Spatial and temporal variation in larval fish assemblage structure in the Chowilla Anabranch system: with reference to water physico-chemistry and stream hydrology

S.J. Leigh, B.P. Zampatti and J.M. Nicol

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South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

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Author(s): S. Leigh, B. Zampatti and J. Nicol
Reviewers: P. Jennings and D. McNeil
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Executive Summary

Regulation of the Murray River system has altered the magnitude, frequency and duration of flow events. The effect of such alterations on aquatic organisms has been compounded by increased salinity, which has affected water quality in many off-channel environments. Changes to the natural flow regime and water physico-chemistry have contributed to declines in the abundance and distribution of native fish.

The Chowilla Anabranch System, South Australia, is the largest remaining area of floodplain habitat in the lower Murray River. Under the Chowilla Integrated Natural Resource Management Project (INRM) environmental watering regimes are being developed for the system based primarily on the modelled response of terrestrial vegetation communities. Nevertheless, preliminary objectives also exist for fish populations, including maintaining successful recruitment of small and large bodied species, reducing barriers to fish movement and maintaining the diversity and distribution of fish species within the Chowilla floodplain system. In order to address these objectives knowledge of the ecology of freshwater fish in the region is essential. Larval fish, in particular, provide a useful tool to assess the effects of river regulation and environmental conditions on spawning and recruitment processes of native and exotic fishes.

We investigated various aspects of the larval fish assemblage in the Chowilla Anabranch system. Specifically we describe spatial and temporal variation in the presence of larval fish, the approximate spawning period of individual species, and investigate the potential interactions between the larval fish community and water physio-chemistry and stream hydrology. Furthermore we discuss the importance of the Chowilla Anabranch system as a recruitment source for native and exotic fish populations. Sites were chosen to represent the diverse range of aquatic habitats present within the Chowilla Anabranch system and were sampled during the spring/summer of 2005/06 and 2006/07.

Flows through Chowilla Anabranch system during the study period were characterised by regulated 'entitlement' flows to South Australia, although a small within-channel rise in flow did occur during the spring/summer of 2005/06. Water physico-chemistry (water temperature, salinity and turbidity) within the Chowilla Anabranch system was similar to the adjacent Murray River. Nevertheless, slow flowing creeks on the outer edge of the

system (Punkah, Salt and Hypurna) generally exhibited greater variation and were more influenced by saline ground water than the fast flowing inner creeks. Historical salinity data for outer creeks indicates that future floodplain runoff may have a significant impact on fish, particularly following the current extended period of lack of floodplain inundation.

Nine species of fish were collected as larvae within the Chowilla system including seven native and two exotic species. Small bodied generalist species were the most abundant (e.g. gudgeons and Australian smelt) and most species were present as larvae each year with the timing and duration of the presence of larvae relatively consistent between years. Two species, however, were only present in a single sampling season, namely golden perch and exotic redfin perch. Notably, golden perch larvae were collected only in 2005/06 in association with a small but prolonged increase in discharge over the spring/early summer period. This finding supports the proposition that this species is a flow cued spawner that may spawn on relatively small increases in discharge.

Species richness and diversity of larval fish was similar across all sites. Gudgeons, Australian smelt, unspecked hardyhead and carp were, however, present in significantly higher abundances in a group of sites that contained slow flowing anabranch sites and the Murray River. Slow anabranch habitats, including the Murray River, were characterised by greater percent cover of submerged aquatic macrophytes and are considered an important spawning and rearing habitat for small bodied species and exotic carp. Abundances of larval large bodied native species (Murray cod and golden perch) were generally higher in fast flowing anabranches and Chowilla Creek although their overall abundances were low.

This study has shown that the Chowilla Anabranch system provides a complex of physical and hydraulic habitats that support a range of life-history phases of native and exotic fish species. In particular, specific habitats within the system appear to provide important spawning locations for the threatened Murray cod. The conservation of the diverse range of aquatic macrohabitats in the Chowilla Anabranch system, along with restoration of a more variable flow regime, will aid in maintaining and potentially restoring native fish populations in the lower Murray River.

Introduction

The Murray-Darling Basin and River Regulation

River regulation has altered the hydrology of large floodplain rivers, such as the Murray, on three temporal scales, namely the flood pulse (days to weeks), flow history (weeks to years) and flow regime (decades or longer) (Walker *et al.* 1995; Puckridge *et al.* 1998; Arthington and Pusey 2003). Such alterations are acknowledged as having significant impacts on the ecosystems of large Australian rivers (Walker 1985; Walker *et al.* 1995; Kingsford 2000; Arthington and Pusey 2003). Consequently, the maintenance of natural flow regimes is considered a critical factor in maintaining the ecological integrity and function of floodplain rivers (Poff *et al.* 1997)

The Murray-Darling River system in south-eastern Australia flows predominantly through a semi-arid landscape, and historically exhibited a highly variable flow regime (Walker and Thoms 1993). Since the early 1900s a series of dams, weirs and barrages have been constructed throughout the river system thus reducing annual discharge, decreasing flow variability and altering the timing and frequency of flow events (Walker and Thoms 1993; Gippel and Blackham 2002). Regulation of the Murray-Darling River system has seen a shift to a relatively stable flow regime particularly in the lower Murray River, downstream of Mildura (Jacobs 1989; Carter and Nicolson 1993; Walker and Thoms 1993; Sharley and Hugan 1995).

Whilst minimum entitlement flows to the lower Murray River have been negotiated to ensure weir pool levels are maintained (Jacobs 1990), the magnitude, frequency and duration of over-bank flows have decreased, reducing the frequency and duration of interactions between the main river channel and associated off-channel habitats (Walker and Thoms 1993; Maheshwari *et al.* 1995). The effects of an altered flow regime have been compounded by rising saline groundwater, which has affected water quality in many off-channel environments (Williams 1987b). The construction of weirs in the lower Murray River has further contributed to increased salt loads as rising water tables bring salt to the surface and irrigation runoff leaches salt from ancient deposits (Walker 1985; Ryan and Davies 1996).

Declines in Native Fishes

Changes to the natural flow regime are thought to have had a significant impact on the health of floodplain and wetland systems of the lower Murray River (Cadwallader 1978; Walker and Thoms 1993; Arthington and Pusey 2003; MDBC 2006) and have been attributed to the decline in abundance and distribution of many riverine biota (Walker *et al.* 1992; Walker and Thoms 1993). This decline has been observed in native fish populations (Cadwallader 1978; Walker and Thoms 1993; Gehrke *et al.* 1995) and is likely due to a number of factors associated with flow regulation including changes to the natural flow regime, barriers to fish passage and altered water physico-chemistry (Cadwaller 1978; Mallen-Cooper 1993).

Native fish populations are recognised as key indicators of the broader physical condition of riverine ecosystems (Ryan and Davies 1996; Humphries and Lake 2000; Boys and Thoms 2006). The study of larval fish in particular can provide important information on the effects of river regulation on the spawning of fish species (Humphries and Lake 2000). High mortality generally occurs at the egg, larval and juvenile stages hence the environmental conditions present at these stages can have a profound influence on the level of recruitment to the adult population (Houde 1987; Trippel and Chambers 1997) and may influence the structure of fish communities. For instance it has been suggested that freshwater fish are more vulnerable to higher salinities at these early stages (Williams and Williams 1991).

In order to manage fish and other aquatic organisms environmental management strategies often include recommendations for specific environmental water allocations or environmental flows. Nevertheless, separating the effect of altered flows from other factors is difficult and hence the effectiveness of enhancing aquatic environments using environmental water allocations is poorly understood (Bunn and Arthington 2002). Furthermore, the importance of floodplains and flooding in the life cycle of native fish for specific regions of the Murray-Darling Basin remains unresolved (Humphries *et al.* 1999; King *et al.* 2003; Graham and Harris 2005). In order to manage off-channel habitats effectively a greater understanding of the effects of flow and water physico-chemistry on fish recruitment ecology is required.

The Chowilla Anabranch System

The Chowilla region in South Australia is the largest remaining area of undeveloped floodplain habitat in the lower Murray River and has been listed as a Wetland of International Importance under the UNESCO Ramsar Convention. Nevertheless, changes to the natural flow regime, grazing pressure and drought are thought to have contributed to the degradation of the Chowilla floodplain and wetland system (MDBC 2006). In an effort to enhance and restore the environmental values of the Chowilla floodplain the Chowilla Integrated Natural Resource Management Project (INRM) has recently been developed (MDBC 2006). A component of this project involved the development of an Asset Environmental Management Plan (AEMP) for the Chowilla floodplain which involves the development of an environmental flows strategy to '*maintain and where possible enhance*' the environmental values of Chowilla.

Environmental watering regimes for the anabranch system have primarily been modelled on the terrestrial vegetation community in particular river red gum and black box populations (DWLBC 2006). Preliminary objectives, however, also exist for fish populations and include maintaining successful recruitment of small and large bodied species, reducing barriers to fish movement and maintaining the diversity and distribution of fish species within the Chowilla floodplain system (DWLBC 2006).

Objectives of this project

In the present study we investigated the spatial and temporal variation in the presence and abundance of larval fish in the Chowilla Anabranch system and adjacent Murray River. Furthermore we describe the approximate spawning period for species captured as larvae within the Chowilla Anabranch system. The primary objectives of the project were to:

- Investigate the potential impacts of water physico-chemistry (primarily salinity) and hydrology on larval fish communities in the Chowilla Anabranch system.
- Assess the importance of the Chowilla Anabranch system as a recruitment source for native and exotic fish species in the Murray River in South Australia.

The findings of this study will assist in the development of models that demonstrate the potential biotic impact of changes to water quality and flow, and will inform the management of native fish in the Chowilla Anabranch system and throughout the lower Murray River.

Methods

<u>The study area</u>

The Chowilla floodplain system covers at total area of 17, 700 ha (MDBC 2006) and is comprised of a series of anabranching creeks that bypass Lock and Weir No. 6 on the Murray River, South Australia. The hydrology of the Chowilla Anabranch system is highly influenced by the weir pool created by Lock 6 and during average flow conditions (i.e. <20,000 ML/d), 40 – 80 % of the discharge into South Australia passes through the Chowilla system (MDBC 2006). This discharge creates a distinct flow and salinity gradient within the creek system where creeks influenced directly by the weir pool generally have high flows and low conductivity and creeks on the outer edge of the floodplain exhibit low flows and higher conductivity. As a result Chowilla consists of a variety of macrohabitat types, such as fast and slow flowing creeks, backwaters, and ephemeral wetlands and terminal lake systems.

River regulation has resulted in a shift in flowing water habitats from the main channel of the Murray River to the Chowilla Anabranch system. Consequently the diversity of aquatic habitats available within Chowilla is now unique along the lower Murray River. This diversity of habitats supports a wide range of aquatic organisms (O'Malley and Sheldon 1990) in particular, significant native fish populations (Lloyd 1990; Pierce 1990; Zampatti *et al.* 2006).

<u>Site selection</u>

Eight sites were chosen to represent the range of permanent aquatic macrohabitat types that occur within the Chowilla Anabranch system, namely fast and slow flowing creeks as qualitatively described by Sheldon and Lloyd (1990) (Table 1). Sites were located in Slaney, Pipeclay, Boat, Punkah, Chowilla, Salt and Hypurna creeks, and the Murray River (Figure 1). Based on average cross-sectional velocities collected as part of a concurrent project, fast flowing creeks were characterised by velocities >0.20 ms^{-1} and slow flowing creeks by velocities <0.15 ms^{-1}. Average water velocity at the site in the main channel of the Murray River was <0.10 ms^{-1}.

Larval sampling

Larval samples were collected fortnightly from September to February (austral spring/summer) in 2005/06 and 2006/07. Drift nets were used to collect larvae passively or actively present in flowing water. At each site three larval drift nets (500 µm mesh, 0.5 m diameter opening, 1.5 m length) were set overnight (range 13 – 18 hours). A General Oceanics Inc. (Florida, USA) flow meter was fixed into the mouth of each drift net to determine the volume of water filtered. Upon retrieval the contents were washed to the cod end, rinsed into a sample jar and preserved in 95% ethanol.

Modified quatrefoil light traps (Floyd *et al*. 1984) were used to sample larval fish with a positive phototactic response to light. A 12 hour Cyalume light stick was placed inside the trap to provide a light source (attractant) and 5 mm stretched mesh was used to prevent predation of larvae by larger fish (Meredith *et al*. 2002). At each site three light traps were set adjacent to available littoral habitats (e.g. submerged and emergent aquatic macrophytes and large woody debris).

Water quality parameters (conductivity and temperature) were measured on each sampling occasion using a TPS 90 FLT water quality meter. In addition, water temperature was collected *in situ* using TidBit temperature loggers. Additional data for discharge, temperature and salinity was obtained from DWLBC/SA Water. Turbidity was measured with secchi disc. Gauge heights were recorded fortnightly where discharge data was not available.

Table 1. Site locations and aquatic macrohabitat type.

Site No.	Location	Macrohabitat Type
1	Chowilla Creek d/s of bridge	Slow Anabranch
2	Boat Creek	Fast Anabranch
3	Pipeclay Creek	Slow Anabranch
4	Slaney Creek u/s Chowilla junction	Fast Anabranch
5	Punkah Creek d/s Punkah Island ford	Slow Anabranch
6	Salt Creek	Slow Anabranch
7	Hypurna Creek	Slow Anabranch
8	Murray River at groynes downstream of Lock 6	Main River Channel

Larval fish identification

Larval fish were defined as described in Serfafini and Humphries (2004) as the phase between hatch and the juvenile stage. Larval fish were separated from vegetation in drift net samples under a magnification lamp (x2). Samples from light traps did not require sorting prior to identification. Fish were then identified under a dissecting microscope using descriptions from Puckridge and Walker (1990) and Serfafini and Humphries (2004). Carp gudgeon (*Hypseleotris* spp.), flathead gudgeon (*Phylipnodon grandiceps*) and dwarf flathead gudgeon (*Phylipnodon macrostomus*) larvae were at times difficult to distinguish due to damage sustained in the drift nets. Consequently, we have grouped these species as a complex and referred to them as gudgeons.

Microhabitat

Using percent cover data (from a concurrent project) collected in March 2006 from representative sites within the Chowilla region seven microhabitat categories were defined, namely emergent, submergent and floating aquatic macrophytes, coarse woody debris (CWD) 1 (twigs <1 cm diameter), CWD 2 (branches 1 - 5 cm diameter), CWD 3 (wood >5 cm diameter) and Red gum roots (RG roots). Sites were then grouped into one of the three macrohabitat types outlined in Table 1.

Data analysis

Conductivity

Conductivity readings taken using TDS water quality meter were averaged for each site and plotted with standard error for both sampling seasons to describe the differences between sites and between sampling years.

Larval fish communities

Drift net data was standardized as the number of larvae per 1000 m^3 of water sampled and light trap data as the number of larvae per 12 hours. Both fishing techniques were combined to represent the catch per unit effort (number of larvae / 1000 m^3 + number of larvae / 12 hr) for each sample. This data was used to perform the following analyses.

The differences in larval fish communities between sites, different macrohabitats and years were compared using NMS ordination, UPGMA clustering, Multi Response Permutation Procedures (MRPP) (McCune *et al.* 2002) and Indicator Species Analysis (Dufrene and Legendre 1997) using the package PCOrd version 5.0 (McCune and Mefford 2005). Bray-Curtis (1956) similarities were used to calculate the similarity matrix for all multivariate analyses. NMS ordinations and UPGMA cluster analyses were performed using pooled data from each site for each year for clarity but all other analyses were performed using unpooled data. A probability significance α value of 0.05 was used for statistical analyses.

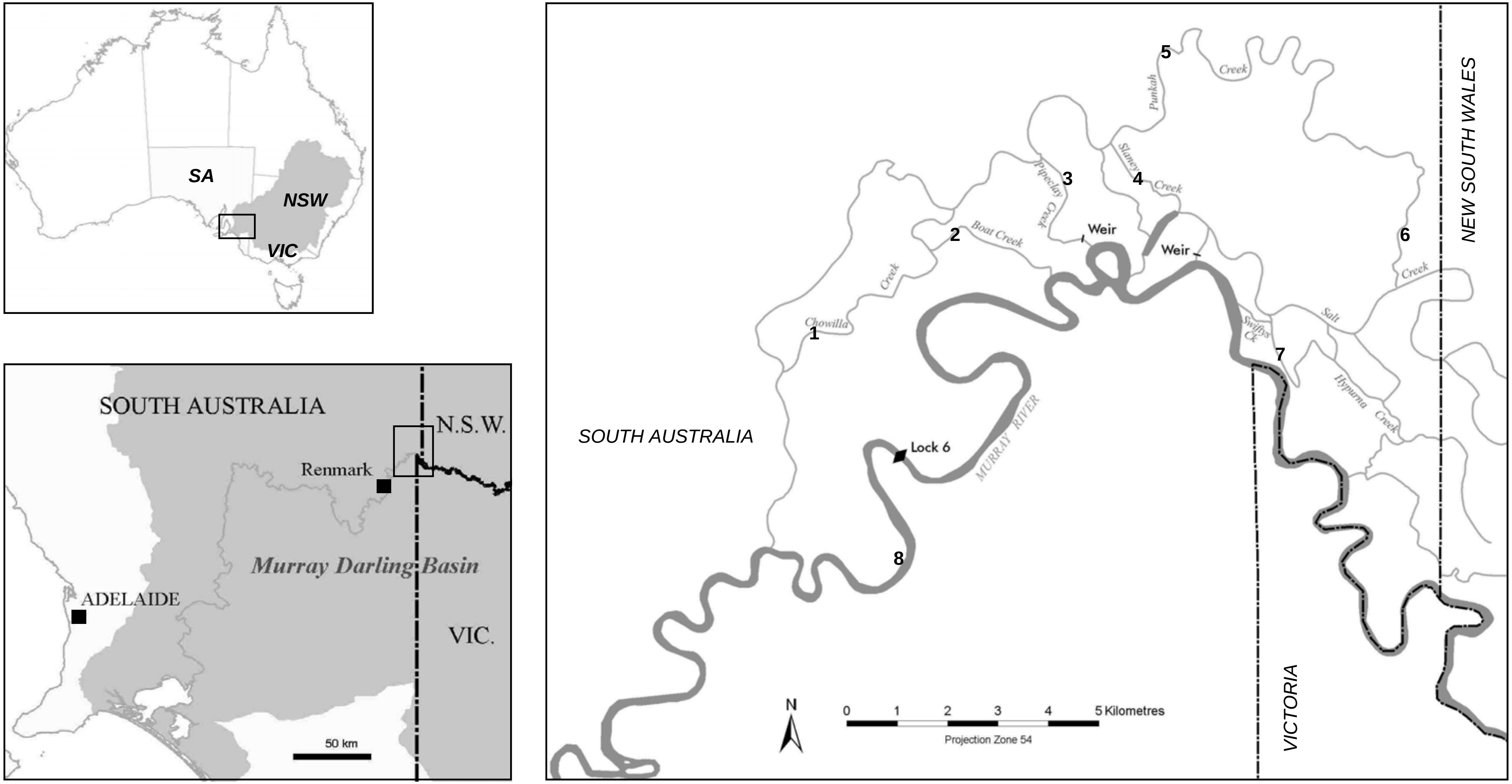

Figure 1. Map of the Chowilla Anabranch system and adjacent Murray River showing the location of the eight sampling sites.

Results

Hydrology

Discharge into South Australia in the Murray River in the spring/summer of 2005/2006 increased from approximately 3800 ML/d to a peak of 15000 ML/d over approximately a 3 month period (Figure 2). The increase in discharge was the result of flow in the Murray River exceeding the capacity of the Lake Victoria inlet channel (Frenchmans Creek) and subsequently being bypassed down the Murray River. Discharge in the Chowilla Anabranch, however, does not clearly reflect this flow event and only a slight increase in discharge was observed (approximately 1500 ML/d to 3000 ML/d). During the same period in 2006/2007 the discharge into South Australia increased from approximately 3500 ML/d to 7500 ML/d (standard winter and summer entitlement flow) and was the result of regulated releases from Lake Victoria. This increase in discharge in the Murray River was reflected by a slight increase in discharge in the Chowilla Anabranch system (1500 ML/d to 2500 ML/d).

Stage heights (Figure 3) recorded within the Chowilla Anabranch system during the two sampling periods (September 2005 to March 2006 and September 2006 to April 2007) show a marked difference in water level between years. Between mid September 2005 and January 2006 water surface levels across the creeks sampled increased by approximately 0.5 – 0.7 m. During the same period, however, in 2006/07 water levels were relatively stable. The increase in water surface level in 2005/06 is likely the result of a combination of increased discharge and the raising of Lock 5 weir pool by 0.5 m.

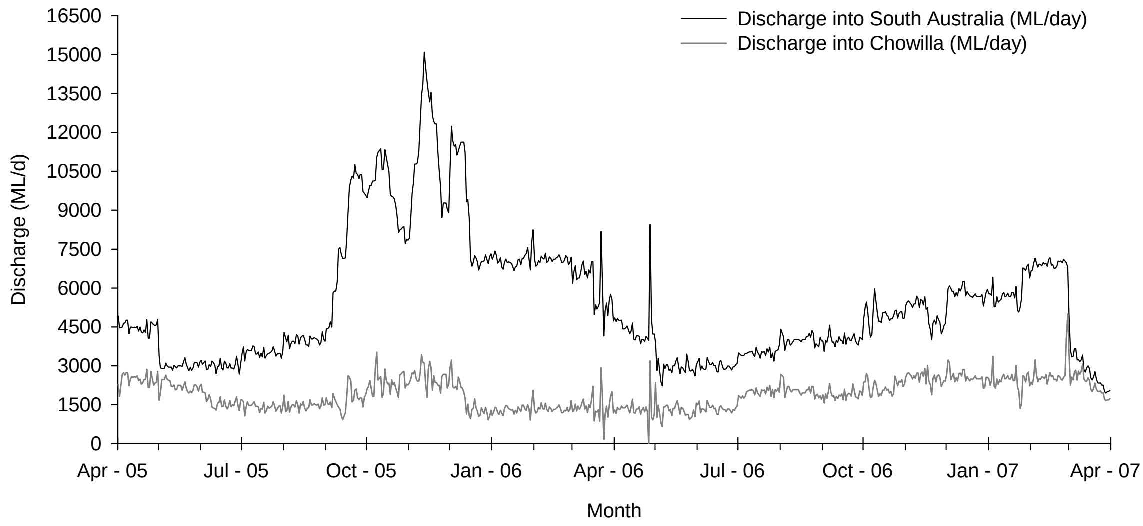

Figure 2. Discharge (ML/d) into South Australia and the Chowilla Anabranch for the period April 2005 to April 2007.

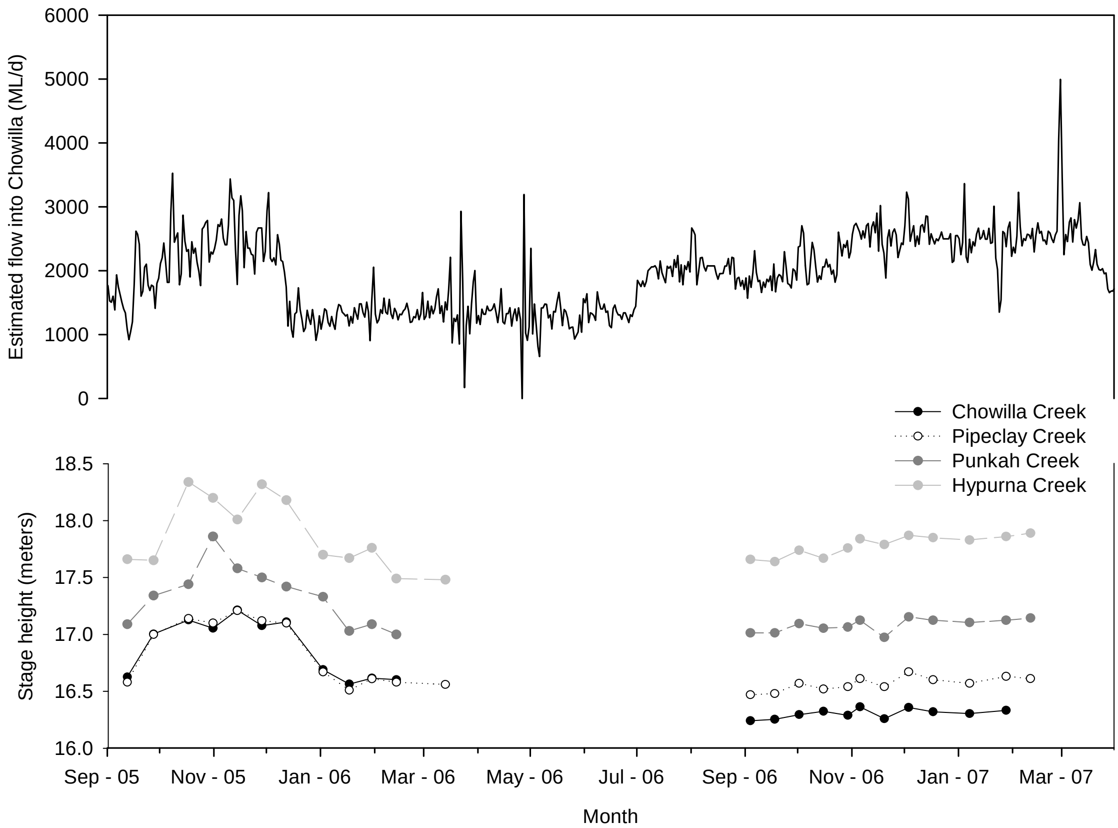

Figure 3. Stage height (mAHD) recorded at four sites within the Chowilla Anabranch System for the period April 2005 to April 2007 plotted with the estimated discharge in Chowilla Creek (ML/d).

Water Physico-chemistry

Water Temperature

Mean daily water temperature was relatively consistent between sites and years with minimum water temperatures in July of approximately 12 ºC and maximum water temperatures in February of approximately 28 ºC (Figure 4). Nevertheless, slow flowing anabranch creeks (i.e. Punkah and Salt Creek) tended to exhibit higher maximum temperatures and greater variability (Figure 4).

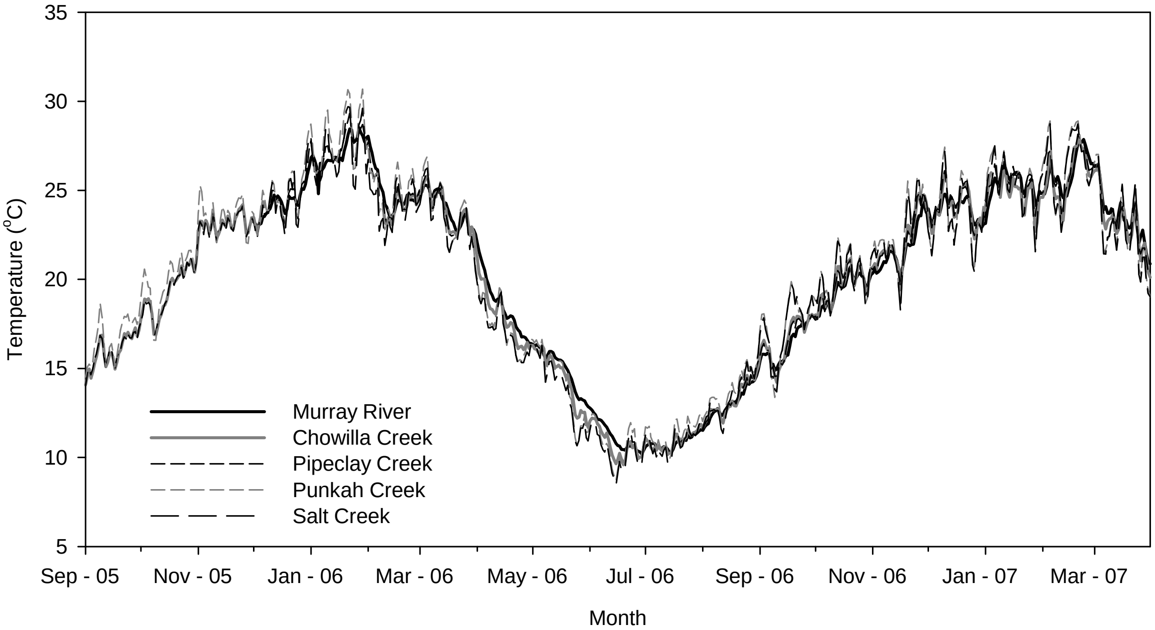

Figure 4. Mean daily water temperature recorded at five sites within the Chowilla Anabranch system and adjacent Murray River for the period September 2005 to April 2007.

Salinity

Salinity as measured by electrical conductivity was relatively low (approximately 150 – 225 μS cm^{-1}) and consistent in the Murray River and Chowilla Creek (Figure 5). However in the slow flowing outer anabranch creeks electrical conductivity was generally higher (approximately 200 – 700 μS cm^{-1}) and more variable (Figure 5).

Mean conductivity readings were consistently slightly higher across sites for the 2005/06 sampling period with the exception of Punkah Creek (Figure 6). Punkah and Salt Creek had higher conductivity readings than other sites for both years. Two-way ANOVA of conductivity data comparing sites and years indicates that there was a significant interaction between sites and years (Table 2)

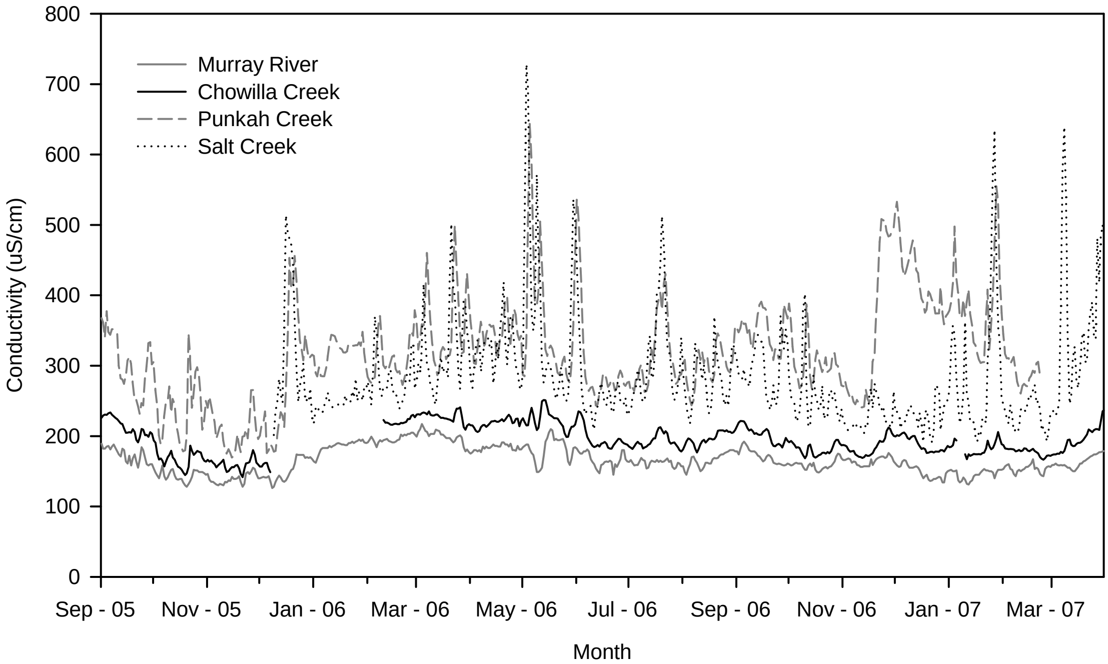

Figure 5. Mean daily electrical conductivity recorded at four sites in the Chowilla Anabranch system and adjacent Murray River during the period September 2005 to April 2007.

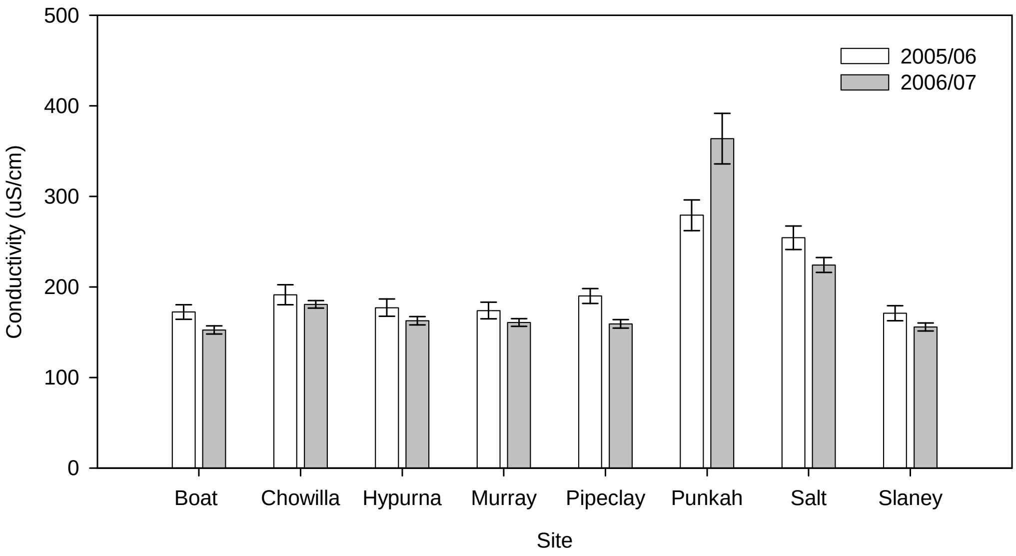

Figure 6. Mean electrical conductivity (µS/cm) and standard error plotted for all sites during both the 2005/06 and 2006/07 sampling seasons.

Table 2. *F* statistics produced from mean conductivity at sites comparing sites and sampling years. Significant comparisons where $P \leq 0.05$.

Factor	*df*	*F*	*P*
Site	7,15	43.631	<0.0001
Year	1,15	0.514	0.474
Site x Year	7,15	5.325	<0.0001

Turbidity

Secchi depth as a measure of water turbidity was generally consistent during the sampling season in 2005/06. The Murray River was characterised by slightly higher secchi depths (lower turbidity) over the sampling period as were Slaney and Pipeclay creeks (Figure 7). In comparison Hypurna and Punkah creeks exhibited lower secchi depths and hence higher turbidity.

A similar trend was seen in 2006/07 where slow flowing outer floodplain creeks (i.e. Hypurna, Punkah and Salt creeks) generally had low secchi depths hence higher turbidities, while inner creeks, directly influenced by the Lock 6 weir pool, such as Boat, Chowilla, Pipeclay and Slaney Creeks and the Murray River had higher secchi depths (Figure 8). Nevertheless, unlike 2005/06, secchi depth at some sites varied considerable over the sampling period, most notably in the Murray River and the associate inner Chowilla creeks. Secchi depths at these sites increased considerably (by 100 – 200 mm) during November and December 2006. This was most likely caused by low flows in the Murray River during this period.

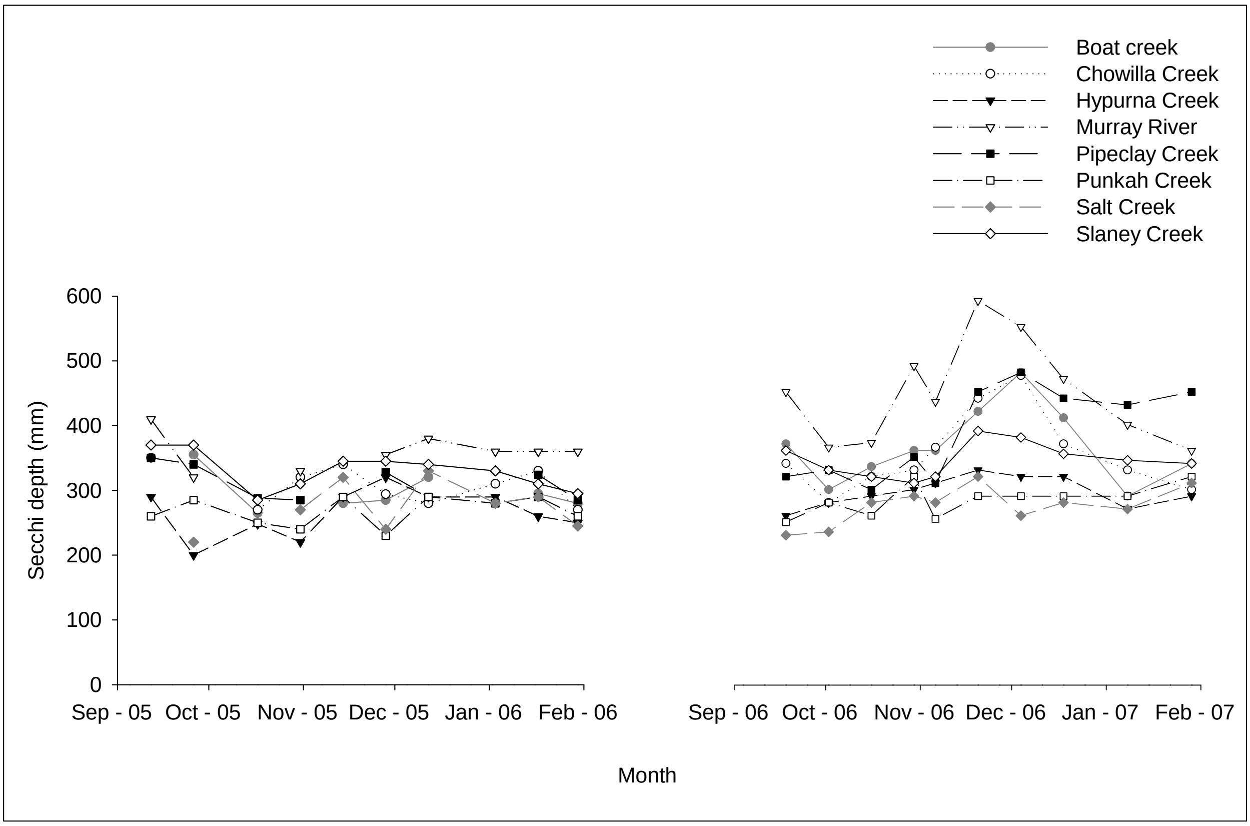

Figure 7. Secchi depth (mm) recorded at each site during the sampling periods 2005/06 and 2006/07.

Larval fish assemblage

In total, 13461 larvae were captured in the Chowilla Anabranch system and adjacent Murray River, representing 7 native and 2 exotic species (Table 3). All species with the exception of golden perch (*Macquaria ambigua*) and exotic redfin perch (*Perca fluviatilis*) were collected in both years. Golden perch were only collected in 2005/06 and redfin perch only in 2006/07.

In both years the catch was dominated by gudgeons (*Hypseleotris* spp. and *Phylipnodon* spp.), Australian smelt (*Retropinna semoni*) and bony herring (*Nematalosa erebi*). The total larval catch was greater in 2006/07 than in 2005/06 (8410 and 3601 larvae respectively) primarily due to greater abundances of Australian smelt, gudgeons, and unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*) in 2006/07 (Table 3).

Two highly regarded recreational fish species were captured as larvae within the Chowilla Anabranch system, namely golden perch and Murray cod (*Maccullochella peelii peelii*). Murray cod are listed as threatened under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*.

Table 3. Total raw abundance of fish captured as larvae (light trap and drift net data combined) for each site sampled within the Chowilla Anabranch system during the 2005/06 and 2006/07 sampling periods.

Common name	Boat Creek		Chowilla Creek		Hypurna Creek		Murray River		Pipeclay Creek		Punkah Creek		Salt Creek		Slaney Creek		Total	
	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07
Unspecked hardyhead	9	4	10	88	5	86	34	224	48	7	5	7	2	8	15	14	128	449
Gudgeon	21	88	407	486	523	176	465	696	275	319	129	175	190	381	320	564	2330	2885
Golden perch	2	-	2	-	1	-	-	-	-	-	-	-	1	-	1	-	7	-
Murray cod	-	1	10	18	-	-	-	2	2	5	3	1	-	-	2	7	17	34
Murray rainbowfish	1	-	2	1	1	1	1	1	1	-	-	-	1	-	-	-	7	3
Bony herring	-	4	61	31	17	2	36	49	8	13	3	12	4	26	72	82	201	219
Australian smelt	9	95	390	878	48	132	40	1572	16	606	121	186	76	538	83	657	783	4664
Carp	29	5	29	12	22	12	-	1	7	37	6	11	26	39	9	8	128	125
Redfin perch	-	1	-	8	-	2	-	4	-	13	-	-	-	-	-	3	-	31
Total	71	198	911	1522	617	411	576	2549	357	1011	267	392	300	992	502	1355	3601	8410

Temporal variation in the presence the larvae

Although the timing, duration and presence of larvae differed for each species, similar intraspecific patterns were apparent between years (Figure 8). Murray cod, golden perch and exotic redfin perch larvae were present for discrete periods. Murray cod larvae were collected in both years from mid October to late November but golden perch were only collected in 2005/06 from late November to early January and redfin perch were only collected in 2006/07 from late September to early November. Larvae of most small-bodied species and bony herring were collected over a protracted period in both years. Gudgeon and Australian smelt appeared in the larval catch from September (the beginning of our sampling season) whilst bony herring, unspecked hardyhead and Murray rainbow fish generally were not collected until mid to late October. Exotic carp larvae were present early in the season in both years for period of approximately 3 months from early September to December.

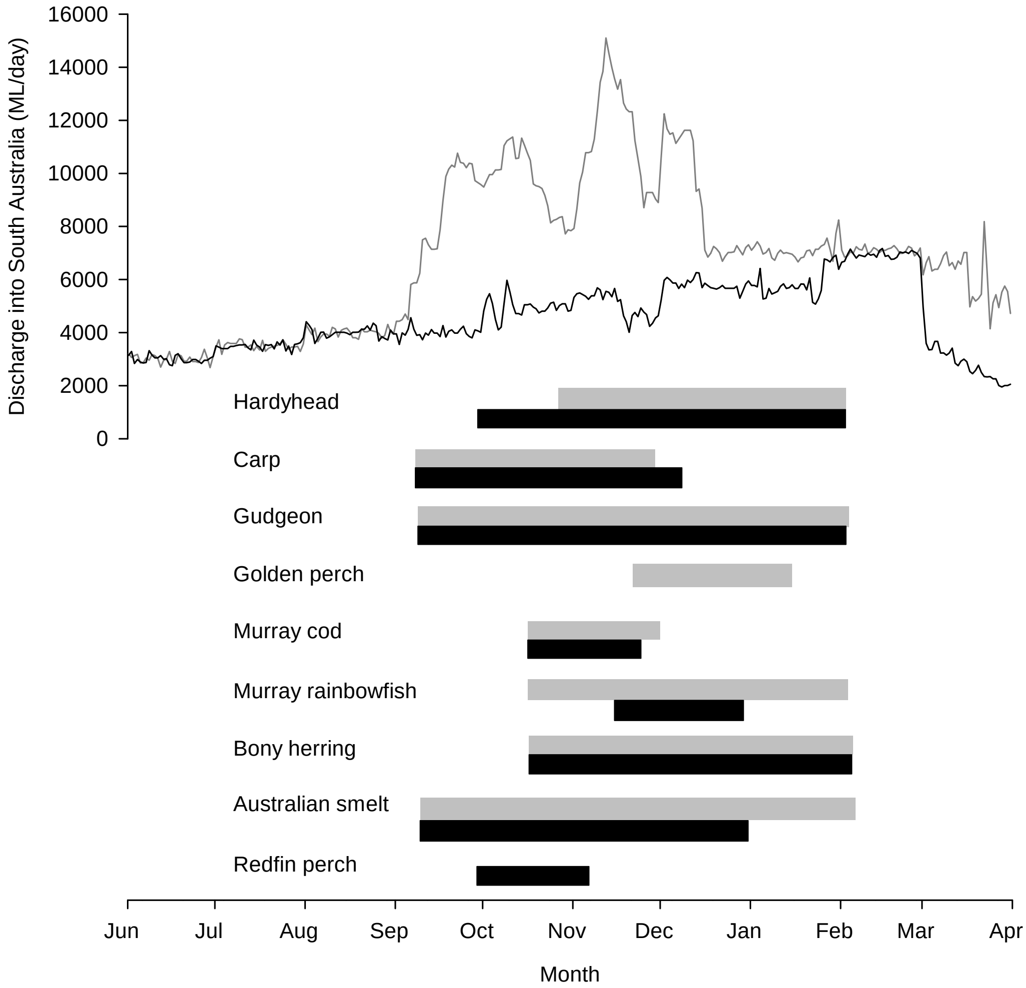

Figure 8. Fish species captured as larvae within the Chowilla Anabranch system during the 2005/06 and 2006/07 sampling events plotted with discharge into South Australia for both years. Grey bars and grey line graph represent 2005/06 and black indicates 2006/07.

Patterns in larval abundance

Table 4. Catch per unit effort (light trap and drift net data combined) of fish captured as larvae for each site sampled within the Chowilla Anabranch system during the 2005/06 and 2006/07 sampling periods.

Common name	Boat Creek		Chowilla Creek		Hypurna Creek		Murray River		Pipeclay Creek		Punkah Creek		Salt Creek		Slaney Creek		Total	
	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	05/06
Unspecked hardyhead	11.9	3.1	6.9	71.6	1.4	21.0	26.5	165.0	34.1	9.0	2.2	3.3	0.7	3.8	8.9	8.5	92.7	285.3
Gudgeon	23.6	61.6	538.6	809.1	6063.4	2337.4	1221.3	1265.9	2245.7	981.8	67.2	675.9	943.3	2934.9	157.9	190.3	11261.0	9256.8
Golden perch	1.3	-	1.3	-	0.8	-	-	-	-	-	-	-	3.5	-	0.7	-	7.7	-
Murray cod	-	0.3	6.0	17.0	-	-	-	2.4	17.1	13.4	2.2	0.7	-	-	0.9	3.2	26.2	37.0
Murray rainbowfish	1.9	-	1.5	0.7	5.7	0.7	0.8	1.8	1.9	-	-	-	1.9	-	-	-	13.8	3.3
Bony herring	-	3.4	155.9	35.8	22.8	97.9	148.7	132.6	285.8	49.0	8.8	29.4	144.7	122.6	44.8	16.5	811.4	487.1
Australian smelt	10.8	54.3	115.1	1473.3	306.6	1242.0	108.9	1799.3	1370.5	2139.2	107.2	1616.1	262.4	3634.6	46.0	324.5	2327.5	12283.3
Carp	34.2	2.8	24.6	12.6	321.7	212.7	-	2.0	36.8	182.2	8.3	139.0	205.8	275.3	3.7	3.1	635.2	829.7
Redfin perch	-	0.7	-	6.1	-	1.4	-	3.8	-	30.6	-	-	-	-	-	1.7	-	44.3
Total	83.8	126.1	849.8	2426.2	6722.3	3913.1	1506.1	3372.9	3991.9	3405.1	196.1	2464.4	1562.3	6971.2	263.0	547.9	15176.8	23226.9

Relative abundance between years

The NMS ordination of the larval fish communities in Table 4 showed that the samples from 2006 and 2007 formed relatively distinct groups (Figure 9). MRPP (A = 0.0098, P = 0.0029) confirmed that the larval fish communities were significantly different between 2005/06 and 2006/07. Indicator Species Analysis showed that the differences were most likely the result of higher abundances of golden perch in 2005/06 and redfin perch and Australian smelt in 2006/07 (Table 5). All other species were present in similar abundances in each year (temporally widespread) (Table 5).

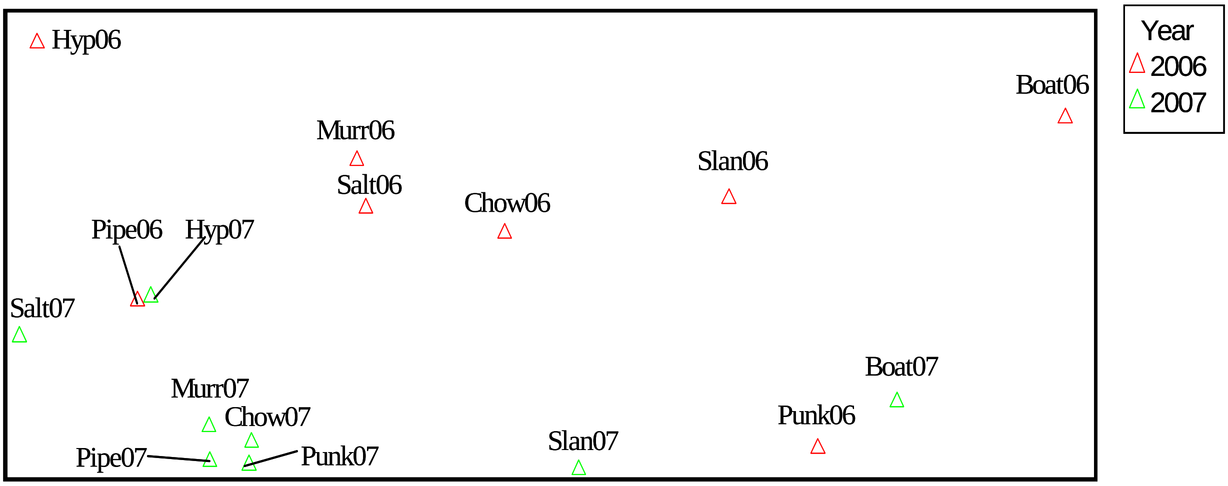

Figure 9. MDS plot showing differences between the two sampling years (2005/06 and 2006/07) (stress = 3.08%).

Table 5. Indicator species analyses comparing the relative abundance of fish species between years. A significant difference (*P*<0.05) indicates that a species occurs in higher abundances in a particular year. Values that are not significant indicate that a species was either sampled in one year in low numbers (U=uncommon) or was sampled in similar abundances over both years (W=widespread).

Species	Year	P-value
Hardyhead	2006/07	0.1184 (W)
Carp	2006/07	0.4117 (W)
Gudgeon	2005/06	0.6347 (W)
Golden perch	2005/06	**0.0246**
Murray cod	2006/07	0.5787 (W)
Murray rainbowfish	2006/07	0.3923 (W)
Bony herring	2006/07	0.6583 (W)
Australian smelt	2006/07	**0.0004**
Redfin perch	2006/07	**0.0026**

Relative abundance between sites

The cluster analysis based on the relative abundances of larval fish from both years showed two distinct groups at a similarity of 25% (Figure 10). The two fast flowing creeks namely Boat and Slaney Creek formed group 1. Punkah Creek, a slow flowing creek, was also present in this group but only in 2005/06 (Figure 10). Group 2 contained the slow flowing creeks (Chowilla, Salt, Hypurna, Pipeclay Creeks and Punkah Creek 2006/07) and the Murray River site. Indicator species analysis showed that gudgeons, bony herring, Australian smelt and carp were significant indicators of the group that contained the majority of slow anabranch and Murray River sites (Table 6).

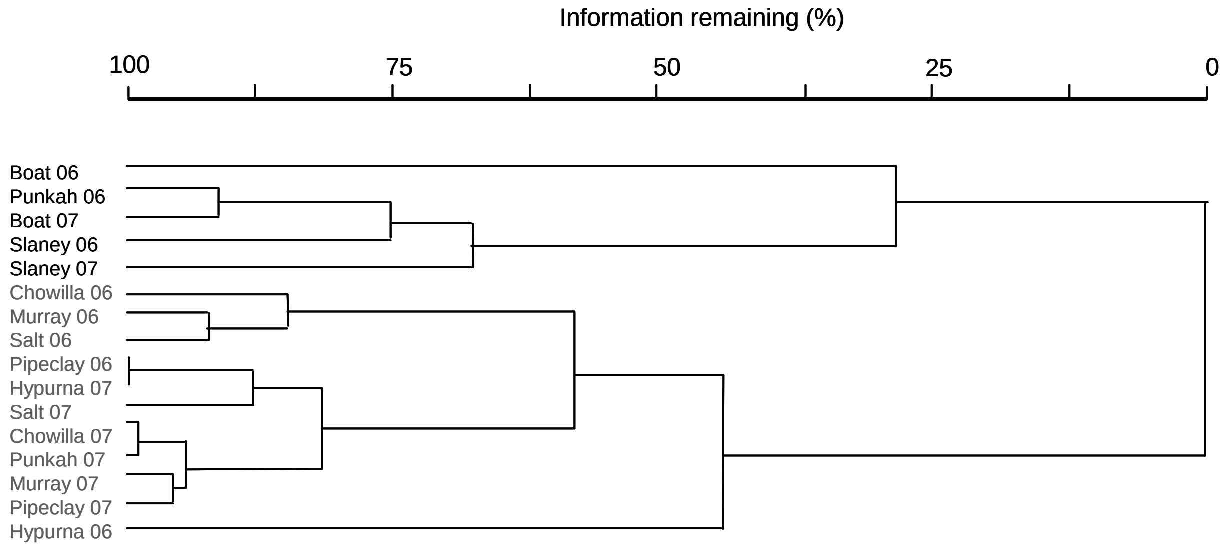

Figure 10. UPGMA cluster dendrogram of sites based on total CPUE abundances for each year. The dendrogram was timed at 25% similarity to produce two groups with significantly different larval fish assemblages.

Table 6. Indicator species analyses comparing the relative abundance of fish species between sites. A significant difference (P<0.05) indicates that a species occurs in higher abundances in a particular group (group 1 or 2 identified by cluster analysis). Values that are not significant indicate that a species was either sampled in one group in low numbers (U=uncommon) or was sampled in similar abundances in both groups (W=widespread).

Species	Group	P-value
Hardyhead	2	0.1608 (W)
Carp	2	**0.0374**
Gudgeon	2	**0.0002**
Golden perch	1	0.7998 (W)
Murray cod	2	0.5339 (W)
Murray rainbowfish	2	0.1812 (W)
Bony herring	2	**0.0010**
Australian smelt	2	**0.0036**
Redfin perch	2	0.3489 (W)

Relative abundance between aquatic macrohabitats

The grouping of sites based on cluster analysis is further supported by a comparison of relative larval fish abundance between aquatic macrohabitats (MRPP, $A = 0.0377$, $P < 0.0001$), which showed that fast anabranch macrohabitats had significantly different larval communities than both slow anabranch (SA) and main channel (MC) habitats but that slow and main channel habitats did not differ (FA ≠ SA = MC). Indicator species analysis revealed that gudgeons, bony herring and Australian smelt occurred in significantly higher abundances in slow anabranch macrohabitats (Table 7).

Table 7. Indicator species analyses comparing the relative abundance of fish species in three aquatic macrohabitat categories. A significant difference ($P<0.05$) indicates that a species occurs in higher abundances at a particular macrohabitat type. Values that are not significant indicate that a species was either sampled in one macrohabitat in low numbers (U=uncommon) or was sampled in similar abundances in both macrohabitats (W=widespread).

Species	Macrohabitat type	P-value
Hardyhead	Slow Anabranch	0.2973 (W)
Carp	Slow Anabranch	0.0652 (W)
Gudgeon	Slow Anabranch	**0.0018**
Golden perch	Fast Anabranch	0.4445 (W)
Murray cod	Slow Anabranch	0.4847 (W)
Murray rainbowfish	Slow Anabranch	0.3443 (W)
Bony herring	Slow Anabranch	**0.0094**
Australian smelt	Slow Anabranch	**0.0124**
Redfin perch	Slow Anabranch	0.4467 (W)

Microhabitat Availability

There was a greater percent cover of submergent and floating aquatic macrophytes in both the slow anabranch sites and Murray River site than in fast anabranch sites (Figure 11). Emergent aquatic macrophytes, however, constituted a greater percent cover in fast flowing sites (Figure 11). The percent cover of woody debris (all types) was similar across macrohabitats although the percent cover of CWD 3 was slightly higher in fast anabranch sites.

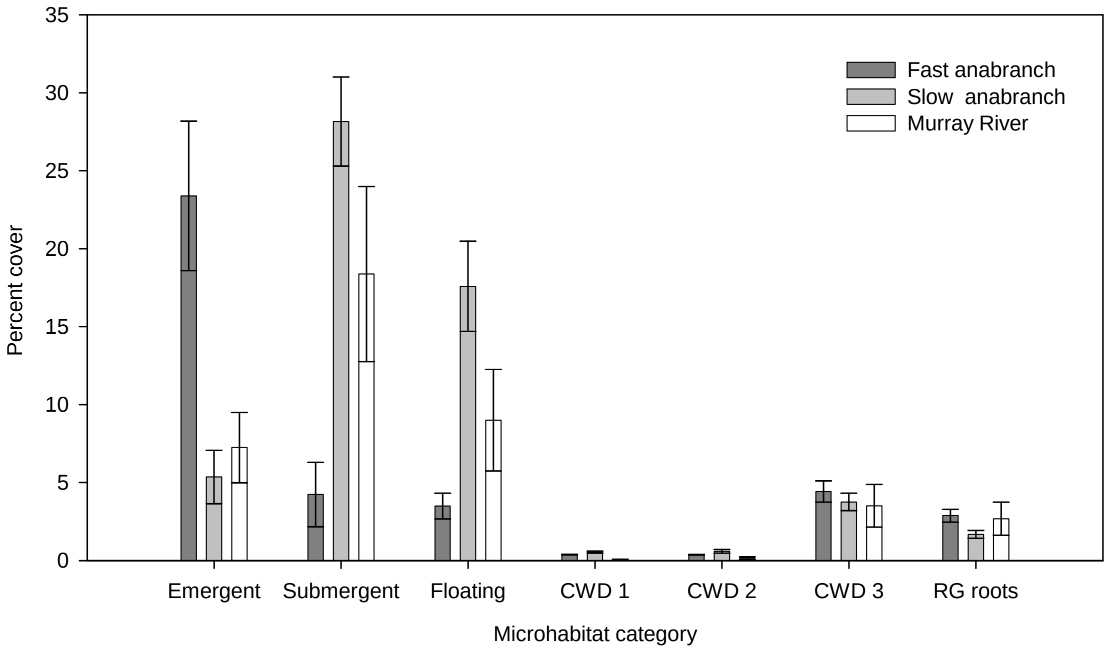

Figure 11. Percent cover of each microhabitat category present within three macrohabitat types, namely fast and slow anabranches and the Murray River.

Discussion

Hydrology

Due to the number of creeks entering the Chowilla system and the combined influence of Murray River discharge and Lock 6 weir pool height, the relationship between discharge in the Murray River and Chowilla Creek is not well quantified. At low Murray River flows (i.e. <3,000 ML/d) up to 90% of the discharge into South Australia (SA) may pass through Chowilla Creek. This proportion decreases as discharge in the Murray increases until at Murray flows of 20,000 ML/d only 10% of discharge to SA flows through Chowilla Creek.

Flows during the study period were generally low with entitlement flows (3,000 ML/d) delivered in the winter of 2005 and 2006 and a small rise in flow in the spring/summer of 2005/06 to a peak of 15,000 ML/d before a return to normal summer entitlement flows (7,500 ML/d) in late December 2005. Due to ongoing drought conditions in the Murray-Darling Basin flows less than the 7,500 ML/d summer entitlement flow were delivered over the spring and summer of 2006/07 with flows ranging from 4,500 to 6,500 ML/d. All flows were well below a bank-full or flood flow of approximately 50,000 ML/d.

The increase in flow in spring 2005 combined with a raising of the Lock 5 weir pool by 0.5 m resulted in an increase in water surface level of 0.5 – 0.7 m in most creeks in the Chowilla system compared to water surface levels observed in spring 2006. Furthermore, we observed a considerable increase in discharge and water velocity in Punkah and Salt Creeks. This increase, particularly in Punkah Creek, resulted in the hydraulics of these outer anabranches appearing more like the fast flowing inner anabranches.

Water physico-chemistry

In general, water physio-chemistry (water temperature, salinity and turbidity) in the inner fast flowing creeks (Slaney and Boat) and Chowilla Creek closely resembled the Murray River, with similar ranges and variability. Water temperature ranged from approximately 12 to 28 ºC in both years and conductivity was low (~200 µS/cm). Secchi depth (as a measure of turbidity) ranged from 300 to 400 mm in 05/06 but was greater (350 to

600 mm) in 06/07. This increase in water transparency was most likely a result of low discharge in the Murray River and the delivery of water from the upper Murray River rather than Lake Victoria.

Sites on the slow flowing outer creeks (Punkah, Salt and Hypurna) were generally characterised by greater daily temperature variation and lower winter, and higher summer temperatures (range 9 to 30 ºC) than the fast flowing creeks, Chowilla Creek and the Murray River. Conductivity was more variable and generally higher (range 200 to 700 µS/cm), and secchi depths were less (range 200 to 300 mm). The outer creeks are less influenced by the Murray River and are generally wider and shallower than the fast flowing creeks (Sheldon and Lloyd 1990; Zampatti and Leigh 2005). Consequently, the slow flowing creeks are more affected by wind, leading to resuspension of fine sediment and increased turbidity. Furthermore these creeks have less thermal mass than the Murray River so water temperature is more affected by ambient air temperature. The outer creeks such as Salt and Punkah are also the first to intercept elevated saline groundwater flowing from the north (DWLBC 2006). The significant increase in salinity in Punkah Creek in 2006/07 is likely due to decreased discharge in this creek compared to 2005/06 leading to greater groundwater discharge.

Salinisation of aquatic systems can lead to a range of potential impacts, including direct toxicity, changed chemical processes and loss of instream, riparian and floodplain habitat (James *et al.* 2003). Native fishes of the lower MDB, however, have a natural level of tolerance and resilience to salinity as a result of the hydro geomorphic history of the Basin. As such, salinities of the magnitude measured in the current study (i.e. 150 – 700 µS/cm) are unlikely to have direct toxic effects on any life stages of the fish species collected as larvae (Williams 1987b; Williams and Williams 1991; Guo *et al.* 1993; James *et al.* 2003). It is also unlikely that current salinities are negatively impacting on instream habitat, particularly aquatic macrophytes (e.g. Morris 1998). Consequently, under current conditions, salinity is unlikely to structure larval fish assemblages in the lotic environments sampled in the Chowilla Anabranch system. Nevertheless, the potential impact of salinity on microinvertebrates, an important food source for larval fish, may need to be considered. Kefford *et al.* (2007) demonstrated salinity may be lethal to microinvertebrates at lower concentrations than it is to macroinvertebrates and fish.

Also of potential concern are the salinities that have previously been recorded on the recession of floodwaters from the Chowilla floodplain. Following a 60,000 ML/d flood in November 1984 conductivities of between 11,000 and 63,000 µS/cm were recorded at sites on Salt and Punkah Creeks as flows returned to entitlement (~3,000 ML/d) in May 1985 (Stace and Greenwood 2004). These spikes, the result of concentrated saline water draining off the floodplain may be cause for considerable concern following the next inundation of the floodplain given that salt has not been flushed from the Chowilla floodplain for at least the past 10 years.

Larval fish assemblage

Of the nine species of fish larvae recorded during the present study, seven were native and two exotic. All species were collected in both years with the exception of golden perch in 2006/07 and exotic redfin perch in 2005/06. In both years the most abundant species were gudgeons and Australian smelt, both small-bodied native species. All species collected as larvae in the Chowilla Anabranch system have also been collected as juveniles and adults in the region (Zampatti *et al.* 2006). Three species, however, that have been collected as adults were not collected as larvae, namely silver perch (*Bidyanus bidyanus*), freshwater catfish (*Tandanus tandanus*) and gambusia (*Gambusia holbrooki*).

Silver perch are considered a flow cued spawner (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003) and may have been expected to be present when larval golden perch, also considered a flow cued spawner, were present. Silver perch larvae were collected by a separate investigation in the Murray River following the 2005/06 flow event (Cheshire unpublished data) but may have been absent, or present in very low abundances, in the Chowilla system. Adult freshwater catfish occur in low abundances in the Chowilla system and low numbers of larval catfish were collected using sweep net electrofishing (King and Crook 2002) in a separate investigation in 2004/05 (Zampatti unpublished data). Exotic gambusia is abundant in Chowilla and the adjacent Murray River, nevertheless, larval gambusia are generally not collected using drift nets and light traps.

Temporal variation in the larval fish assemblage

Inter-annual variation

The relative abundance of larvae captured in 2006/07 was greater than in 2005/06 due primarily to significantly higher abundances of Australian smelt. These results concur with those of King *et al.* (2007) for a similar study in the Barmah-Millewa region of the mid Murray, and Cheshire and Ye (2008) for the main channel of the Murray River in South Australia. Both studies collected substantially higher numbers of Australian smelt in 2006/07 compared to 2005/06. The mechanism for this increase in abundance of Australian smelt larvae is unclear. Australian smelt typically inhabit slow flowing or lentic habitats and Lintermans (2007) suggests it is collected in highest abundances in these habitats. These habitats were more common in the Chowilla system in 2006/07 during low flows and may have resulted in increased spawning success for this species.

The relative abundances of most species did not differ significantly between years, with the exception of golden perch and exotic redfin perch. Golden perch larvae were only collected in 2005/06 in association with a small but prolonged increase in discharge over the spring/early summer period. Golden perch larvae were also collected during this time at a number of locations in the main channel of the Murray River in South Australia but not in the same period in 2006/07 (Cheshire and Ye 2008). Golden perch is recognised as a flow cued spawner (Humphries *et al.* 1999, Mallen-Cooper and Stuart 2003) and the presence of larvae in Chowilla and the Murray River main channel supports the notion that this species may spawn on relatively small increases in discharge. Nevertheless, the relationship between flow and recruitment to the adult population remains uncertain. The success of such a spawning event will ultimately be determined by larval survival and subsequent contribution to the adult or spawning population. Therefore monitoring the age structure in the adult population in conjunction with larval studies is recommended.

It also remains unclear if the golden perch larvae captured within the Chowilla region occurred as a result of a spawning event within in the Chowilla anabranch or were drifting larvae spawned further upstream. Nevertheless, regardless of spawning site, it is likely that the Chowilla Anabranch provides an ideal habitat for growth and development because of the diverse aquatic habitats available within the system.

Redfin perch larvae were only collected during the 2006/07 season albeit from all three aquatic macrohabitats. Redfin perch have been conspicuous in their absence from the juvenile/adult fish community in the Chowilla system (Zampatti unpublished data) and little is documented on their ecology in the lower Murray River. The absence or low abundance of redfin perch larvae is most likely a result of the current low abundance of this species within the region.

Intra-annual variation

In both years fish larvae were present throughout the study period. Most species, with the exception of golden perch and redfin perch, appeared to have spawned each year and the timing and duration of occurrence of larvae for each species was relatively consistent between years. Nevertheless, there was considerable inter-specific variation in the timing and duration of occurrence of larvae in any given year. Species could generally be grouped as having a discrete or prolonged and a late or early spawning season. Species present as larvae at the beginning of our sampling season (September) were gudgeons, Australian smelt and exotic carp. Gudgeons and Australian smelt were generally present for the entire sampling season (September to February) and can be considered as having the most prolonged spawning season of the species collected. Carp larvae were present from September until December but may have been present prior to the start of sampling thus suggesting they have an early commencing, prolonged spawning season.

Unspecked hardyhead, Murray rainbow fish and bony herring were first collected in October-November and were then present throughout the season until sampling ceased in February and can be considered as having late commencing, prolonged spawning periods. The species with the most discrete periods of occurrence were Murray cod, golden perch (in 2005/06) and redfin perch (in 2006/07). The timing and duration of occurrence of Murray cod larvae has been well documented in the mid reaches of the Murray River and several tributaries (Humphries 2002; Humphries 2005; King *et al.* 2005; Koehn and Harrington 2006). Larvae have been documented as beginning to drift early in November and extending until mid December. In the Chowilla system, however, Murray cod larvae were collected in the drift by mid October, thus suggesting that Murray cod may spawn earlier in the lower reaches of the Murray River. Water temperature may be an important stimulus for Murray cod spawning and a threshold of approximately 15 ºC has been proposed (Humphries 2005; Koehn and Harrington 2006).

This water temperature was reached by early September in 2005/06 and 2006/07 in the Chowilla system and may result in earlier spawning than the mid reaches of the Murray River.

Low numbers of golden perch larvae were collected in 2005/06 in association with a small but prolonged within-channel rise in discharge. No larvae were collected when discharge was relatively stable in 2006/07. Golden perch larvae were present in the catch for approximately a two month period, from late November to mid January. Unlike Murray cod, golden perch do not appear to spawn annually and instead appear to rely on a hydrological cue (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003).

Redfin perch larvae were only collected for a brief period between October and November 2006/07. Humphries (2002) observed a similar discrete period of occurrence for redfin perch larvae in the Campaspe and Broken Rivers (tributaries of the mid reaches of the Murray River) and a similar timing (October-November). Nevertheless, Humphries (2002) recorded the occurrence of redfin larvae on an annual basis over four years. Conversely, Engledow and Vilizzi (2006) only recorded redfin perch larvae in one year (2005/06) of a five year investigation of larval fishes in the Lindsay-Mullaroo system in the lower reaches of the Murray River. From the available data it appears that redfin perch spawning and/or survival to the larval stage may not occur annually in the lower Murray River.

For all of the species collected as larvae in the current study, similar temporal patterns of occurrence have been observed for other regions in the MDB, nevertheless, initial timing of occurrence for a number of species appears earlier in the Chowilla and Lindsay systems than in the mid reaches of the Murray River (Humphries 2002; Meredith *et al.* 2002; Engledow and Vilizzi 2006; King, *et al* 2007).

<u>Spatial variation in the larval fish assemblage</u>

Species richness and diversity of larval fish was similar across all sites. Most species were widespread although generalist species such as gudgeons, Australian smelt, unspecked hardyhead and carp were present in significantly higher abundances in a group of sites that contained slow flowing anabranch sites and the Murray River. Fast anabranch creeks such as Slaney and Boat creek formed another distinct group which also included

Punkah Creek in 2005/06. During the 2005/06 increase in discharge the hydraulics of Punkah Creek more closely resembled those of the fast flowing creeks; consequently this may have structured the larval fish assemblage to one similar to that observed in the fast flowing creeks.

Gudgeons, bony herring and Australian smelt were captured in significantly higher abundances in slow flowing macrohabitats. The use of still or slow flowing areas by fish larvae has been widely documented (Scheidegger and Bain 1995; Merigoux and Ponton 1999). Research within the Lindsay Island region, an anabranch system immediately upstream of the Chowilla region, identified a similar trend in larval abundances in still-slow flowing environments (Meredith *et al.* 2002; Engledow and Villizzi 2006). Humphries *et al.* (1999) suggests that these slow flowing environments provide ideal habitats for larval fish due to greater densities of food items and less turbulence. Our data also indicate that slow anabranch habitats, including the Murray River, were characterised by greater percent cover of submerged aquatic macrophytes than fast flowing anabranches. This complex habitat is considered an important spawning and rearing habitat for small bodied species such as gudgeons and Australian smelt and may help explain the significantly greater abundance of larvae in this hydraulic macrohabitat.

Exotic carp larvae were found to be significantly associated with sites grouped as slow flowing habitats. Adult and juvenile carp have also been shown to prefer slow flowing and backwater habitats, and have been shown to be significantly associated with areas with a high percent cover of submerged aquatic macrophytes (*Valisneria spiralis* and *Potamogeton crispus*) within the Chowilla Anabranch system (Zampatti *et al.* 2006). These findings suggest that slow flowing environments in the Chowilla system are potential spawning and recruitment habitats for this species.

Murray cod and golden perch were captured in low abundances and were not significantly associated with a macrohabitat type, although abundances of both these species were generally higher in fast flowing anabranches and Chowilla Creek. Adult Murray cod occur in significantly higher abundances in the fast flowing macrohabitats of the Chowilla system (Zampatti *et al.* 2006) and we propose that spawning takes place in these creeks and larvae are then transported to the slow flowing Chowilla Creek. Such slow flowing environments are less turbulent and potentially more productive thus providing abundant zooplankton as a food source for larval fish (Humphries *et al.* 1999). This spatial separation of habitats is a permanent feature of the Chowilla system and represents a process that would normally be temporally defined during floods in the Murray River.

The Chowilla Anabranch system provides a complex of physical and hydraulic habitats that support a range of life-history phases of native and exotic fish species. The separation of spawning (fast flowing anabranches) and rearing habitats (slow flowing anabranches) particularly for large bodied native fish species is a facet of the Chowilla system that is now absent from the homogeneous weir pool habitats of the lower Murray River. Importantly, the habitat complexity and hydraulic diversity present within the system facilitate some level of recruitment of threatened species such as Murray cod in the absence of detectable recruitment in the main channel of the Murray River in South Australia (Ye and Zampatti 2007). The conservation of the diverse range of aquatic macrohabitats in the Chowilla Anabranch system, along with restoration of a more variable flow regime, will aid in maintaining and potentially restoring native fish populations in the lower Murray River.

Conclusions

- In general, water physico-chemistry in the inner fast flowing creeks of the Chowilla Anabranch system (i.e. Boat and Slaney creeks) and Chowilla Creek closely resembled the Murray River, with similar ranges and variability. Salinities in these creeks throughout the study period were low (~200 μS/cm). Sites on the outer slow flowing creeks (i.e. Punkah, Salt and Hypurna), however, were generally characterised by greater variation in temperature, salinity and turbidity due to their shallow nature, the interception of saline groundwater, and less hydrological influence from the Lock 6 weir pool. The maximum conductivity recorded during the study was 728 μS/cm in Salt Creek.

- Salinities of the magnitude measured in the current study (< 750 μS/cm) are unlikely to have direct toxic effects on any life stages of the fish species collected as larvae. Nevertheless, historical salinity spikes (> 60,000 μS/cm) in the outer creeks following floodplain inundation may be of concern. The Chowilla Floodplain has not been inundated for at least the past 10 years and salinities in the receiving creeks following the next flooding event are likely to be high. Furthermore, salinisation and the consequent degradation of the riparian zone and floodplain in the Chowilla system may have long-term impacts on native fish populations.

- Nine species of fish larvae were recorded during the present study, seven native and two exotic. The relative abundance of larvae captured in 2006/07 was greater than in 2005/06 due primarily to significantly higher abundances of Australian smelt. The relative abundances of all other species did not differ significantly between years, with the exception of golden perch and exotic redfin perch. Golden perch larvae were only collected in 2005/06 in association with a small but prolonged increase in discharge over the spring/early summer period.

- For all of the species collected as larvae in the current study, similar temporal patterns of occurrence have been observed for other regions in the MDB, although the initial timing of occurrence for a number of species appears earlier in the Chowilla and Lindsay Anabranch systems than in the mid reaches of the Murray River.

- Most species were widespread although generalist species such as gudgeons, Australian smelt, carp and unspecked hardyhead were present in significantly higher abundances in a group of sites that contained slow flowing anabranch sites and the Murray River. These sites were characterised by greater percent cover of submerged aquatic macrophytes than fast flowing anabranches. This complex habitat is considered an important spawning and rearing habitat for small bodied species such as gudgeons and Australian smelt and may help explain the significantly greater abundance of larvae in this hydraulic macrohabitat.

- The Chowilla Anabranch system provides a complex of physical and hydraulic habitats that support a range of life-history phases of native and exotic fish species. The separation of spawning (fast flowing anabranches) and rearing habitats (slow flowing anabranches) particularly for large bodied native fish species (e.g. Murray cod) is a facet of the Chowilla system that is now absent from the homogeneous weir pool habitats of the lower Murray River.

- Abundances of Murray cod larvae were generally higher in fast flowing anabranches and Chowilla Creek. Adult Murray cod occur in significantly higher abundances in the fast flowing macrohabitats of the Chowilla system and we propose that spawning takes place in these creeks and larvae are then transported to the slow flowing Chowilla Creek, a high productivity, low turbulence environment that may benefit larval survival. As such, the Chowilla system facilitates some level of recruitment of Murray cod in the absence of detectable recruitment for at least the past seven years in the main channel of the Murray River in South Australia.

Management implications and future research

The Chowilla Anabranch system provides a complex of physical and hydraulic habitats that support a range of life-history phases of native and exotic fish species. The separation of spawning (fast flowing anabranches) and rearing habitats (slow flowing anabranches) particularly for large bodied native fish species (e.g. Murray cod) is a facet of the Chowilla system that is now absent from the homogeneous weir pool habitats of the lower Murray River. Furthermore, different aquatic macrohabitats (i.e. fast and slow flowing anabranches) in Chowilla are characterised by significantly different larval fish assemblages. As such, any alteration to the hydrodynamics of the Chowilla system (e.g. changes to discharge or operation of existing and proposed regulatory structures) should consider the potential impacts on fish assemblage structure, and spawning and recruitment. This is particularly important for threatened Murray cod for which the Chowilla system appears to have supported recruitment in the absence of detectable recruitment during a low flow period (2001-2008) in the main channel of the Murray River in South Australia (Ye and Zampatti, 2007).

The Chowilla Anabranch system is one of three significant anabranch systems in the lower Murray River, along with Katarapko Creek, the Pike/Mundic system and the Lindsay/Mullaroo system. The contribution of these flowing anabranch systems to the long-term recruitment success of freshwater fish in the Murray River is largely unknown and requires investigation. Anabranch systems may also provide important structural habitat (e.g. large woody debris) at higher densities than the main river channel. Further investigation of the association between fish population dynamics and physical and hydraulic habitat in other anabranch systems, and the main river channel, is required to improve our understanding of the role of anabranches in the lower Murray River.

Salinities of the magnitude measured in the current study are unlikely to have direct toxic effects on any life stages of the fish species collected as larvae. Nevertheless, historical salinity spikes (> 60,000 μS/cm) in the outer creeks following floodplain inundation may be of concern. Inundation of the Chowilla Floodplain has not occurred for at least the past 10 years and hence salinities in the receiving creeks following the next flooding event are likely to be high. The potential impact of this high salinity runoff on fish spawning and early life history stages is not understood and should be closely monitored.

In addition, the impact of salinity on microinvertebrates, an important larval fish food source, should be investigated.

Golden perch larvae were only collected in 2005/06 in association with a small but prolonged increase in discharge over the spring/early summer period. The presence of larvae in Chowilla and the Murray River during this small increase in discharge supports the notion that this species is a flow cued spawner (Humphries *et al.* 1999, Mallen-Cooper and Stuart 2003). Nevertheless, the relationship between flow and recruitment to the adult population remains uncertain. The success of such a spawning event will ultimately be determined by larval survival and subsequent contribution to the adult or spawning population. Therefore monitoring the age structure in the adult population in conjunction with larval studies is recommended.

Our investigations were conducted over two years during an eight year period of unprecedented (since river regulation) low flows in the lower Murray River. Significant over bank flows (floods) have not occurred in the Chowilla system since the mid 1990s. Consequently our results and the conclusions drawn from this study reflect the larval ecology of this system during relatively low within-channel flows. Given the importance of riverine/floodplain interactions in lowland rivers (*sensu* Bunn *et al.* 2006), and the impact of this on productivity and larval survival, we strongly suggest that these investigations are repeated during a high flow event that facilitates extensive floodplain inundation.

References

Arthington, A. H., and Pusey, B. J. (2003) Flow restoration and protection in Australian rivers. *River Research and Applications*. **19:** 377-395.

Boys, C. A. and Thoms, M. C. (2006) A large-scale, hierarchical approach for assessing habitat associations of fish assemblages in large dryland rivers. *Hydrobiologia*. **572:** 11-31.

Bray, J. R. and Curtis, J. T. (1957) An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* **27:** 325-349.

Bunn, S. E. and Arthington, A. H. (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*. **30(4):** 492-507.

Bunn, S. E., Thoms, M. C., Hamilton, S. K. and Capon, S. J. (2006). Flow variability in dryland rivers: boom, bust and the bits in between. *River Research and Applications* **22:** 179-186.

Cadwallader, P. L. (1978) Some causes of the decline in range and abundance of native fish in the Murray-Darling River system. Proceedings of the Royal Society of Victoria. **90:** 211-224.

Carter, J. and Nicolson, C. (1993) *Wetland Management. A manual for wetlands of the River Murray in South Australia*. South Australian Department of Environment and Land Management.

Cheshire, K. and Ye, Q. (2008) *Raising the bar: monitoring the response of larval fish assemblages to water level manipulations bellow Locks 5 and 6, in the River Murray, South Australia.* Report to the Department of Water, Land and Biodiversity Conservation. SARDI Aquatic Sciences.

Dufrene, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*. **67:** 345-366.

DWLBC (2006) *Asset Environmental Management Plan: Chowilla Floodplain (excluding Lindsay – Wallpolla) Significant Environmental Asset.* DWLBC.

Engledow, K. and Vilizzi, L. (2006) *Flow-related patterns in the abundance and distribution of lowland river fish communities: Lindsay Island, Victoria.* Technical Report 08/06. Murray-Darling Freshwater Research Centre, Mildura.

Floyd, K. B., Hoyt, R. D. and Pimbrook, S. (1984) Chronology of appearance and habitat partitioning by stream larval fishes. *Transactions of the American Fisheries Society* **112:** 280-285.

Gehrke, P. C., Brown, P., Schiller, C. B., Moffatt, D. B. and Bruce, A. M. (1995) River regulation and fish communities in the Murray-Darling River system, Australia. *Regulated Rivers: Research and Management.* **11:** 363-375.

Gippel, C. J. and Blackham, D. (2002) *Review of environmental impacts of flow regulation and other water resource developments in the River Murray and Lower Darling River system.* Final report by Fluvial Systems Pty Ltd, Stockton, to Murray-Darling Basin Commission, Canberra, ACT.

Graham, R. and Harris, J. H. (2005) *Floodplain inundation and fish dynamics in the Murray-Darling Basin. Current concepts and future research: a scoping study.* CRC for Freshwater Ecology. ISBN 0-9751642-09.

Guo, R., Mather, P. B. and Capra, M. F. (1993) Effect of salinity on the development of silver perch (*Bidyanus bidyanus*) egg and larvae. *Comparative Biochemistry and Physiology.* **104A:** 531-533.

Houde, E. D. (1987) Fish early life dynamics and recruitment variability. *American Fisheries Society Symposium.* **2:** 17-29.

Humphries, P. and Lake, P. S. (2000) Fish larvae and the management of Regulated Rivers. *Regulated Rivers: Research and Management.* **16:** 421-432.

Humphries, P., King, A. J. and Koehn, J. D. (1999) Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes*. **56:** 129-151.

Humphries, P., Serafini, L. G. and King, A. J. (2002) River regulation and fish larvae: variation through space and time. *Freshwater Biology*. **47:** 1307-1331.

Humphries, P. (2005) Spawning time and early life history of Murray cod, *Maccullochella peelii peelii* (Mitchell) in an Australian river. *Environmental Biology of Fishes*. **72:** 393-407.

Jacobs, T. A. (1990) *River regulation*. In Mackay, N., and Eastburn, D. (eds), The Murray. Murray-Darling Basin Commission. Canberra, ACT pp. 39-58.

Jacobs, T. A. (1989) *Regulation of the Murray-Darling River System*. In Proceedings of the workshop on native fish management. Murray-Darling Basin Commission. Canberra, ACT pp 55-96.

James, K. R., Cant, B. and Ryan, T. (2003) Responses of freshwater biota to rising salinity levels and implications for saline water management: a review. *Australian Journal of Botany*. **51:** 703-713.

Kefford, B. J., Fields, E. J., Clay, C. and Nugegoda, D. (2007) Salinity tolerance of riverine microinvertebrates from the southern Murray-Darling Basin. *Marine and Freshwater Research*. **58:** 1019-1031.

King, A. J. and Crook, D. A. (2002). Evaluation of a Sweep Net Electrofishing Method for the Collection of Small Fish and Shrimp in Lotic Freshwater Environments. *Hydrobiologia*. **472:** 223-233.

King, A. J., Humphries, P. and Lake, P. S. (2003) Fish recruitment on floodplain: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences*. **60:** 773-786.

King, A. J., Crook, D. A., Koster, W. M., Mahoney, J. and Tonkin, Z. (2005) Comparison of larval fish drift in the Lower Goulbourn and mid-Murray Rivers. *Ecological Management and Restoration*. **6(2):** 136-139.

King, A. J., Tonkin, Z. and Mahoney, J. (2007) *Assessing the effectiveness of environmental flows on fish recruitment in Barmah-Millewa Forest.* Prepared by Arthur Rylah Institute for Environmental Research, DSE. MDBC Project No. BMF 2004.09.

Kingsford, R. T. (2000) Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology*. **25:** 109-127.

Koehn, J. D. and Harrington, D. J. (2006) Collection and distribution of the early life stages of the Murray cod (*Maccullochella peelii peelii*) in a regulated river. *Australian Journal of Zoology*. **53:** 137-144.

Lintermans, M. (2007) *Fishes of the Murray-Darling Basin: An introductory guide.* MDBC publication No. 10/07.

Lloyd, L. (1990). Fish communities. In: *Chowilla Floodplain Biological Study* (eds O'Malley, C. & Sheldon, F.), pp 183-193. Nature Conservation Society of South Australia, Adelaide.

Maheshwari, B. L., Walker, K. F. and McMahon, T. A. (1995) Effects of flow regulation on the flow regime of the River Murray, Australia. *Regulated Rivers; Research and management*. **10:** 15-38.

Mallen-Cooper, M. (1993). Habitat changes and declines of Freshwater fish in Australia: what is the evidence. *Bureau of Resources Sciences Proceedings*. 118-123.

Mallen-Cooper, M. and Stuart, I. G. (2003) Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications*. **19:** 697-719.

McCune B, Grace J. B., Urban D. L. (2002) 'Analysis of ecological communities.' (MjM Software Design: Glendon Beach, Oregon)

McCune, B. and Mefford, M. J. (2005) PC-ORD. *Multivariate Analysis of Ecological Data, Version 5*. (MjM Software Design: Glendon Beach, Oregon, USA).

MDBC (2006) *The Chowilla Floodplain and Lindsay-Wallpolla Islands Icon Site Environmental Management Plan 2006-2007*. MDBC Publication No. 33/06.

Meredith, S., Gawne, B., Sharpe, C., Whiterod, N., Conallin, A. and Zukowski, S. (2002) *Dryland floodplain ecosystems: influence of flow pattern on fish production*. Murray-Darling Freshwater Research Centre. Technical Report 1/2002.

Merigoux, S., Ponton, D. and de Merona, B. (1998) Fish richness and species-habitat relationships in two coastal stream of French Guyana, South America. *Environmental Biology of Fishes*. **51:** 25-39.

Morris, K (1998) Salinity and Nutrients; Growth and Water Use of Aquatic Macrophytes Under Controlled and Natural Conditions. PhD thesis, The University of Adelaide.

O'Malley, C. and Sheldon, F. (1990) *Chowilla Floodplain Biological Study*. Nature Conservation Society of South Australia, Adelaide.

Pierce, B. E. (1990) *Chowilla Fisheries Investigations*. South Australian Department of Fisheries, Adelaide.

Poff, N. L., Allen, J. D., Bain, M. B., Karr, J. R. Prestegaard, K. L. Richter, B. D., Sparks, R. E. (1997) The natural flow regime: A paradigm of river conservation and restoration. *Bioscience*. **47(11):** 769-784

Puckridge, J. T., Sheldon, F., Walker, K. F. and Boulton, A. J. (1998) Flow variability and the ecology of large rivers. *Marine and Freshwater Research*. **49:** 55-72.

Puckridge, J. T. and Walker, K. F. (1990) Reproductive Biology and Larval Development of a Gizzard Shad, *Nematalosa erebi* (Gunther) (Dorosomatinae : Teleostei), in the River Murray, South Australia. *Australian Journal of Freshwater Research.* **41:** 695-712.

Pusey, B. J. and Arthington, A. H. (2003) Importance of the riparian zone to the conservation and management of freshwater fish: a review. *Marine and Freshwater Research*. **54:** 1-16.

Ryan, T. and Davies, P. (1996) *Environmental effects of salinity and nutrients from salt disposal: approaches to the development of management criteria.* Flora and Fauna Technical Report No. 137. Department of Natural Resources and Environment, Melbourne.

Scheidegger, K. J. and Bain, M. B. (1995) Larval distribution and microhabitat use in free flowing and regulated rivers. *Copeia.* **1995:** 125-135.

Sharley, and Hugan, (1995) Chowilla Resource management plan final report. Murray-Darling Basin Commission, Canberra.

Sheldon, F. and Lloyd, L. (1990) Physical limnology and aquatic habitats. In: *Chowilla Floodplain Biological Study* (eds O'Malley, C. and Sheldon, F.) pp 121-135. Nature Conservation Society of South Australia, Adelaide.

Serfafini, L. G. and Humphries, P. (2004) *Preliminary Guide to the identification of larvae of Fish, with a Bibliography of their Studies, from the Murray Darling Basin.* Cooperative Research Centre for Freshwater Ecology, Identification and Ecology Guide No. 48.

Stace, P. M. and Greenwood, A. J. (2004) *Chowilla Anabranch System surface water information summary.* South Australia. Department of Water, Land and biodiversity Conservation. Report, DWLBC 2004/06

Trippel, E. A. and Chambers, R. C. (1997) *The early life history of fishes and its role in the recruitment processes*. In: Early life history and recruitment in fish populations. (Eds) Trippel, E.A. and Chambers, R.C. pp. 21-32 (Chapman and Hall: London, UK)

Walker, K. F. (1985) A review of the ecological effects of river regulation in Australia. *Hydrobiologica.* **125:** 111-129.

Walker, K. F., Thoms, M. C. and Sheldon, F. (1992) *Effects of weirs on the littorial environment of the River Murray, South Australia.* Boon. P. J., Calow, P., and Petts, G. E. (Eds) River conservation and management. Wiley, Chichester pp. 271-292.

Walker, K. F. and Thoms, M. C. (1993) Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research and Management.* **8:** 103-119.

Walker, K. F., Thoms, M. C. and Sheldon, F. (1995) *Effects of weirs on the littoral environment of the River Murray, South Australia.* (Eds) Boon, P. J., Calow, P., Petts, G. E. River Conservation and Management. Wiley, Chichester, pp. 271-292.

Williams, W. D. (1987b) Salinization of rivers and streams: an important environmental hazard. *Ambio.* **16(4):** 180-185.

Williams, M. D. and Williams, W. (1991) Salinity tolerances of four species of fish from the Murray-Darling River system. *Hydrobiologia.* **210:** 145-160.

Ye, Q. and Zampatti, B. (2007) *Murray cod stock status: the Lower River Murray, South Australia.* Stock status report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 32pp. SARDI Publication No. F20007-000211-1

Zampatti, B. and Leigh, S. (2005) *A preliminary Assessment of Potential Obstructions to Fish Passage in the Chowilla Anabranch System, River Murray, South Australia.* SARDI Aquatic Sciences Publication No. RD04/0234 – 3, SARDI Research Report Series No. 90. Prepared for the Department of Water, Land and Biodiversity Conservation.

Zampatti, B., Nicol, J., Leigh, S. and Weedon, J. (2006) *2006 Progress Report for the Chowilla Fish and Aquatic Macrophyte Project.* SARDI Aquatic Sciences, Inland Waters Program.