% volume (±1S.E.)	% occurrence
Teleost (*G. brasil*)						
Trichoptera			**1.76 (6.79)**	**15.4**		
Odonata larvae	**1.00 (3.89)**	**11.1**				
Arachnida	**1.71 (4.49)**	**22.2**				
Chironomidae (larvae)	**3.57 (9.92)**	**33.3**	**1.89 (6.35)**	**23.1**	**0.57 (3.13)**	**12.5**
Culicidae						
Coleoptera (larvae)	**3.71 (5.98)**	**44.4**	**1.76 (7.84)**	**15.4**	**4.32 (15.58)**	**25.0**
Coleoptera (adult)	**0.43 (1.67)**	**11.1**	**4.46 (9.40)**	**46.2**	**5.80 (16.58)**	**37.5**
Terrestrial insect			**11.42 (39.09)**	**30.8**	**7.95 (29.03)**	**25.0**
Parastacidae					**12.27 (67.5)**	**12.5**
Ostracoda	**2.54 (3.51)**	**77.8**	**0.28 (1.21)**	**15.4**	**1.70 (6.16)**	**25.0**
Cladocera	**2.40 (3.77)**	**66.7**	**0.12 (0.69)**	**7.7**	**0.00**	**0.0**
Ancylidae						
Vegetation/detritus	**84.63 (46.69)**	**100.0**	**78.31 (46.27)**	**100.0**	**67.39 (88.20)**	**100.0**

Table 3B Percentage contribution (% volume) and percentage occurrence of the different food items in the stomachs of Pearl Cichlid in the Bennett Brook system in April 2010.

	< 50 mm (n=12)		50-150 mm (n=11)		>150 mm (n=7)	
Prey Type	% volume (±1S.E.)	% occurrence	% volume (±1S.E.)	% occurrence	% volume (±1S.E.)	% occurrence
Teleost (*G. brasil*)					**2.78 (12.60)**	**14.3**
Trichoptera					**3.33 (15.12)**	**14.3**
Odonata larvae	**5.71 (13.48)**	**16.7**	**8.50 (18.56)**	**27.3**	**1.11 (5.04)**	
Arachnida						
Chironomidae (larvae)	**31.71 (32.51)**	**91.7**	**22.13 (26.43)**	**72.7**	**7.36 (15.13)**	**28.6**
Culicidae			**7.50 (27.27)**	**9.1**		
Coleoptera (larvae)	**5.00 (11.94)**	**16.7**	**2.25 (8.18)**	**9.1**	**4.17 (15.12)**	**28.6**
Coleoptera (adult)			**5.00 (18.18)**	**9.1**	**14.44 (39.90)**	**42.9**
Terrestrial insect						
Parastacidae			**4.00 (14.54)**	**9.1**	**24.17 (81.33)**	**28.6**
Ostracoda	**2.76 (5.64)**	**33.3**	**3.75 (5.05)**	**45.5**	**1.81 (4.13)**	**28.6**
Cladocera	**21.43 (36.36)**	**33.3**				
Ancylidae	**20.24 (29.63)**	**41.7**				
Vegetation/detritus	**13.14 (15.91)**	**58.3**	**46.88 (42.38)**	**90.9**	**40.83 (51.86)**	**85.7**

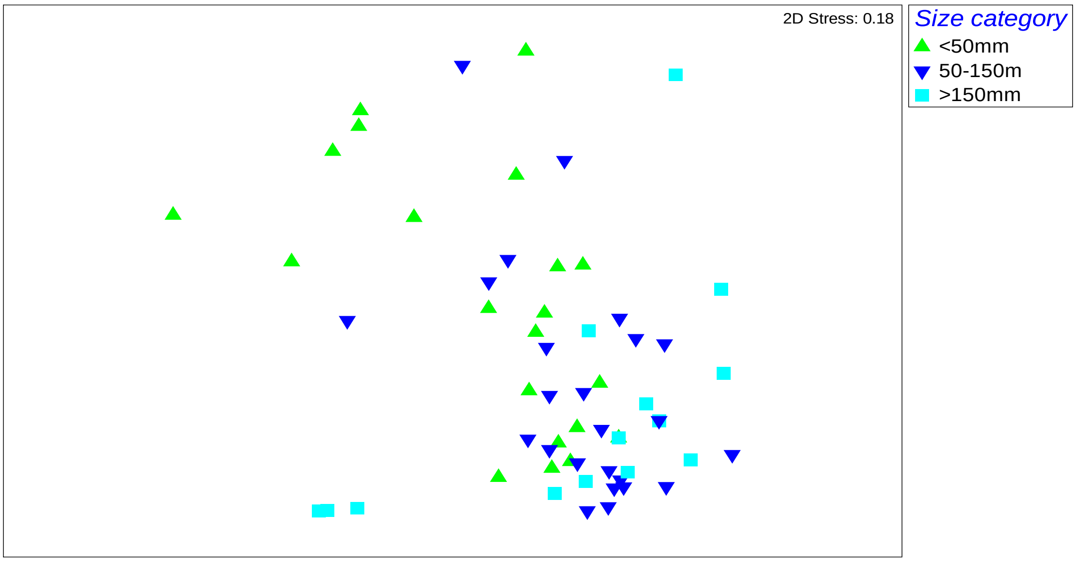

Figure 11: Multidimensional scaling (MDS) ordination of the similarity matrix of dietary composition (from the % volume data) of the different size categories of Pearl Cichlid from Bennett Brook.

Table 4 *R* values for two-way crossed analysis of similarities (ANOSIM) of dietary composition (calculated from % points) of the different dietary data of Pearl Cichlid from different size classes in Bennett Brook. * indicates that *R* value is significant at $P < 0.05$.

Size category (TL)	<50 mm	50-150 mm	>150 mm
<50 mm	-		
50-150 mm	0.208*	-	
>150 mm	0.347*	0.068	-

This benthic dwelling species is well known to have a broad omnivorous diet including detritus, algae, other vegetation, aquatic insects, zooplankton and fish (Arscifa *et al*. 1988, Romanini 1989, Arcifa and Meschiatti 1993, Moraes *et al*. 2004). As its 'eartheater' name suggests, the bottom feeding habitat means it has commonly been shown to consume sediment, detritus and benthic organisms (Arcifa and Meschiatti 1993).

The shift in diet with size revealed in the current study is consistent with that reported in Marcos *et al*. (2004) who reported that smaller (20-60 mm TL) Pearl Cichlids consumed smaller items including parts of arthropods, dipteran larvae and sediments whereas larger individuals consumed larger prey items such as Odonata, Trichoptera and Gastropoda. Lazzaro (1991) also found ontogenetic shifts in the omnivorous diet with fish <30 mm being visual feeders (consuming mobile prey such as copepods) while fish >40 mm had a more diversified diet utilising a pump-filter feeding mode (that effectively sifts through the sediment). However, the variability in the diet of the species means that an ontogenetic shift may not necessarily be observed, with diets of small and large Pearl Cichlid being similar, as has previously been recorded in a Brazilian reservoir (Arcifa *et al*. 1988, Arcifa and Meschiatti 1993).

This broad, adaptable diet suggests that the species may have a considerable impact on the structure and function of the Bennett Brook ecosystem and others it may colonise; including the Swan River Estuary. Being an omnivorous (mostly) benthic consumer, it consumes items from multiple trophic levels within the ecosystem and therefore predicting impacts based on trophic cascade theory is very difficult as it may de-couple these relationships. For example, it may be predicted that upon introduction of a species that consumes primarily herbivorous invertebrates (e.g. gastropods) that algal or macrophyte growth within that system may increase. However, this species also consumes benthic vegetation which makes such predictions of ecosystem change much more complex.

Interestingly, within a Brazilian River in its native range, the Pearl Cichlid competes with an introduced tilapia species *Oreochromis niloticus* and the relative abundance of the invasive species was positively associated with degraded (polluted) habitats whereas Pearl Cichlid abundance was negatively associated with such pollution (Linde *et al*. 2008). This highlights the propensity of invasive species to thrive in altered habitats outside its native range compared to within its native range where more unaltered natural habitats are favoured (Marvier *et al*. 2004). Therefore, maintaining undisturbed habitats and preventing habitat fragmentation is a cost-effective way of reducing risks of establishment and impacts of invasive species in general (Marvier *et al*. 2004).

Conclusions and recommendations

The current study represents the most comprehensive investigation of the distribution, biology and ecology of the introduced Pearl Cichlid within the Swan River catchment. The species was shown to reproduce at the end of its first year of life, has a very protracted spawning period, considerable growth rate and omnivorous diet. All of these characteristics have facilitated this introduced fish becoming established within the Bennett Brook system. These traits would likely have led to it having had a considerable impact on the pre-existing ecosystem in Bennett Brook and also potentially impacting the Swan River Estuary or other tributaries should it become established.

A key finding of the current study is that the overwhelming evidence suggests that the large majority of fishes in Bennett Brook are recruiting from the Altone Park wetlands via the perennial flows in Lanius Drain. This was supported by the complete lack of juvenile fish <20 mm TL being found in the Lanius Drain and Bennett Brook, much higher densities in the Lanius Drain *cf* Bennett Brook, and the large, relatively consistent monthly downstream (noting that upstream colonisation is prevented by instream barriers) recolonisation of the Lanius Drain from the Altone Park wetlands. Due to this downstream recolonisation, the current study did not result in a sustained reduction in the density of the species within Lanius Drain or Bennett Brook.

Although known to favour relatively warm environments, it can tolerate relatively low temperatures, allowing it to become established in regions such as south-western Australia and its successful establishment following introduction within the Bennett Brook system is therefore not surprising. The species is also known to have a relatively broad salinity tolerance (de Graaf and Coutts 2010) and this would potentially allow it to move throughout the upper Swan River and even breed within the system for a large part of the year. However, although a few individuals have previously been reported near the Bennett Brook confluence, sampling in the current study, along with numerous previous studies by the Centre for Fish and Fisheries Research (Murdoch University) throughout the Estuary, did not record the species within the Swan River or any of the major tributaries near the established population in Bennett Brook.

Management options

The future eradication of the Pearl Cichlid from the system would be difficult yet is a highly desirable ecological outcome as this would limit the risk of establishment of the species in the Swan River or other tributaries. The fact that we now have strong evidence to suggest that recruitment is largely confined to the Altone Park wetlands, makes eradication of the species possible, although still extremely difficult given the size of that groundwater maintained waterbody.

Another management option that requires more serious consideration is the design and construction of a purpose built fish trap to prevent the downstream colonization of the species from the Altone Park wetland. This also has its own challenges (namely ongoing removal of debris and possibly fish to prevent flooding), however, may be a feasible option should adequate resources be available.

A further option is to undertake ongoing (possibly annual) monitoring of the Swan River adjacent to Bennett Brook and nearby tributaries as undertaken in the current study in order to detect whether the species colonises other ecosystems in the future. Given that the species has anecdotally existed in the Bennett Brook system for upwards of 10 years, it may not become established outside this system. Although a few small Pearl Cichlids have previously been recorded by the public within the Swan River near the confluence of Bennett Brook, it is possible that despite the conditions in the Swan River being adequate to allow the species to survive, the majority of individuals that have reached that point may have been unwilling to exit the fresh water of Bennett Brook or are quickly predated on by estuarine fishes and/or birds. However, unless there is another environmental tolerance of the Pearl Cichlid that is actually exceeded in the Swan River (possibly temperature), its eventual colonisation into other systems is inevitable.

Key recommendations:

- Monthly sampling should continue until December 2010 in order to add to the data presented here that will provide a complete examination of the biology and ecology of the Pearl Cichlid within Bennett Brook (e.g. confirm overall breeding period) and monitor the prevailing environmental conditions within the Bennett Brook system.
- Altone Park wetlands should be sampled in summer and autumn 2010-2011 in order to confirm this as the breeding habitat of the species (e.g. by recording juvenile and larval fish and by making comparisons with the results of the current study).
- The temperature tolerance of this species (including minimum temperatures required for breeding) should be determined to better identify conditions required for recruitment.
- Feasibility studies examining control options for the species be undertaken to re-visit the potential to either eradicate the Altone Park wetland population, or prevent the ongoing downstream movement of the species into Lanius Drain, Bennett Brook and potentially the Swan River.

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