Inland Waters & Catchment Ecology

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2011 baseline survey of the fish assemblage of Warriparinga Wetland and the adjacent Sturt River- implications for native and invasive fish species management

Leigh Thwaites and Josh Fredberg

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January 2012

A summary report for the Marion City Council

Government of South Australia

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SUMMARY

Warriparinga Wetland is an artificial or constructed wetland located in a 3.5 ha reserve on the corner of Sturt and Marion Roads, Bedford Park, South Australia. At present, the wetland's primary function is to treat storm water from the Sturt River but it also has aesthetic, cultural and community values. An intent of the Warriparinga Wetland management plan is to create a self sustaining native ecosystem, supporting a diverse range of aquatic and terrestrial native flora and fauna. A key threatening process to the establishment of healthy native fish populations is the presence of invasive species, such as redfin perch, gambusia and common carp. In an attempt to prevent these species dominating the wetland's fish assemblage, native fish were introduced in the early stages of the wetlands development. However, recent surveys and initial site inspections indicate that common carp, redfin perch and gambusia have invaded the wetland. With these species threatening the function of the Warriparinga Wetland, the Marion City Council engaged SARDI Aquatic Sciences to assess the resident fish assemblage and to develop preliminary management recommendations in regards to the control of invasive species and the ongoing management of native fish stocks. The results of the survey indicate that Warriparinga Wetland is dominated by two invasive species with a total of 70 redfin perch and 2 common carp captured across all four ponds. Only one native species, common galaxias, was captured in low abundance (n=2). While no gambusia were captured in nets or traps during the survey, this species was visually observed within the wetland. In contrast, the assemblage of the adjacent Sturt River was dominated by common galaxias with a total of 83 captured. Invasive species were in low abundance with only 2 redfin perch and 11 gambusia captured. The presence of invasive species within Warriparinga Wetland is likely to cause detrimental impacts including a decline in native species recruitment and survival and a reduction in the effectiveness of the stormwater treatment process. In this regard, it is important to consider the most cost effective control/eradication/exclusion strategies that align with existing and future management objectives of the invaded system. However, given the multifaceted intent of the wetland (stormwater treatment/biodiversity), invasive species control/management will represent a difficult challenge and will first require prioritisation of the systems primary objective.

BACKGROUND

Warriparinga Wetland is an artificial or constructed wetland designed to take seasonal stormwater overflows from the adjacent Sturt River. These overflows are treated via passage through and retention within the vegetated wetland ponds using natural processes to improve water quality prior to its return into the Sturt River and subsequent discharge to sea at the Patawalonga Creek outlet, Glenelg (WWMMP 2011). While constructed wetlands form part of Marion City Councils stormwater management infrastructure they are also intended to provide a broad range of environmental, cultural and aesthetic outcomes including aquifer recharge, stormwater reuse, re-establishment of native flora and fauna, enhancement of landscape and community amenity and capacity building opportunities which involve passive and active recreation, education and learning (WWMMP 2011). Warriparinga Wetland and its surrounding parklands also represent an important area for its traditional owners, the Kaurna people, and were once used for celebration and ritual. Archaeological evidence suggests the area was inhabited more or less continuously by the Kaurna people prior to European settlement. In recognition, the Living Kaurna Cultural Centre and interpretative trail have been established adjacent to the Warriparinga Wetland (WWMMP 2011).

An intent of the Warriparinga Wetland management plan is to create a self sustaining native ecosystem, supporting a diverse range of aquatic and terrestrial native flora and fauna. In this regard, the wetland and surrounding parklands are being rehabilitated using indigenous species. The primary aim is to establish a revegetated landscape similar to the original Grey Box (*Eucalyptus microcarpa*) woodland of the Adelaide plains (WWMMP 2011).

A key threatening process to the establishment of healthy native fish populations within Warriparinga Wetland is the presence of introduced redfin perch (*Perca fluviatilis*), eastern gambusia (*Gambusia holbrooki*) and common carp (*Cyprinus carpio*) (see McNeil *et al*. 2011). In an attempt to prevent these species dominating the wetlands fish assemblage, native fish were introduced in the early stages of the wetlands development (WWMMP 2011). The introduced native species were:

- black bream (*Acanthopagrus butcheri*),
- common galaxias (*Galaxias maculatus*),

- small-mouthed hardyhead (*Atherinosoma microstoma*),
- congolli (*Pseudaphritis urvillii*),
- big-headed or flat-headed gudgeon (*Philypnodon grandiceps*),
- blue-spot goby (*Psuedogobius olorum*), and
- bridled goby (*Amoya bifrenatus*).

A recent survey commissioned by the Adelaide and Mount Lofty Ranges Natural Resource Management Board (AMLRNRMB) indicated a moderate to high abundance of common galaxias and a moderate abundance of blue-spot gobies (McNeil *et al*. 2011). While this finding resulted in a relatively high score for native fish values, the authors also reported a high abundance of redfin, gambusia and common carp. Due to the dominance of these invasive species and the associated impacts, McNeil *et al*. (2011) scored the wetland poorly in terms of fish health and recommended that invasive species control be a key management objective. Indeed, the presence of these invasive species threatens several of the wetlands key service criteria, including quality, effectiveness and condition e.g. water, soil and native biota (WWMMP 2011), and may represent a severe threat to the survival of stocked native species. Given the multifaceted intent of the wetland (stormwater treatment/biodiversity), invasive species management may represent a difficult challenge that will first require prioritisation of the systems primary objective.

The Marion City Council has responsibility for the ongoing management and maintenance of the Warriparinga Wetland. With invasive species threatening the function and ecological objectives of the Warriparinga Wetland, the Council engaged SARDI Aquatic Sciences to assess the resident fish assemblage and to develop preliminary management recommendations in regards to the control of invasive species and the ongoing management of native fish stocks. Specifically, the objectives of this study were to:

- develop and conduct a baseline survey of the resident fish assemblage of both the Warriparinga Wetland and the adjacent Sturt River, and
- provide a brief report outlining the resident fish assemblage and preliminary recommendations regarding the management of invasive and native species.

METHODS

Site description

Warriparinga Wetland is a constructed wetland located in a 3.5 hectare reserve on the corner of Sturt and Marion Roads, Bedford Park, South Australia (35^{o}1.136'S; 138^{o}33.633'E) (Figure 1). The wetland comprises four vegetated ponds designed to intercept and treat seasonal stormwater overflows from the adjacent Sturt River. Intercepted stormwater is treated during passage and retention via natural processes before being returned to the Sturt River and discharged to sea at the Patawalonga Creek outlet, Glenelg, South Australia. The ponds have a depth ≤ 3 m and varying side slopes up to a maximum of 1V:6H. The ponds are able to hold 22,650 m^3 of water when full. The pond arrangement permits linear flow through the wetland from inlet to outlet without any possibility of short circuiting. The pond arrangement and bathymetry provides for distinct inlet, dense emergent macrophyte beds between each pond and open water zones within the system. Emergent macrophytes have also colonised large areas of the shallow littoral zone fringing each pond. Collectively, macrophyte beds occupy approximately 20-40% of the total pond area (WWMMP 2011).

Figure 1. Google earth image of Warriparinga Wetland showing the four ponds and the adjacent Sturt River

Water quality

Dissolved oxygen, conductivity, pH, and temperature data was collected on the first day of sampling (27th June, 2011) from the surface at a central location within each of the four ponds and from within the Sturt River using a TPS 90-FLT portable water quality logger (TPS Pty Ltd, Springwood, Brisbane, Australia).

Fish survey

To assess the Warriparinga Wetland fish assemblage, sampling was conducted in each of the four ponds and the adjacent Sturt River from 27th to 29th June, 2011. In each pond, two fyke nets (10 mm stretched mesh, 5 m leader, 3 m funnel, 7 support rings and 3 chambers), one multi-panel gill net (15 m total length, comprising 3 × 5 m panels of 3″, 4″ and 5″ mesh each) and two box traps were set. Five fyke nets and five box traps were set in the adjacent Sturt River. Nets and traps were set and retrieved mid-morning over three consecutive days (two overnight sets of 24 h). In addition, backpack electrofishing (Smith Root® LR24; 150-200V, 60-120Hz, 20% duty cycle using pulsed direct current) was conducted in the inlet pond of the wetland (Pond 1; Figure 1) and within the Sturt River on 29th June. Length (Total Length (TL) mm) and weight (g) data was collected from all fish immediately after capture. Invasive species were euthanized prior to processing and all native fish were released at their capture location after processing.

RESULTS

Water quality

Water quality within Warriparinga Wetland and the Sturt River during the time of the survey was well within acceptable levels for both native and invasive fish spawning, recruitment and survival (Table 1).

Table 1. Water quality parameters for each of the four Warriparinga Wetland ponds and the Sturt River

Sample Area	Dissolved Oxygen (ppm)	Conductivity (µs.cm^{-1})	pH
Pond 1	10.68	1257	7.27
Pond 2	9.24	1216	7.12
Pond 3	8.91	1205	7.18
Pond 4	8.14	1192	7.64
Sturt River	7.26	660	7.76

Fish survey

The fish assemblage of the Warriparinga Wetland was dominated by two invasive species with a total of 70 redfin perch (157 mm TL ± 6.8 S.E.; 66.9 g ± 6.8 S.E.) and 2 common carp (618.5 mm TL ± 18.5 S.E.; 3573 g ± 18.5 S.E.) captured across all four ponds (Figure 2). Only one native species, common galaxias (166 mm TL ± 16 S.E.; 32 g ± 1 S.E.), was captured in low abundance (*n*=2) within the wetland. While no gambusia were captured in nets or traps during the survey, this species was visually observed within the wetland. In contrast, the assemblage of the adjacent Sturt River was dominated by common galaxias with a total of 83 captured (130 mm TL ± 2 S.E.; 13 g ± 1 S.E.). Invasive species where in low abundance with only 2 redfin perch (142 mm TL ± 0 S.E.; 37 g ± 0 S.E.) and 11 gambusia captured (36 mm TL ± 1 S.E.; 8 g combined weight). In addition, 1 yabbie (*Cherax destructor*) was captured from within the Sturt River (Table 2 and Figure 2).

Table 2. Species assemblage for all fish captured from within the Warriparinga Wetland and the Sturt River

Site	Species	Abundance	Average Length (TL-mm ± SE)	Average Weight (g ± SE)
Warriparinga Wetland	Common galaxias (*Galaxias maculatus*)	2	166 ± 16	32 ± 1
	Redfin perch (*Perca fluviatilis*)	70	157 ± 7	68 ± 8
	Common carp (*Cyprinus carpio*)	2	619 ± 19	3573 ± 636
Sturt River	Common galaxias (*Galaxias maculatus*)	83	130 ± 2	13 ± 1 (*n*=30)
	Redfin perch (*Perca fluviatilis*)	2	142 ± 0	37 ± 0
	Eastern gambusia (*Gambusia holbrooki*)	11	36 ± 1	8 g combined weight
	Yabbie (*Cherax destructor*)	1	n/a	24

Length frequency of species found in both Warriparinga Wetland and the Sturt River are shown in histograms below (Figure 2). Most notably was the dominant size class of 100-120 mm TL (juveniles) redfin perch which is indicative of a large recruitment year for the species. Also of note, was the size class of common galaxias found in the Sturt River. This was dominated by adult individuals (120-150 mm TL) which is likely representative of a spawning aggregation. In addition, the distribution of length classes indicates the population is consistently recruiting and long lived.

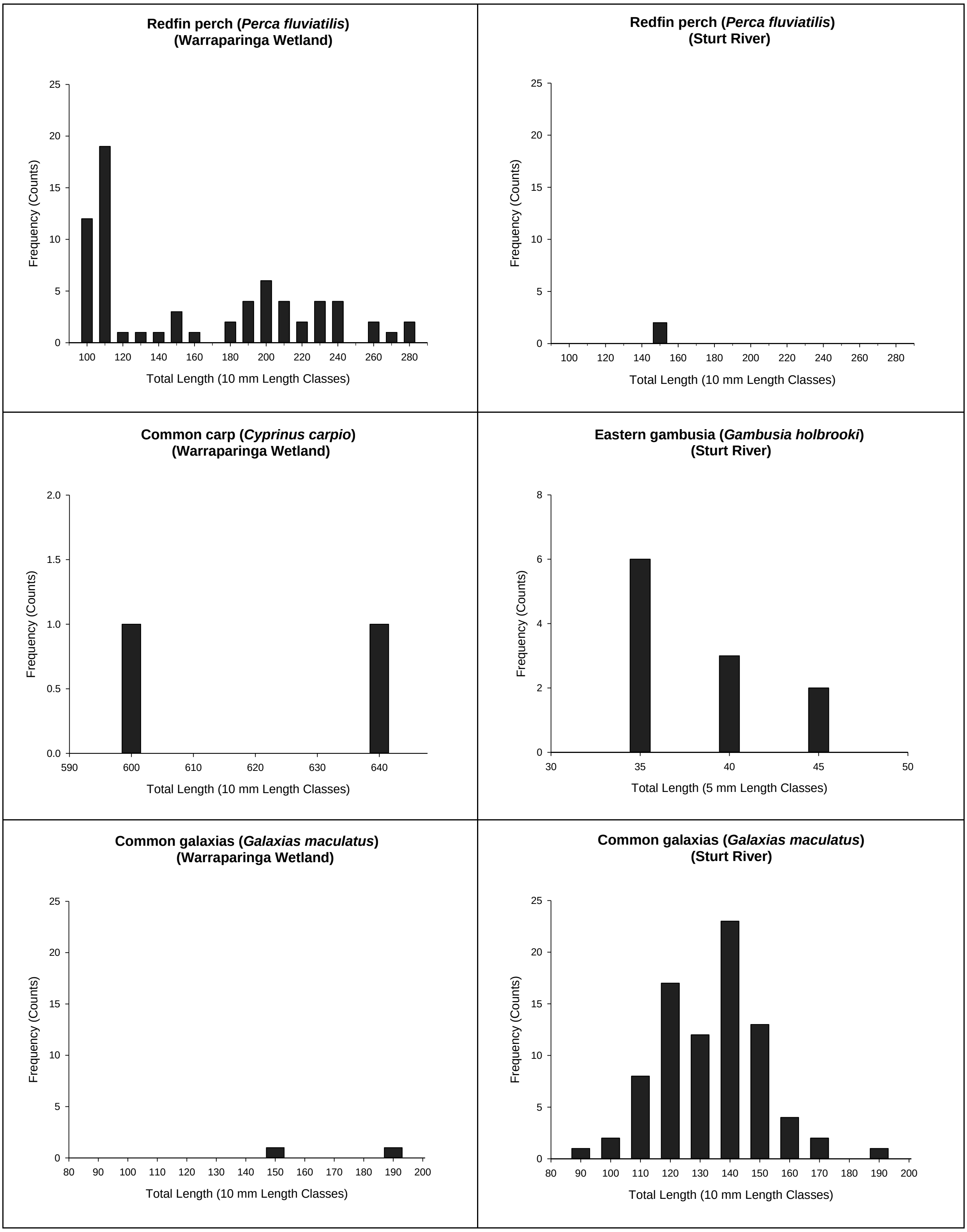

Figure 2. Length-frequency histograms for all species captured from within the Warriparinga Wetland and the Sturt River

Gut content analysis of redfin perch

Gut content analysis was conducted on five redfin captured from within the Warriparinga Wetland (Table 3). This analysis indicted a level of intraspecific predation with two of the specimens containing redfin perch- the only other species observed were yabbies. In addition, one redfin perch captured within the fyke nets was found with a common galaxias protruding from its mouth (Figure 3). While this predation may have occurred in the confines of the fyke net, it highlights the aggressive nature of the species and may also indicate why native species were found in such low abundance within the wetland.

Table 3. Gut content analysis of redfin captured from within the Warriparinga Wetland

Fish No.	Species	Sex	Gonad Stage	Length (TL, mm)	Gut Content
1	Redfin	F	3	275	1 x yabbie
2	Redfin	F	3	258	1 x yabbie, 1 x redfin (96 mm TL)
3	Redfin	F	3	237	2 x redfin (102 and 95 mm TL, respectively)
4	Redfin	F	3	261	Empty
5	Redfin	M	ripe	200	Empty

Figure 3. Redfin perch captured within one of the fyke nets with a large common galaxias protruding from its mouth (Photo: Josh Fredberg)

DISCUSSION

Stocking of native species was used in the developmental phase of the Warriparinga Wetland to discourage the establishment of invasive species. While this strategy may have had some benefit in the initial phases, the results of the present survey indicate the wetland is now dominated by redfin perch and to a lesser extent common carp and gambusia. The combined effects of these invasive species are likely to cause detrimental impacts to the Warriparinga Wetland, including a decline in native species recruitment, survival and abundance and a reduction in the effectiveness of the stormwater treatment process.

Redfin perch

Since their introduction into Australia during the 1860's redfin perch (Figure 4) have been implicated in the decline of several threatened and non-threatened native fish species (McDowall 1996; Morgan *et al*. 2002). This impact stems from the species ability to establish large numbers within enclosed water bodies, from their voracious predatory behaviour toward native species, invasive species, fish eggs and invertebrates and from direct competition for available food resources (Lintermans 2007; Lintermans *et al.* 2007). The combined effects generally result in a severe decline in native species abundance and an alteration in the behaviour and resource utilisation of native prey i.e. native species may be displaced from the relative safety of preferred edge habitats into open water habitat where they are more susceptible to predation (Shirley 2002; Closs *et al*. 2006). The high abundance and aggressive predatory behaviour of redfin may also result in cascading effects through heavy predation on algal-grazing zooplankton communities which may increase the relative abundance of algae and potentially increase the frequency of algal blooms (Hicks *et al.* 2007). In addition, redfin may also devastate native fish communities through the transmission of Epizootic Haematopoietic Necrosis Virus (EHNV) (Lintermans 2007; Lintermans *et al.* 2007).

Figure 4. Redfin perch (*Perca fluviatilis*) (Photo: Guther Schmida)

Common carp

Common carp (Figure 5) is a formidable invader and a declared pest fish in several countries including Australia, New Zealand, Canada and the United States (Koehn 2004). The success of carp stems from their high fecundity (100,000 eggs.kg^{-1}; up to 1 million eggs.y^{-1}; 40% survival), their longevity (28+ years), their ability to occupy a broad range of habitats and their tolerance to extreme environmental conditions (Smith 2005).

Carp occupy two broad habitats: shallow wetland habitats during spring through autumn (water temperature ≥16^{o}C) and deep water habitats during winter (water temperature ≤16^{o}C). The shallow habitat enables feeding, spawning and the replenishment of populations via recruitment (Smith and Walker 2004b; Stuart and Jones 2006). The deep habitat maintains warmer stable temperatures in comparison with surface waters (Johnsen and Hasler 1977; Inland Fisheries Service 2008; Penne and Pierce 2008). Migrations between these two habitats occur annually (Penne and Pierce 2008).

The environmental impacts of carp relate to their bottom-feeding behaviour (Sibbing *et al.* 1986) and are most commonly reported in shallow wetlands (Parkos *et al.* 2003) where large numbers of carp congregate annually to feed and breed (Smith and Walker 2004a; Stuart and Jones 2006). Bottom feeding or mumbling commences at approximately 30 days of age (25 mm TL) and can result in (adapted from Gehrke and Harris 1994; Smith 2005; Miller and Crowl 2006; Matsuzaki *et al*. 2009):

- suspension of sediments- increased turbidity- decreased photo-depth,
- aquatic vegetation being undermined- potentially uprooted,
- prevention of the establishment of seedlings,
- a reduction in the available seed bank- consumption/redistribution,
- reduction in zooplankton/macroinvertebrates- consumption,
- undermining banks,
- increase relative abundance of nutrients through excretion (and death/decay) - algal blooms,
- suspension of sediments through bottom feeding behaviour, and
- competition for available food resources.

While the results of the present survey indicate that carp are in low abundance within the Warriparinga Wetland these catch rates may be a result of the overwintering behaviour of carp i.e. reduced movements or movement back into the main river channel. However, the latter is unlikely at Warriparinga due to the inlet trash rack and the outlet flow control structure suggesting that the few carp within the wetland either washed in as larvae/juveniles or were illegally stocked by recreational anglers. Indeed, one recreational angler reported he had stocked six carp into the wetland within the previous year and that he would restock the wetland beyond draining. The reasons for the nil catch rates of young-of-year carp is unclear as there is sufficient fringing vegetation and suitable water quality for carp spawning and recruitment. Notwithstanding, the high abundance and aggressive predatory behaviour of redfin perch and to a lesser extent gambusia may explain the nil catch rates and this warrants further investigation.

Figure 5. Common carp (*Cyprinus carpio*) (Photo: Guther Schmida)

Eastern gambusia

Eastern gambusia (Figure 6) are a live-bearing small bodied fish (typically 10-30 mm TL and less than 80 mm TL). They were first introduced into Australian freshwater systems in 1925 in an attempt to control mosquitoes, hence the common name 'mosquito fish' (Kerezsy 2009). However, it was subsequently found that mosquito larvae did not feature prominently within their diet- their principle food source is aquatic invertebrates and zooplankton (Cadwallader 1979; Bence and Murdoch 1986; Arthington 1988; Arthington 1989; Mansfield and McArdle 1998; Garcia-Berthou 1999; Margaritora *et al*. 2001; Blanco *et al.* 2004; Rowe *et al.* 2008). Gambusia prefer shallow (5-15 cm in depth) low flow or still water habitats commonly found in wetlands, lakes and slow-flowing streams (Lintermans 2007; Pyke 2005; Rowe *et al.* 2008). They are able to withstand a wide range of temperatures, oxygen levels, salinities and turbidity's, which when combined with their ability to reproduce over a protracted period (up to 9 batches a year), makes this species one of the ultimate freshwater invaders (Lintermans 2007). In inland Australia, particularly within the Murray-Darling Basin (MDB), gambusia have well established populations and have been implicated in the decline of at least nine native fish species and more than ten species of frogs (Roberts *et al*. 1995; Stuart & Jones 2006; Lintermans 2007; Kerezsy 2009). This decline can be partly attributed to gambusia being an aggressive carnivorous species, known to fin-nip fish much larger than themselves, prey on the eggs of both native fish and frogs as well as native fish larvae and reduce the growth rates of small native fish, by means of habitat and food resource competition (Lintermans 2007).

Figure 6. Gambusia (*Gambusia holbrooki*) (Photo: Deon J. Hampton)

Native species

Common galaxias (Figure 7) is a small-bodied slender fish native to both coastal streams in the Mount Lofty Ranges (MLR) and the Lower River Murray in South Australia. Maximum size is 190 mm TL, however majority are usually < 100 mm TL (Lintermans 2007). Common galaxias life history typically displays that of a diadromous fish species, whereby newly hatched larvae, from eggs deposited in the lower reaches of coastal rivers and streams, are washed into the ocean during winter and spring flows (McDowall 1976; Koehn and O'Conner 1998; McNeil *et al*. 2009). Larvae develop in the marine environment, before returning *en mass* as juveniles to recolonise freshwater rivers and streams in the following spring (McNeil *et al*. 2009). Further growth and adult residence occurs in preferred freshwater habitats, which includes still or slow-flowing streams and margins of lakes, lagoons and wetlands (Lintermans 2007), before downstream spawning migrations to coastal areas in winter and spring (McNeil *et al*. 2009). Galaxias are carnivorous with a diet consisting of amphipods, mircrocrustaceans, insects and insect larvae (Lintermans 2007). In both the MLR and the Lower River Murray common galaxias are usually found in high abundance, however, potential threats such as the impedance of fish passage e.g. by weirs and barrages, and predation from voracious predators such as redfin are likely to cause a decline in the overall population.

Figure 7. Common galaxias (*Galaxias maculatus*) (Photo: Sydney Olympic Park Authority)

Management

The most efficient and cost-effective method in invasive species control/management is to prevent incursion. However, this is extremely difficult when invasive species seed stocks are established within surrounding and connected catchments and when stocking of invasive species by recreational anglers is likely to occur. In this regard, it is important to consider the most cost effective control/management strategies that align with existing and future management objectives of the invaded system and that will mitigate or minimise any potential impacts on native species. It is important to note that all invasive species control/management strategies carry the potential to severely impact native species and require professional consultation (i.e. Adelaide and Mount Lofty Ranges Natural Resource Management Board, PIRSA Fisheries and Aquaculture and SARDI Aquatic Sciences) before they are implemented.

Controlling and managing common carp has been a primary focus of invasive species research over the last decade. This research has produced several strategies which aim to understand and exploit innate behaviours for the purpose of reducing numbers through targeted harvesting efforts, controlling movements via physical exclusion (i.e. carp screens to restrict access to breeding grounds) or eliminating populations via the use of chemical pesticides. Genetic (‘daughterless’ carp; Thresher 2008), biological (Kio herpes virus; McColl *et al*. 2007) and chemical (pheromones; Sorensen and Stacey 2004) control technologies are also in development, but they are largely untested and still many years from deployment. Recent research has also developed strategies which focus on the control of redfin and gambusia (e.g. heat traps) however, these strategies are in the early stages of development and are generally adapted from carp control techniques. Thus, this discussion will focus on control/management strategies derived from carp research that are readily available and that may be applicable in the control of other invasive species. Table 4 lists and describes several invasive species control/management strategies that have potential application at Warriparinga Wetland. While all strategies have been proven effective in certain circumstances, some have limited application due to expense, aesthetics, potential impacts and the level of expertise required to apply the technique. Notwithstanding, they are presented as they may become more applicable as the level of invasive species incursion or the management objectives of the wetland change (i.e. increased or decreased stormwater treatment capacity or increased emphases on native species biodiversity).

Table 4. Invasive species control/management options for the Warriparinga Wetland.

Control mechanism	Description
Wetland draining/drying	• Draining and drying can be extremely effective in eradicating invasive species. • Not species specific, so will destroy native species and may become a complicated process if native species are re-stocked. • Native species rescue should be considered. Fish can be removed prior to draining, stored in culture facilities and released once the wetland is refilled. • If the wetland cannot be fully drained then there is potential to destroy any fish remaining in residual pools with Rotenone (see Chemical piscicides below). • Clean-up of stranded fish is labour intensive but required in order to ensure all invasive species are removed and to avoid smell and potential biohazards that may arise from decaying fish. • The installation of a sump (deeper section) within the wetland will assist in aggregating fish during the draining process. A custom made fine mesh net could be placed into the sump before draining for easy removal of aggregated fish. To ensure optimum operation of this system, the sump placement, dimensions and netting should be developed through consultation with scientists and design engineers. • High possibility of invasive species re-establishing from the Sturt River populations.
Chemical piscicides such as Rotenone (Clearwater *et al.* 2008)	• Can be extremely effective at eradicating invasive species however it is not species specific and will destroy native species within the wetland. • Native species rescue should be considered. Fish can be removed prior to draining, stored in culture facilities and released once the chemical is neutralised. • Will require large quantities of chemical and potentially several applications- so can be expensive. However, may have some application if the wetland is drained down to a single pool or a series of isolated pools. • Wetland will need to be isolated and residual chemical treated to avoid downstream mortalities. • Issues associated with collecting dead fish. If not done correctly then potential offensive odours and biohazards may become evident. • Requires specialised training and permits. • May be difficult acquiring permits due to presence of native species.

Control mechanism	Description
Disconnection	• Disconnect the wetland at the inlet and utilise fish smart irrigation off-take techniques to pump water from the Sturt River into the wetland (irrigation pumps and fine mesh self cleaning foot valve strainers- capable of pumping up to 16 ML d^{-1}; http://www.sure-flo.com/scs_page.html). • Off-the-shelf technology in wide scale use throughout the USA. • Will stop large and small bodied fish (native and invasive) from entering the wetland. • Depending on the mesh utilised and the time period when pumping occurs there may be some potential to still introduce eggs and larvae but these will likely be destroyed in the pump- this will need to be monitored and managed to minimise or mitigate the risk. • Potential issues with the mesh basket fouling with entrained debris/fish- regular cleaning. This can be minimised by using relatively low-medium flow pumps, by position of the off-take, by managing the delivery of water to avoid high debris loads (i.e. after high rainfall events), and by installing a fine mesh self cleaning foot valve strainer. • Will enable the wetland to still operate as a stormwater treatment facility and a biodiversity hotspot (for non-diadromous species). • Due to the outlet flow control structure there is minimal possibility of invasive fish entering the wetland via the outlet. • Potential high impact as complete disconnection will exclude native diadromous species from accessing the wetland.
Education	• An important component of invasive fish control is public education and support. Education programs and signage can be used to highlight the negative impacts of invasive species and to discourage the illegal stocking of these species into the wetland. In addition, education can also promote stocking of native species which may further discourage the stocking of invasive species. • If native species are stocked then it may be advantageous to engage community groups, school groups and recreational angling groups. These groups can assist in developing and implementing appropriate education programs as well as further aid in protecting the wetland as a native biodiversity hotspot. • There is potential to develop monitoring programs for these groups which will aid in the early detection of invasive species as well as supporting the ongoing management and maintenance of native fish stocks. • The Murray Darling Basin Authority Native Fish Strategy supplies education kits for school groups and community groups- these kits provide accessible information on native and invasive fish species management.

Control mechanism	Description
Velocity Barriers (Wisniewski 2006)	• High flow has been used to restrict upstream movements of invasive species such as carp, redfin and gambusia. • Due to slower water velocities required to treat stormwater this strategy may not be applicable. Notwithstanding, the outlet flow control structure could be augmented to restrict flow in order to increase outflow velocities. This will require further investigation.
Exclusion screens (French *et al*. 1999, Hillyard *et al*. 2010)	• Vertical jail bar configuration (10 mm) with apertures between the bars of 31 mm. • Specifically designed to restrict movements of carp ≥250 mm TL (body width >31 mm) but will restrict movements of any species with similar or larger body dimensions. Notwithstanding, the vast majority of small bodied native species can pass through these screens. • To mitigate or minimise restrictions on the passage of native species a strong understanding of the movement patterns and size range of the resident fish assemblage is required. • May have some application beyond draining (see above). However, will require screens to be tailored for the inlet and outlet of Warriparinga Wetland. Due to the small aperture required to restrict the size class of redfin perch and gambusia within the wetland and Sturt River, these screens will also restrict the movement of small and large bodied native species. • Flow control structures are required and screens are fabricated from galvanized steel which may be aesthetically unpleasing.
Permeable rock barrier	• A variation of the exclusion screen design using a permeable gabion basket rock barrier below the inlet trash racks and at the outlet weir may have some application. • This is a novel idea and will require further investigation in order to define suitable rock dimensions which permit appropriate levels of flow while restricting fish passage including larvae and juveniles. • If designed and managed correctly this method will exclude all fish species from entering the wetland via the Sturt River and assist in the long term feasibility of stocking native fish into the wetland i.e. if invasive species can be excluded then draining (see above) to destroy these species will not be required. • A rock barrier will be more aesthetically pleasing than metal exclusion screens. • Potential high impact as it will exclude native diadromous species from accessing the wetland (i.e. common galaxias, congolli).

Control mechanism	Description
Targeted harvesting	• Electrofishing, netting (fyke, gill), trapping (box traps) and acoustic herding. • Unlikely to eradicate all invasive species but will aid in controlling/reducing numbers. • Depending on the level of effort required to achieve a satisfactory reduction in the biomass of invasive species this may be an expensive option. • While there may be some native species by catch, these fish can be release unharmed.
Water level manipulations (Shields 1957; Yamamoto *et al.* 2006)	• Used to expose and desiccate eggs which are deposited on fringing vegetation. • Can be effective for carp and redfin which spawn on submerged vegetation. • Minimal effect for gambusia as they give birth to live young. • Requires flow and water level control structures. • Timing of manipulations is critical as there is potential to impact native species spawning (i.e. common galaxias).
Jumping and pushing traps (Stuart *et al*. 2006; Thwaites *et al*. 2010)	• Designed to separate carp from native species by exploiting the innate jumping and pushing behaviour of carp. Native species have not been observed displaying these behaviours. • Most effective when targeting annual migrations between river channels and off-channel habitat. • Requires cages and infrastructure to mechanically lift and empty captured fish- expensive and aesthetically unpleasing. • Given that very few carp were captured during the present survey this control method may not be cost effective. • Push trap may have application to allow large carp to exit the wetland and not return. This will require further investigation.
Barrier netting (Inland Fisheries Service 2008)	• Fine mesh netting is deployed to restrict access of fish to preferred spawning habitat i.e. fringing vegetation. • Has been effective in Tasmania at reducing spawning success of carp. However carp may use the netting as spawning substrate and deposited eggs will need to be destroyed by the application of lime. • The volume of fine mesh netting required to net-off all fringing habitat is expensive and aesthetically unpleasing. • Labour intensive to install, remove and maintain. • Limited application for gambusia and small bodied redfin. • Timing is critical as there is potential to impact native species spawning (i.e. common galaxias).
Heat traps (pers.comm Adam Daniel, Invasive species ecologist)	• Currently in development but early research has produced promising results. • Utilises gas or solar generated energy to heat sections of water in order to attract and aggregate gambusia for targeted harvesting efforts however, requires further research in order to develop cost effective portable systems.

Control mechanism	**Description**
Tracking “Judas” fish (Inland Fisheries Service 2008)	• Has been shown to be effective in controlling carp in Tasmania as the behaviour of tracker “Judas” fish mirrors that of untagged fish thereby permitting focused harvesting efforts. • Requires expertise for surgical implantation of tags into “Judas” tracking fish and specialised tracking equipment. • Can provide good movement and habitat association data. • Tag weights should be less than 2% of body weight therefore limited application with small body species. • Can be expensive.
Electrical barriers (Verrill and Berry 1995)	• Used to restrict movements of fish by establishing an electrical field between two electrodes. Fish are shocked and either turn around or are briefly paralysed and flow downstream before recovery from paralysis. • Unsuitable for the Warriparinga Wetland due to cost and potential risks to the general public and native species.

Key recommendations

- Invasive species management: There is a current proposal to drain the Warriparinga Wetland in order to undertake earthworks to remove excess silt and to re-shape for the re-establishment and expansion of aquatic reed beds and submerged vegetation (WWMMP 2011). As indicated in the Warriparinga Wetland Maintenance and Management Plan (2011) this will provide an ideal opportunity to remove invasive species. It is recommended that all ponds are drained and dried during this process. As carp can burrow into the sediment, monitoring will be required to make sure all carp are removed or perish. Draining will destroy both invasive and native species and its utility as an ongoing management strategy will require careful consideration if native species re-stocking is to occur (see Table 4 for further considerations).

- Invasive species management: An important first step in developing an ongoing invasive species management plan is to succinctly define the primary objective of the wetland. At this stage, the objectives are multifaceted in terms of stormwater treatment and a public amenity which aims to support rich biodiversity and community involvement. The most appropriate invasive species control strategy (beyond draining) will differ depending on whether stormwater treatment or biodiversity becomes a higher ranking priority. Once the objective is established, it is recommended that the development of an invasive species control strategy be undertaken through further consultation with the Adelaide and Mount Lofty Ranges Natural Resource Management Board, PIRSA Fisheries and Aquaculture and SARDI Aquatic Sciences.

- Native species: Several of the species used in the initial stocking phase were unsuitable as they were either estuarine (black bream, smallmouthed hardyhead, bridled goby) or diadromous (congolli, common galaxias- although a population currently exists within the wetland) and were therefore restricted in their ability to complete their life-cycles within the wetland. While the diadromous species are endemic and do access inland waters, fish passage and suitable flow management is required to assist in the establishment of self sustaining populations. If provision cannot be made for diadromous species then species which are endemic and which can complete their lifecycle within inland waters should be considered (i.e. flathead gudgeon, blue-spot goby etc.). If native species re-stocking is to be considered then it is recommended this process is undertaken through consultation with the Adelaide and Mount Lofty Ranges Natural Resource Management Board, PIRSA Fisheries and Aquaculture and SARDI Aquatic Sciences.

REFERENCES

Arthington, A.H. (1988). Diet of *Gambusia affinis holbrooki* (Baird and Girard) in streams of the Brisbane region, south-eastern Queensland, Australia. *Ver. Internat. Verein. Theor. Ange. Limn.* **23**: 177-182.

Arthington, A.H. (1989). Impacts of introduced and translocated freshwater fishes in Australia. *In* De Silva, SS. (*ed*.). Proceedings of the Workshop on Introduction of Exotic Aquatic Organisms in Asia, Manila. *Asian Fisheries Society Special Publication No. 3*.

Bence, J.R. and Murdoch, W.W. (1986). Prey size selection by the mosquitofish: relation to optimal diet theory. *Ecology* **67**: 324-336.

Blanco, S., Romo, S. and Villena, M-J. (2004). Experimental study on the diet of mosquitofish (*Gambusia holbrooki*) under different ecological conditions in a shallow lake. *International Review of Hydrobiology* **89**: 250-262.

Cadwallader, P.L. (1979). Distribution of native and introduced fish in the Seven Creeks River system, Victoria. *Australian Journal of Ecology* **4**: 361-386.

Clearwater, S. J., Hickey, C. W. and Martin, M. L. (2008). Overview of potential piscicides and molluscicides for controlling aquatic pest species in New Zealand. Department of Conservation, *Te Papa Atawhai*, Wellington.

Closs, G.P., Balcombe, S.R., Driver, P., McNeil, D.G. and Shirley, M.J. (2006). The importance of floodplain wetlands to Murray-Darling fish: What's there? What do we know? What do we need to know? In *Native fish and wetlands in the Murray-Darling Basin: Action plan, knowledge gaps and supporting papers* (Ed. B. Phillips), pp. 14–28, Proceedings of a workshop held in Canberra ACT, 7 – 8 June 2005. Murray-Darling Basin Commission, Canberra.

French, J. R. P., Wilcox, D. A. and Nicols, S. J. (1999). Passing of northern pike and common carp through experimental barriers designed for use in wetland restoration. *Wetlands* **19**: 883-88.

Garcia-Berthou, E. (1999). Food of introduced mosquitofish: ontogenetic diet shifts and prey selection. *Journal of Fish Biology* **55**: 135-147.

Gehrke, P. C. and Harris, J. H. (1994). The role of fish in cyanobacterial blooms in Australia. *Australian Journal of Marine and Freshwater Research* **45**: 905-915.

Hicks, B., Hamilton, D.P., Ling, N. and Wood, S. (2007). Top down or bottom up? Feasibility of water clarity restoration in the lower Karori Reservoir by fish removal. Draft report prepared for the Karori Wildlife Sanctuary Trust by the Centre for Biodiversity and Ecology Research, Department of Biological Sciences and the School of Science and Engineering, University of Waikato, New Zealand, CBER Contract Report 54.

Hillyard, K. A., Smith, B. B., Conallin, A. and Gillanders, B. M. (2010). Optimising exclusion screens to control exotic carp in an Australian lowland river. Marine and Freshwater Research **61**: 418-429.

Inland Fisheries Service (2008). Carp management program annual report for 2007 / 2008. Inland Fisheries Service, New Norfolk, Tasmania.

Johnsen, P. B. and Hasler, A. D. (1977). Winter aggregations of carp (*Cyprinus carpio*) as revealed by ultrasonic tracking. *Transactions of the American Fisheries Society* **106**: 556-59.

Kerezsy, A. (2009). Gambusia control in spring wetlands. Final report to the South Australian Arid Lands Natural Resources Management Board, Port Augusta, SA.

Koehn, J.D. and O'Connor, J. P. (1998) 'Biological Information for Management of Native Freshwater Fish in Victoria.' Department of Conservation and Environment Fresh Water Management Branch, Arthur Rylah Institute, Victoria.

Koehn, J. D. (2004). Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. *Freshwater Biology* **49**: 882-94.

Lintermans, M. (2007) 'Fishes of the Murray-Darling Basin: An Introductory Guide. MDBC Publication No. 10/07.' (Murray-Darling Basin Commission: Canberra).

Lintermans, M., Raadik, T., Morgan, D. and Jackson, P. (2007). Overview of the ecology and impactof three alien fish species: Redfin perch, Mozambique mouthbrooder (Tilapia) andOriental weatherloach. In *Emerging issues in alien fish management in the Murray-Darling Basin: Statement, recommendations and supporting papers* (Eds. D. Ansell and P. Jackson), pp. 22–32, Proceedings of a workshop held in Brisbane Qld, 30 – 31 May 2006. Murray-Darling Basin Commission, Canberra.

Mansfield, S. and McArdle, B. (1998). Dietary composition of *Gambusia affinis* (Family Poeciliidae) populations in the Northern Waikato Region of New Zealand. *New Zealand Journal of Marine and Freshwater Research* **32**: 375-383.

Margaritora, F.G., Ferrara, O. and Vagaggini, D. (2001). Predatory impact of the mosquitofish (*Gambusia holbrooki* Girard) on zooplanktonic populations in a pond at Tenuata di Castelporziano (Rome, Central Italy). *Journal of Limnology* **60**: 189-193.

Matsuzaki, S. S., Usio, N., Takamura, N. and Washitani, I. (2009). Contrasting impacts of invasive engineers on freshwater ecosystems: an experiment and meta-analysis. *Oecologia* **158**: 673-86.

McColl, K. A., Sunarto, A., Williams, L. M. and Crane, M. (2007). Koi herpes virus: dreaded pathogen or white knight? *Aquaculture Health International* **9**: 4-6.

McDowall, R.M. (1976) The role of estuaries in the life cycles of fishes in New Zealand. *Proceedings of the New Zealand Royal Society*. **23**: 27-32.

McDowall, R.M. (1996). *Freshwater Fishes of South-eastern Australia*. Second edition. Reed Books, Australia.

McNeil, D.G., Fredberg, J. and Wilson, P.J. (2009). Coastal Fishes and Flows in the Onkaparinga and Myponga Rivers. Report to the Adelaide and Mount Lofty Ranges Natural Resource Management Board. South Australian Research and Development Institute, Aquatic Sciences. SARDI Report Series No.400.

McNeil, D., Schmarr, D. and Mathwin, R. (2011) Condition of Freshwater fish Communities in the Adelaide and Mount Lofty Ranges Management Region. Report to the Adelaide and Mount Lofty Ranges Natural Resources Management Board. SARDI Publication Number F2011/000502/1. 64pp.

Miller, S. A. and Crowl, T. A. (2006). Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. *Freshwater Biology* **51**: 85-94.

Morgan, D.L., Hambleton, S.J., Gill, H.S. and Beatty, S.J. (2002). Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*) (Percidae) in Western Australia. *Marine and Freshwater Research* **53**: 1211-1221.

Parkos, J. J., Santucci, V. J. and Wahl, D. H. (2003). Effects of adult common carp (*Cyprinus carpio*) on multiple trophic levels in shallow mesocosms. *Canadian Journal of Fisheries and Aquatic Sciences* **60**: 182-92.

Penne, C. R. and Pierce, C. L. (2008). Seasonal distribution, aggregation, and habitat selection of common carp in Clear Lake, Iowa. *Transactions of the American Fisheries Society* **137**: 1050-62.

Pyke, G.H. (2005). A review of the biology of *Gambusia affinis* and *G. holbrooki*. *Reviews in Fish Biology and Fisheries* **15**: 339-365.

Roberts, J., Chick, A., Oswald, L. and Thompson, P. (1995). Effects of Carp, *Cyprinus carpio* L., an Exotic Benthivorous Fish, on Aquatic Plants and Water Quality in Experimental Ponds. *Australian Journal of Marine and Freshwater Research* **46**: 1171 – 1180.

Rowe, D. K., Moore, A., Giorgetti, A., Maclean, C., Grace, P., Wadhwa, S. and Cooke, J. (2008). Review of the impacts of gambusia, redfin perch, tench, roach, yellowfin goby and streaked goby in Australia. Prepared for the Australian Government Department of the Environment, Water, Heritage and the Arts.

Shields, J. T. (1957). Experimental control of carp reproduction through water drawdowns in Fort Randall Reservoir, South Dakota. *Transactions of the American Fisheries Society* **87**: 23-32.

Shirley, M.J. (2002). The ecology of billabong fish communities of the River Murray, with a focus on the interactions of European perch (*Perca fluviatilis*). Unpublished Ph.D. thesis, Biological Sciences, Monash University, Clayton, Victoria.

Sibbing, F. A., Osse, J. W. M. and Terlouw, A. (1986). Food handling in the carp (*Cyprinus carpio*): Its movement patterns, mechanisms and limitations. *Journal of the Zoological Society of London* **210**: 161-203.

Smith, B. B. (2005). The state of the art: a synopsis of information on common carp (Cyprinus carpio) in Australia. Final Technical Report, SARDI Aquatic Sciences Publication No. RD04/0064-2; SARDI Research Report Series No. 77, prepared by the South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 68 pp.

Smith, B. B. and Walker, K. F. (2004a). Reproduction of common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries. *Transactions of the Royal Society of South Australia.* **128**: 249-57.

Smith, B. B. and Walker, K. F. (2004b). Spawning dynamics of common carp in the River Murray, South Australia, shown by macroscopic and histological staging of gonads. *Journal of Fish Biology* **64**: 336-54.

Sorensen, P. W. and Stacey, N. E. (2004). Brief review of fish pheromones and discussion of their possible uses in the control of non-indigenous teleost fishes. *New Zealand Journal of Marine and Freshwater Research* **38**: 399-417.

Stuart, I.G. and Jones, M. (2006). Large, regulated forest floodplain is an ideal recruitment zone for non-native common carp (*Cyprinus carpio* L.) *Australian Journal of Marine and Freshwater Research* **57**: 333 - 347.

Stuart, I., Williams, A., Mckenzie, J. and Holt, T. (2006). Managing a migratory pest species: a selective trap for common carp. North American Journal of Fisheries Management **26**: 888-893.

Thresher, R. E. (2008). Autocidal technoloogy for the control of invasive fish. *Fisheries* **33**: 114-120.

Thwaites, L. A., Smith, B. B., Decelis, M., Fleer, D. and Conallin, A. (2010). A novel push trap element to manage carp (*Cyprinus carpio* L.): a laboratory trial. Marine and Freshwater Research **61**: 42-48.

Wisniewski, C. (2006). Liawenee Canal anti jump barrier and fish trap: design and construction, Inland Fisheries Service, Tasmania.

WWMMP (2011) Warriparinga Wetland Maintenance- Management Plan 2011-2012. City of Marion, 25pp.

Verrill, D. D. and Berry, C. R. (1995). Effectiveness of an electrical barrier and lake drawdown for reducing common carp and bigmouth buffalo abundances. *North American Journal of Fisheries Management* **15**: 137-41.

Yamamoto, T., Kohmatsu, Y. and Yuma, M. (2006). Effects of summer drawdown on Cyprinid fish larvae in Lake Biwa, Japan. *Limnology* **7**: 75-82.