Larval fish assemblages below Locks 5 and 6, in the River Murray, South Australia from 2005 to 2007: with reference to water manipulation trials.

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EXECUTIVE SUMMARY

The River Murray, South Australia (SA), is characterised as a wide valley consisting of two geomorphologically distinct sections, one encompassing limestone cliffs, the other broad floodplains and riparian swamplands, and is heavily regulated by the presence of six weirs. River regulation has significantly changed the natural flow regime, and has had a profound impact on native fish within this region.

The response of fish populations to water management, such as raising the height of weir pools and inundation of floodplain habitats, is poorly understood in SA. Therefore, SARDI has been requested by the Murray-Darling Basin Commission's Living Murray programs to conduct fish monitoring with a focus on larval fish assemblage and survivorship as a component of the ecological monitoring program for the 'weir pool manipulation project'.

During 2005/06, the heights of Lock 4 and Lock 5 weir pools were raised, 30 and 50 cm respectively, in conjunction with a small increase in discharge to SA. The combination of these events raised water levels to a maximum of 0.9 m above normal pool level. This rise in water level increased the area of floodplain inundated, when compared to a normal entitlement year. Larval fish comprising 11 species, nine native and two exotic were collected during 2005/06, including the iconic species, Murray cod, golden perch, silver perch, and freshwater catfish. In 2006/07, discharge to SA only followed entitlement volumes and no raising of the weir pool was conducted. Larvae of nine species were collected, consisting of seven native and two exotic, notably, the larvae of two iconic species, golden perch and silver perch, were absent.

There were significant differences in the larval fish assemblage structure between 2005/06 and 2006/07. For the common native species, Australian smelt, flathead gudgeon and bony herring were collected in higher abundances during 2006/07 under low discharge and stable water level conditions; and carp gudgeons were similarly abundant in both years. For the iconic species, Murray cod and freshwater catfish appeared relatively unaffected by the water levels, although there was a reduction in abundance particularly for catfish larvae, due to high variability this was not deemed significant. Although, there is evidence in the literature to suggest that Murray cod larval survivorship and recruitment may be impacted by low flow conditions. Contrastingly, golden perch and silver perch, demonstrated a negative spawning response in the low flow and stable water level year as no larval fish were collected/detected for either species in the 2006/07. This suggests protracted low flow conditions pose a significant risk to spawning success and larval survivorship of Murray cod, golden perch and silver perch. Thus, given their significant conservation, ecological, and social/economic values in the MDB, these species should be of greatest concern, particularly when considering water management strategies.

Further research into weir pool manipulation techniques is needed before a full picture of the ecological responses and affects can be gleaned. Recommendations for future research are provided at the end of this report.

1 INTRODUCTION

The Murray-Darling is Australia's largest river catchment, and its aquatic ecosystems have been severely affected by river regulation, potentially more so than any other Australian catchment (Arthington and Pusey 2003; Cadawallader 1978; Gehrke et al. 1995; Humphries and Lake 2000; Maheshwari et al. 1995). River regulation impacts on natural flow variability by reducing the frequency and duration of major flooding events, the magnitude and frequency of smaller within channel flows, and by maintaining a relatively stable water levels within the weir pools (DWLBC 2000; Maheshwari et al. 1995). In the Lower Murray, South Australia, the presence of six weirs has created a system wherein the entire main channel is operated, not as a flowing river system, but as a series of slow-flowing, deep weir pools, which is particularly pronounced in low flow years. Seasonal variation in the water level of the Lower Murray has dramatically reduced due to river regulation (Maheshwari et al. 1995). Economic benefits aside, river regulation has caused considerable ecological damage and the loss of important ecosystem services, which are often highly valued by society (Baron et al. 2002).

River regulation has had a profound impact on native fish in the Murray-Darling Basin, due to changes in the hydrological regime following extensive modification of the system (Cadawallader 1978; Gehrke et al. 1995; Humphries et al. 2002). In Australia and throughout the developed world, dams and weirs have a range of negative impacts on fish, they limit access to suitable habitats, affect water quality, change the bank structure, act as fish passage barriers by obstructing movement of migratory fish species, and affect conditions for spawning, recruitment and dispersal of eggs and larvae (Gehrke et al. 1995; Humphries et al. 1999; Humphries and Lake 2000; Mallen-Cooper 2001; Mallen-Cooper and Stuart 2003; Mallen-Cooper et al. 1995).

Manipulating the water levels in weir pools by raising or lowering the level of the weirs is one method that attempts to increase overall variability of water levels within the system to improve ecosystem health (DWLBC 2000). The ecological and physical monitoring of weir manipulation trials was conducted in the SA reach of the River Murray as a part of the Living Murray Intervention Monitoring Program the 'Lower Murray Weir Pool Manipulation Intervention Monitoring Project'. The levels of the weir pools at Locks 4 and 5 were raised by 30 and 50 cm, respectively, during 2005/06 enabling a series of ecological and physical factors to be assessed. A series of projects monitored the impact of this rise of weir pool level on: within channel fish larvae, littoral and floodplain vegetation (including red gum and lignum), biofilms, and groundwater, the major findings will be combined into a synthesis report by the DWLBC. The overall aim of the weir manipulation trials was to collect data that will be used to inform future weir management in a way that improves the ecological health of the river channel, wetland and floodplain environments. This report details the results of within channel larval fish monitoring during the 2005/06 trial with a comparison to a no trial year 2006/07. Discussion is also made on the possible effect of weir manipulation on spawning/larval survivorship of native and exotic fish species.

2 LITERATURE REVIEW: EARLY LIFE HISTORY OF FISH IN THE MURRAY-DARLING BASIN

2.1 River regulation in Australian Rivers

Many Australian rivers are regulated through reservoirs and dams, locks and weirs, direct abstractions, and water transfer schemes. As a result, Australia's rivers have become, and continue to be, increasingly more degraded and natural flow regimes have become heavily modified. The Murray-Darling River has been severely altered, to the point where total river flows and associated temporal patterns have changed significantly (Maheshwari *et al.* 1995). The magnitude, frequency, duration and seasonality of 'natural' flows have been severely altered, having a detrimental affect on aquatic organisms (Gehrke *et al.* 1995; Humphries *et al.* 2002). Furthermore, the early life history of native species may also be negatively impacted, as many utilise down stream dispersal for eggs and larvae (Humphries *et al.* 1999; Humphries and Lake 2000; Humphries *et al.* 2002; Meredith *et al.* 2002). In addition, a high degree of mortality has been demonstrated for larval Murray cod and golden perch when travelling through undershot weirs (Baumgartner *et al.* 2006).

2.2 Fish recruitment ecology

In order to manage ecosystems to rehabilitate native fish populations, we first require an understanding of population dynamics and the forces that govern changes within these. Population dynamics are defined as the variations in time and space in the sizes and densities of populations (Begon *et al.* 1996). Changes in populations are regulated by the rates of births and deaths, emigration and immigration (Begon *et al.* 1996). Ecologically, the entry of new individuals into a population by reproduction or immigration is defined as *recruitment* (Lawrence 1989). In fisheries, recruitment is typically defined as the survival from embryo to an adult stage, thus, requiring the spawning of adults, hatching of viable eggs and survival of young fish to a defined reference point, such as a certain age, size or migration out of established nursery areas (King 1995; Trippel and Chambers 1997; Willis and Murphy 1996). Recruitment studies are often aimed at determining the selective processes, which include abiotic and biotic events that will influence the growth and survival rates of individuals (Trippel and Chambers 1997).

The early life history of fish is the period from fertilisation, embryonic and larval periods, up to the early portion of the juvenile stage (Trippel and Chambers 1997). Numerous studies have been conducted outside of Australia, on the distributions of eggs and the distribution and behaviour of larvae, given the importance of the early life stage to population and fisheries studies (Kelso and Rutherford 1996). The studies have included determining spawning and nursery areas, temporal and spatial differences in spawning characteristics and ontogenetic shifts in habitat and diets. The early life history stage is particularly sensitive and is a time of exceptionally high mortality, often in the order of 90-99% (Kelso and Rutherford 1996; Trippel and Chambers 1997). Mortality during these times is most commonly attributed to inherited defects, egg quality, starvation and predation. Furthermore, environmental variability, such as changing physiochemical conditions can have a substantial effect (Houde 1997; Kelso and Rutherford 1996; Trippel and Chambers 1997).

Models of recruitment variability typically assume the most limiting factor during early life history is food availability and that other aspects such as growth and predator avoidance are consequently linked to prey resources (Houde 1997). Therefore, many studies suggest that the rate of larval growth, survival and recruitment, is similarly linked to the availability of prey, and this relationship has formed the basis for many of the fish recruitment models currently in use. In floodplain river systems the most widely accepted model is the *flood pulse concept* (FPC) (Junk *et al.* 1989).

2.3 Native fish in the Murray-Darling Basin

The lower River Murray in South Australia has 24 species of fish (Allen *et al.* 2002; Hammer and Walker 2004; McDowall 1996). It has been suggested that changes to flow regime and construction of regulatory structures in the Murray-Darling Basin have significantly contributed to the decline of native fish populations (Cadawallader 1978; Gehrke *et al.* 1995; Humphries *et al.* 2002). Thus, it may be possible to improve larval survivorship through allocating environmental water and/or managing flow regimes, creating suitable conditions for the survival of larval and young fish.

Attempts have been made to classify the reproductive strategies for the fish of the MDB (Humphries *et al.* 1999; King 2002). These have been based on life cycle aspects, such as spawning cues, timing and length of spawning period, egg development, larval feeding and parental care which follow those defined by Winemiller and Rose (1992). Humphries *et al.* (1999) classified the key species of the MDB into four life cycle styles, *Mode 1, 2, 3a & b* (Table 1). King (2002) presented a generalised conceptual model for fish recruitment under both high and low flow conditions, which was later expanded in conjunction with the CRCFE (2003) (Table 2). Each of these classifications differs in terms of the groupings of species, due to the aspects considered when developing the models, although there are inherent similarities. Humphries *et al.* (1999) developed a very detailed classification system using all aspects of the reproductive cycle, including spawning cues, and egg and larval development. King (2002) included the influence of flows and habitat type on spawning and recruitment success, this model differed from others as it emphasised the importance of influences on recruitment as well as spawning. However, it should be noted that the categorisation of the floodplain specialist has since been re-developed as within channel spawning and recruitment is now thought to be common. Further research into the influence of flow regime, habitat requirements and influence of food availability for larval and immediately post-larval stages of many of the Murray-Darling Basin fish species is required (Humphries *et al.* 1999; Humphries and Lake 2000; King 2004; King 2005; Lake 1967b; Lake 1967c; Meredith *et al.* 2002).

Table 1. Life cycle styles for key Murray-Darling Basin fishes (sourced from Humphries *et al.* 1999).

Variable	Mode 1	Mode 2	Mode 3a	Mode 3b
Duration of spawning	Short	Variable	Long	Short
Spawning style	Single spawning, approx same time each year	Single spawning, timing, delay	Protracted, serial or repeat	Single spawning
Spawning time	October -December	October-March	September-March	Late winter or summer
Cues for spawning	Circannual rhythm and min. temp.	Rising water level (?) and min. temp.	Uncertain	Uncertain
Number of eggs	1,000's-10 000's	100 000's	100's-1, 000's	100's-1, 000's
Type of eggs	Demersal	Semi-buoyant or planktonic	Planktonic or demersal	Planktonic or demersal
Parental care of embryo/larvae	Yes	No	No	No
Incubation period	10+days	Hours	<10 days	<10 days
Size of embryo at hatching	6-9 mm	3-6 mm	3-4 mm	2-7 mm
Time to first feeding	ca. 20 days	ca. 5 days	ca. 3 days	ca. 3 days
Development of embryo/larva at first feeding	Advanced, large gape, well-formed fins, highly mobile	Undeveloped, small gape, limited mobility	Undeveloped, small gape, limited mobility	Undeveloped, small gape, limited mobility
Examples of species	Murray cod, Trout cod, Freshwater catfish, River blackfish	Golden perch Silver perch	Australian smelt Flathead gudgeon	Carp gudgeon, Murray rainbowfish, Southern pygmy perch

Table 2. Spawning and recruitment strategies of Murray-Darling Basin fish species (sourced from, CRCFE 2003; King 2002).

Strategy	Species	Hydrology	Habitats
Flood spawners	Golden perch and Silver perch	Spawn and recruit following flow rises. Major spawning events occur during periods of floodplain inundation	Main channel and anabranches
Wetland specialists	Australian smelt, Bony herring, Carp gudgeons, Southern pygmy perch, Hardyheads, *Galaxias rostratus*	Spawn and recruit during in-channel flows	Floodplain wetlands and lakes, anabranches and billabongs
Main channel generalists	Australian smelt, Bony herring, Flathead gudgeons, redfin perch	Spawn and recruit in high or low flow	Main channel
Main channel specialists	Murray Cod, Trout cod, River blackfish, Two-spined blackfish	Spawn and recruit under high or low flow	Main channel. Woody debris important habitat attribute
Low-flow specialists	Crimson-spotted rainbow fish, Carp gudgeons, gambusia	Only spawn and recruit during low flow	Main channel or floodplain habitats
Freshwater catfish		Spawn any flow conditions, recruitment needs further investigation	Builds nests in coarse sediment beds (usually sand or gravel)
Flood opportunists	Common carp	Spawning under any conditions recruitment may be enhanced under higher flows	Main channel/ wetlands/ floodplain

2.4 Fish recruitment 'models' in floodplain rivers

The *floodplain* is an area of relatively flat land beside a river that is inundated when the river overflows its banks during high water flows (Young 2001). Floodplain inundation is believed to play a major role in the life cycles of much of the riverine biota. In floodplain river systems, the most widely accepted recruitment model is the *flood pulse concept* (FPC) (Junk *et al.* 1989). The FPC emphasises this role, suggesting floodplain inundation provides spawning cues, higher abundance of food and increased habitat areas (Junk *et al.* 1989). In temperate systems, where distinct seasonal temperature differences occur, the coupling of high temperatures and high flows has been shown to be a major spawning cue. It is on this foundation that the FPC is based, suggesting that the result is successful utilisation of the floodplain by fishes for spawning and recruitment (Junk *et al.* 1989). Floodplain inundation, however, whilst accepted as one of the major driving forces behind recruitment, is not the sole stimulus. Many studies have documented the use of main channel habitats, such as littoral areas, backwaters, and embayments as nursery areas providing successful recruitment (Haines and Tyus 1990; King 2004; Sempeski and Gaudin 1995; Tyus 1991; Watkins *et al.* 1997).

Two analogous models have been developed for Australian floodplain rivers through observations and studies conducted in the Murray-Darling Basin; the *flood recruitment model* (FRM) (Harris and Gehrke 1994) and the *low flow recruitment hypothesis* (LFRH) (Humphries *et al.* 1999).

The FRM is consistent with the FPC (Junk *et al.* 1989), but differs in that it is designed for large, low gradient river systems with productive floodplains. The FRM proposes that flooding cycles are the major driving force behind enhanced fish recruitment producing strong year classes. The model proposes that high flows in spring or summer inundate floodplains, which results in abundant food and habitat allowing for high survival of larvae and subsequent high recruitment of the species (Harris and Gehrke 1994). The main assumption of this model is that the main channel in floodplain regions does not support high enough densities of food, but that the inundated floodplain does (Harris and Gehrke 1994; Lake 1967a; Rowland 1992). The FRM, however, fails to discriminate between the two roles of flooding, 1) controlling gonadal maturation and spawning behaviour as in the adult phase of the FRM, or 2) whether it enhances the survival and growth of cohorts of larvae and juveniles, as in the larval phase of the FRM, irrespective of the factors which induced spawning (Ye 2005).

The *low flow recruitment hypothesis*, LFRH, (Humphries *et al.* 1999), emphasises the importance of recruitment during within channel flows for particular species (Mode 3a & 3b). The LFRH indicates the recruitment of mode 3a and 3b species can occur in the main channel during low flows through habitat specialisation, into still, warm and shallow littoral and backwaters (Humphries *et al.* 1999). King *et al.* (2003) tested assumptions of both the FRM and LFRH, and found that abundant food does exist in the main channel during periods of low flow. Contrastingly, while habitat associations occurred in line with Humphries *et al.* (1999) assumptions, there was scant evidence for a relationship between prey density and habitat use (King *et al.* 2003a). Given this, further research is required into the relationship between prey density, habitat and larval communities.

2.5 Weir pool raising trials

Manipulating the water levels in weir pools is one method that attempts to improve the local health of a river system. By raising or lowering the level of the lock and weirs, managers can potentially mimic variability in water height in a more natural manner which follows historical patterns, and increase overall variability within the system (DWLBC 2000). Hydrological manipulations involving raising and lowering water levels in the Kissimmee River, indicated that a simple manipulation is not sufficient to reproduce the outcomes of flood pulses through the surrounding floodplain (Toth *et al.* 1998). Thus, raising the water level in a weir pool is not a replacement for increasing flows. However, when used in conjunction with naturally high flows or adaptively managed with environmental flow allocations, manipulating the weir height may increase the total area of floodplain inundated.

Increasing the total wetted area on the floodplain could have both positive and negative influences on the fish community. Positive influences potentially include improving survival of native fish through providing habitat and food resources. While on the other hand increased floodplain inundation may aid in the spawning and recruitment of exotic species, namely carp. It is unlikely, however, that rasing the water level alone will initiate spawning in any of the key native species, as flow rather than water level is believed to influence selected species.

Recently, two weir-raising trials have been conducted in the SA section of the River Murray, the first in 2000/01, and the second in 2005/06. Both were used to enhance the impact of an increase in discharge. The impacts of the raisings included increasing the wetted perimeter of the river channel, increasing discharge in anabranch systems, and flooding a number of managed wetlands (DWLBC 2000). The main aim of these raisings was to improve the health of stressed vegetation communities by providing them with water, but they may also provide additional benefits for animal communities.

3 OBJECTIVES

The following objectives were developed for fish monitoring, using presence of larval fish as an indicator of spawning success to determine if differences could be detected between 2005/06, under weir pool manipulation and 2006/07 a non-trial year:

1. Describe and compare species composition and temporal variations of relative abundance of larval fish assemblages between 2005/06 and 2006/07.

2. Describe the spawning periods and patterns for the species collected throughout the duration of the project.

3. Investigate possible linkages between differences in larval fish assemblages and key environmental parameters (temperature, flow and water level).

4 METHODS

4.1 Study sites

The present study was confined to the main channel of the River Murray in SA, in the *floodplain* region (Figure 1). The Murray is a heavily regulated lowland river, characterised by low-flow channels, most stream diversity occurs during high flows when adjacent floodplains become inundated. Sampling was conducted at two sites, below Lock 5 (34°11.435' S, 140°45.893' E) and Lock 6 (33°59.558' S, 140°51.314) (Figure2).

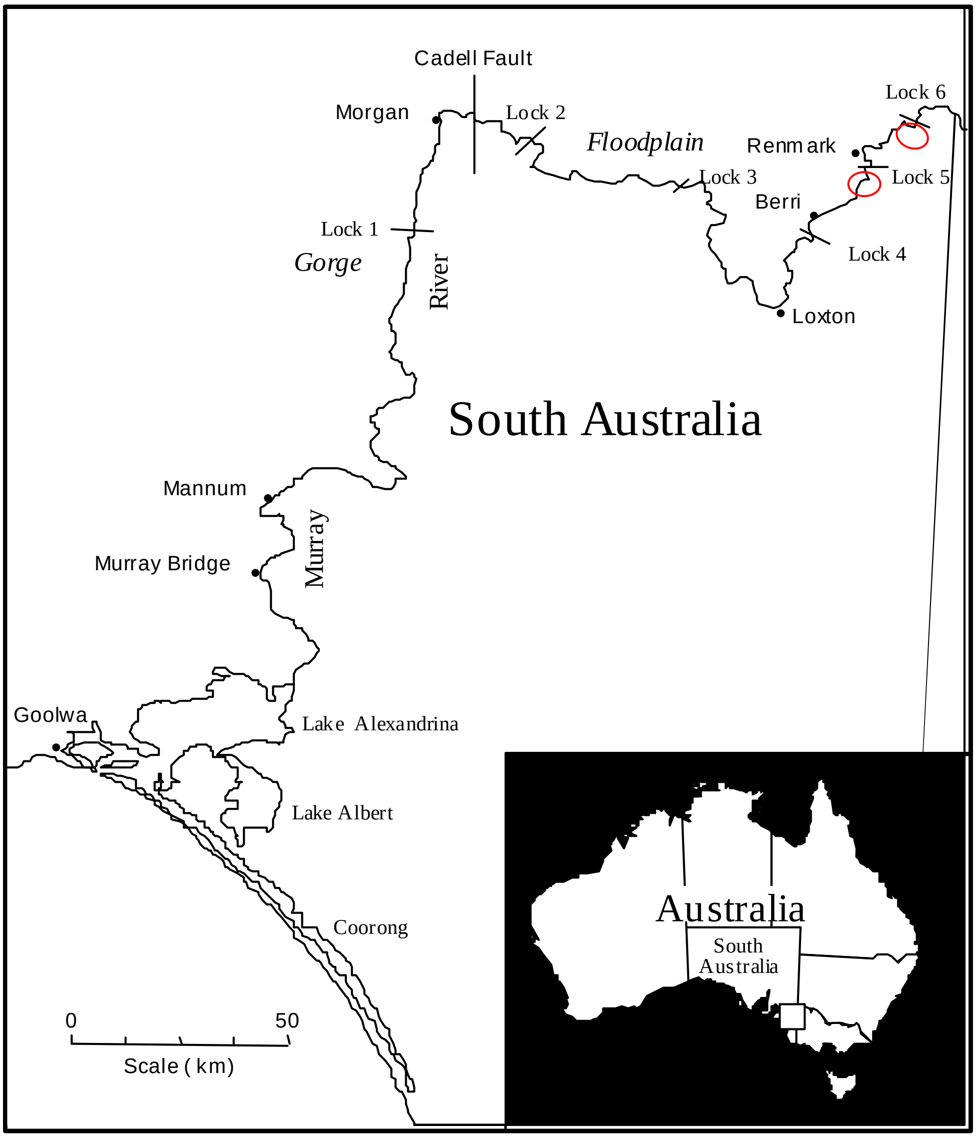


Figure 1. A map of the River Murray and Lower Lakes in South Australia, showing the six locks. The circles highlight the larval fish sampling sites below Locks 5 and 6.

4.2 Larval fish

4.2.1 Sampling trips

Larval fish sampling was conducted in 2005/06 and 2006/07, from mid September through February. This sampling period was selected based on the peak spawning season and larval abundances within the river system as identified by Humphries *et al* (2002) and Meredith *et al.* (2002). Sampling was conducted fortnightly from mid September through December, and monthly in January and February, resulting in nine trips each year.

4.2.2 Sampling equipment and methodology

Plankton tows were conducted using a pair of square-framed, 0.5 x 0.5 m, 3 m long bongo nets of 500 µm mesh. Nets were equipped with 30 cm pneumatic floats either side of the frame, so the frame sat 5 cm below the water surface. They were towed in circles using a 20 m rope, in the centre of the main river channel. Four replicate samples, consisting of 15 min tows, were taken at each site during the day and the night, of the same day, and both sites were sampled within a three-day period. Tows were conducted between 0 and 5 km below each lock during the day and at night giving a total of eight replicated tows below each lock. Day and night samples were grouped for analysis giving a total of eight replicate samples for each site, to provide an overall picture of the sampling sites (further information on day/night variation can be obtained from the authors). Samples from left and right nets were grouped for analysis. The volume of water filtered through each net was determined using a flow meter (General Oceanics), fitted in the centre of the mouth openings. Plankton tow data was standardised to relative abundance of fish per 1,000 m^3.

Figure 2. Bongo nets with flow meters used for sampling.

4.2.3 Sorting and identification

Samples were immediately preserved in 95% ethanol in situ and returned to the laboratory for sorting using magnification lamps. All larvae were identified to species level, where possible, using published descriptions (Lake 1967c; Neira *et al.* 1998; Puckridge and Walker 1990; Serafini and Humphries 2004), with the exception of carp gudgeons (*Hypseleotris* spp) and hardyheads (*Craterocephalus* spp). Each genus was treated as species complex due to close phylogenetic relationships and very similar morphologies (Serafini and Humphries 2004). Some damaged specimens could only be identified to the gudgeon level. Since large-bodied fish species such as Murray cod, golden perch, silver perch and freshwater catfish, can be difficult to collect as true larvae, immediately post-larval fish were included in counts, juvenile fish were noted but not included in the analysis. Each fish was categorised according to developmental stage, as preflexion larvae (no curvature at tip of notochord), postflexion (upward flexion of notochord, caudal fin rays developing), metalarvae (caudal fins rays developed and pelvic fins forming) or juvenile/adult (rays in all fins fully developed) (Kelso and Rutherford 1996).

4.2.4 Larval age estimates

Sagittal otoliths were removed from larval golden perch sampled in 2005/06 for estimating age and backdating spawning. The total length of each fish was recorded and both sagittal otoliths were dissected using a fine pair of forceps. For preparation, both sagittae were used for age determination and mounted on to slides using thermoplastic cement (CrystalBond 509). The anterior and posterior planes of each otolith were hand polished using 30 and 3 μm lapping film to attain transverse sections, otoliths were flipped twice to gain the most clear read (Secor *et al.* 1992). Transverse sections were viewed and photographed under light magnification (1,000×) and the number of daily rings from the primordium was counted three times by the same reader. Age estimates from both otoliths were used, in the case where they did not concur the average of the two was taken for the fish; if one otolith was lost, the count from the other was used.

4.3 Data analysis

4.3.1 Comparisons of the general larval fish assemblages

Differences in general larval fish assemblages between years (inter-annual variation) and downstream of the two locks (spatial variation) were examined using Bray-Curtis dissimilarity measures (Bray and Curtis 1957) and two-way crossed Analysis of Similarities (ANOSIM) was used to test for significant differences (Clarke 1993). The average data of relative abundances (number of larval fish per 1,000 m^3) were used, ending with 72 replicates (2 years x 9 trips x 2 locks x 2 sampling time: day or night). Data were fourth-root transformed to prevent abundant species from influencing the dissimilarity measure excessively (Clarke 1993). Where differences existed, a similarity percentages (SIMPER) analysis was subsequently performed to identify species contributing most to the differences between groups with a cut-off level of 80%

cumulative contribution. Non-metric Multidimensional Scaling (MDS) ordination was used to visualise the temporal and/or spatial patterns. The multivariate analyses followed the methods described by Clarke (1993) using PRIMER v.6.1.6 (Plymouth Routines in Multivariate Ecological Research) software package.

4.3.2 Linking larval fish assemblages with environmental parameters

The following environmental parameters were selected for analyses because they have been identified as either spawning cues or have direct or indirect effects on larval survivorship and recruitment success for MDB fish species (Humphries *et al.* 1999; King 2002; Lake 1967b; Lake 1967c):

- Daily discharge (ML per day).
- Daily relative water level (m AHD[1]) was calculated based on the change from normal pool level, where Lock 5 is 16.3, Lock 4 is 13.2 (sourced from DWLBC).
- Daily water temperature (°C).

Data for these parameters were obtained for the entire sampling season through the DWLBC Knowledge and Information Division, surface water archive.

Weekly maximums and minimums were calculated from the above data, generating six sets of environmental parameters linking to the sampling trips. The protocols given by Clarke and Ainsworth (1993) were followed to assess the relationship between these environmental parameters and the general larval fish assemblages as well as the iconic fish assemblages. The routine BIOENV in the software PRIMER v.6.1.6 (Clarke and Warwick 2001) was used for this correlation analysis. The rank similarity matrices (Bray-Curtis similarity for fish assemblages and Euclidean distance for environmental parameters) were compared using the Spearman rank correlation. The rank correlation coefficient (ρ_s) lies between –1 and +1, corresponding to the cases where the fish assemblage and environmental patterns are in complete opposition or complete agreement. Values around 0 correspond to the absence of any match between the two patterns (Clarke and Ainsworth 1993). Values of significance level of sample statistic were also provided. Symbols scaled in size to represent the values of the 'best fit' environmental parameters were also individually superimposed onto the two-dimensional MDS plots of general fish assemblages and the iconic fish assemblages in order to identify visual concordance (Field *et al.* 1982).

[1] AHD = Level relative to Australian Height Datum

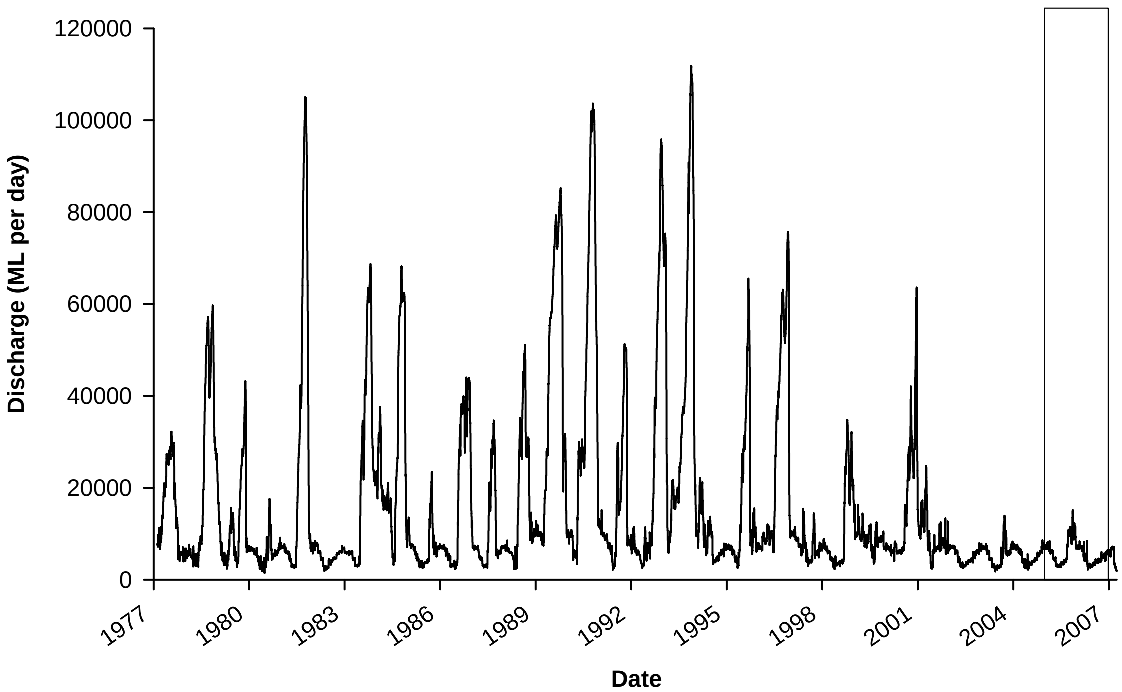
5 RESULTS

5.1 Environmental conditions during 2005/06 and 2006/07

Discharge through Locks 5 and 6 was substantially higher in 2005/06 (Figure 3b). Nevertheless, this only represented a small flow pulse in comparison with historical data (Figure 3a), a flow of approximately 50,000 ML per day is required to break the banks as a flood. During November 2005 the discharge exceeded entitlement, with a maximum of 15,700 ML per day above Lock 5. Discharge in 2006/07 followed the entitlement allocation of a maximum of 6,000 ML per day, although this was only reached in late January and was followed by a sharp cut off at the end of February, given recent drought conditions (Figure 3b). Water is diverted upstream of Lock 6 through the Chowilla anabranch system, returning to the main channel below Lock 6, accounting for the lower volume through Lock 6 when compared with Lock 5 (Figure 3b). The change in relative water level followed patterns of increased water discharge rates, thus the two must be treated together as they are highly correlated (Figure 3b). Therefore, discussion about discharge and water level will be restricted to water level in reference to the water level raising that occurred in 2005/06.

Mean daily water temperature increased steadily during the sampling periods with a similar pattern in both years Figure 4). Temperature peaked in late January then steadily decreased throughout February (Figure 4). In both years the temperature increased from approximately 16 °C in late September, and peaked in late January at approximately 28 °C (Figure 4).

There was a substantial difference in water level between the two years with 2005/06 being higher than 2006/07 (Figure 4). The Lock 4 and 5 weir raising in 2005 was initiated in September, coinciding with the increase in discharge (Figure 4). . At peak flow below Lock 6 in November, the estimated total area of the floodplain inundated by the 50 cm raising was 254 hectares, accounting for approximately 2% of the total floodplain in that section of the river (Table 4), this effect was generally concentrated around low lying areas. Without the raising the estimated area inundated below Lock 6 would have been 7 hectares, thus the raising may have accounted for 247 hectares, equalling approximately 97% of the wetted area (Table 4). Similar patterns exist for the weir pool below Lock 5, the 30 cm raising of Lock 4 is estimated to have inundated an additional 63 hectares of the total 307 hectares (Table 3). The total wetted area created by the weir raising can be influenced by the discharge volumes (Table 3 & 4), and effectively acts to increase the total wetted area, increasing floodplain inundation.



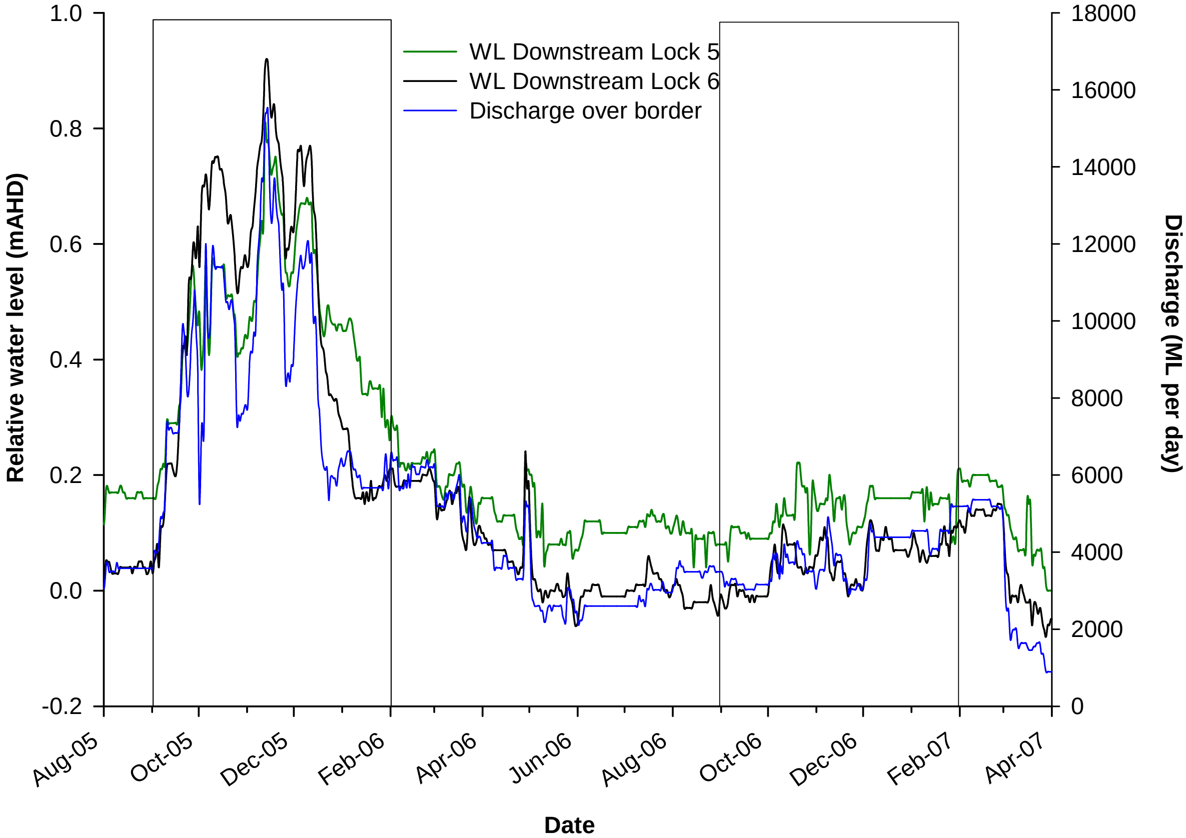


Figure 3. Daily discharge (ML per day) a) over the SA border from 1977-2007, and b) relative water level (mAHD)downstream of Locks 5 and 6 from August 2005-April 2007, daily discharge (ML per day) over the SA border is presented on the secondary axis. Larval sampling periods indicated in boxes.

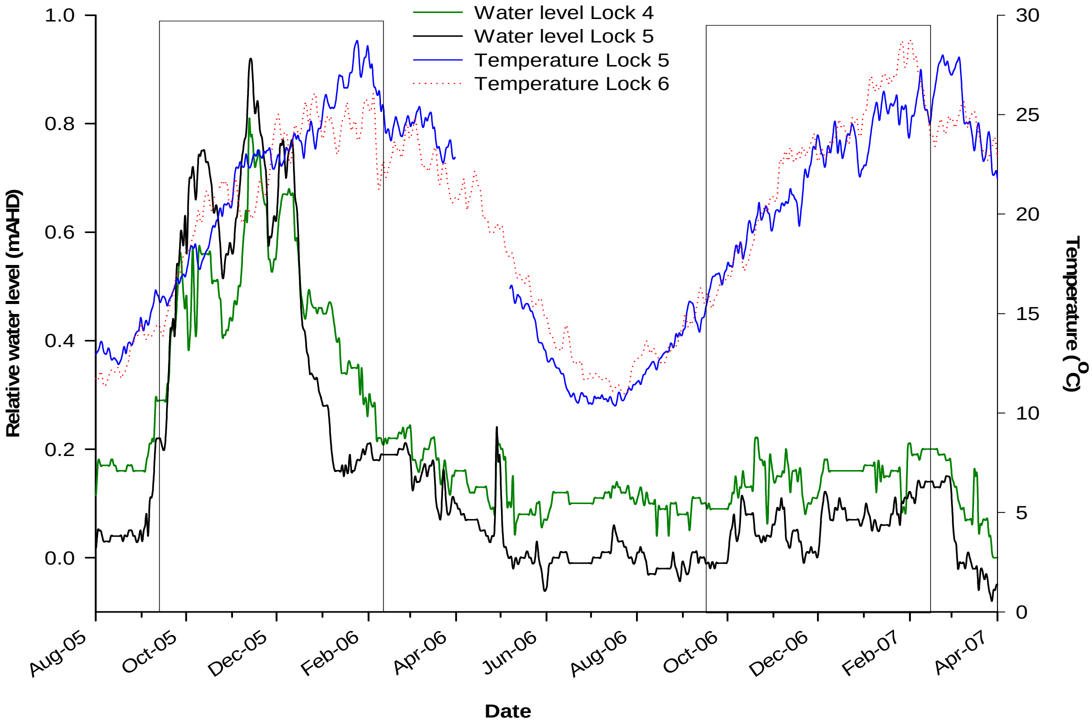


Figure 4. Relative water level (mAHD), directly downstream of Locks 5 and 6 from August 2005 to April 2007, water temperature (ºC) presented on secondary axis. Larval sampling periods are shown in box. AHD = Level relative to Australian Height Datum, standard pool height D/S Lock 6, 16.3, D/S Lock 5, 13.2.

Table 3. The estimated total area inundated through raising the Lock 4-5 weir pool, at given flow rates, note highlighted rows indicate level of weir pool raise (sourced from DWLBC).

	Total area inundated (ha) at a given flow rate (ML per day)							
Raising (cm)	5000	8000	10000	15000	20000	30000	40000	50000
0	**0**	**0**	**0**	**244**	**259**	**373**	**464**	**1328**
15	**20**	**20**	**267**	**269**	**280**	**399**	**505**	**1328**
30	**234**	**275**	**276**	**307**	**313**	**414**	**538**	**1328**
50	**320**	**321**	**321**	**330**	**357**	**485**	**741**	**1328**

Table 4. The estimated total area inundated through raising the Lock 5-6 weir pool, at given flow rates, note highlighted rows indicate level of weir pool raise (sourced from DWLBC).

	Total area inundated (ha) at a given flow rate (ML per day)							
Raising (cm)	5000	8000	10000	15000	20000	30000	40000	50000
0	**0**	**5**	**5**	**7**	**23**	**355**	**523**	**998**
15	**29**	**46**	**49**	**66**	**99**	**430**	**801**	**1210**
30	**77**	**84**	**87**	**125**	**156**	**580**	**1091**	**1445**
50	**139**	**157**	**182**	**254**	**563**	**1022**	**1403**	**2297**

5.2 Larval fish monitoring during 2005/06 and 2006/07

5.2.1 Catch summary

During 2005/06, 5,350 fish larvae comprising nine native and two exotic species were collected below Locks 5 and 6 (Table 5). The most abundant native species were Australian smelt, carp gudgeons, flathead gudgeon, and bony herring (Table 5, Figure 5). Additional species sampled were freshwater catfish, Murray cod, golden perch, silver perch, hardyheads, carp and redfin (Table 5). Species diversity was higher in 2005/06 than 2006/07 (Figure 5, Table 5), this was due to the presence of golden perch and silver perch in 2005/06 (Figure 5).

Comparatively, during 2006/07, 13,173 fish larvae were collected below Locks 5 and 6 (Table 5), consisting of seven native and two exotic species. Similarly, the most abundant native species were Australian smelt, carp gudgeons, flathead gudgeon, and bony herring (Table 5, Figure 5). Additional species sampled were freshwater catfish, Murray cod, hardyheads, carp and redfin. Notably, silver perch and golden perch were absent from all samples collected during 2006/07 (Table 5, Figure 5).

Hardyhead larvae were collected in very low numbers and rainbow fish larvae were absent in both years. While these species are common as adults in the river system, this was probably due to the limitation of the sampling method, given larvae of these species were sampled in higher catch rates using light traps for other projects (KJ Cheshire unpublished data).

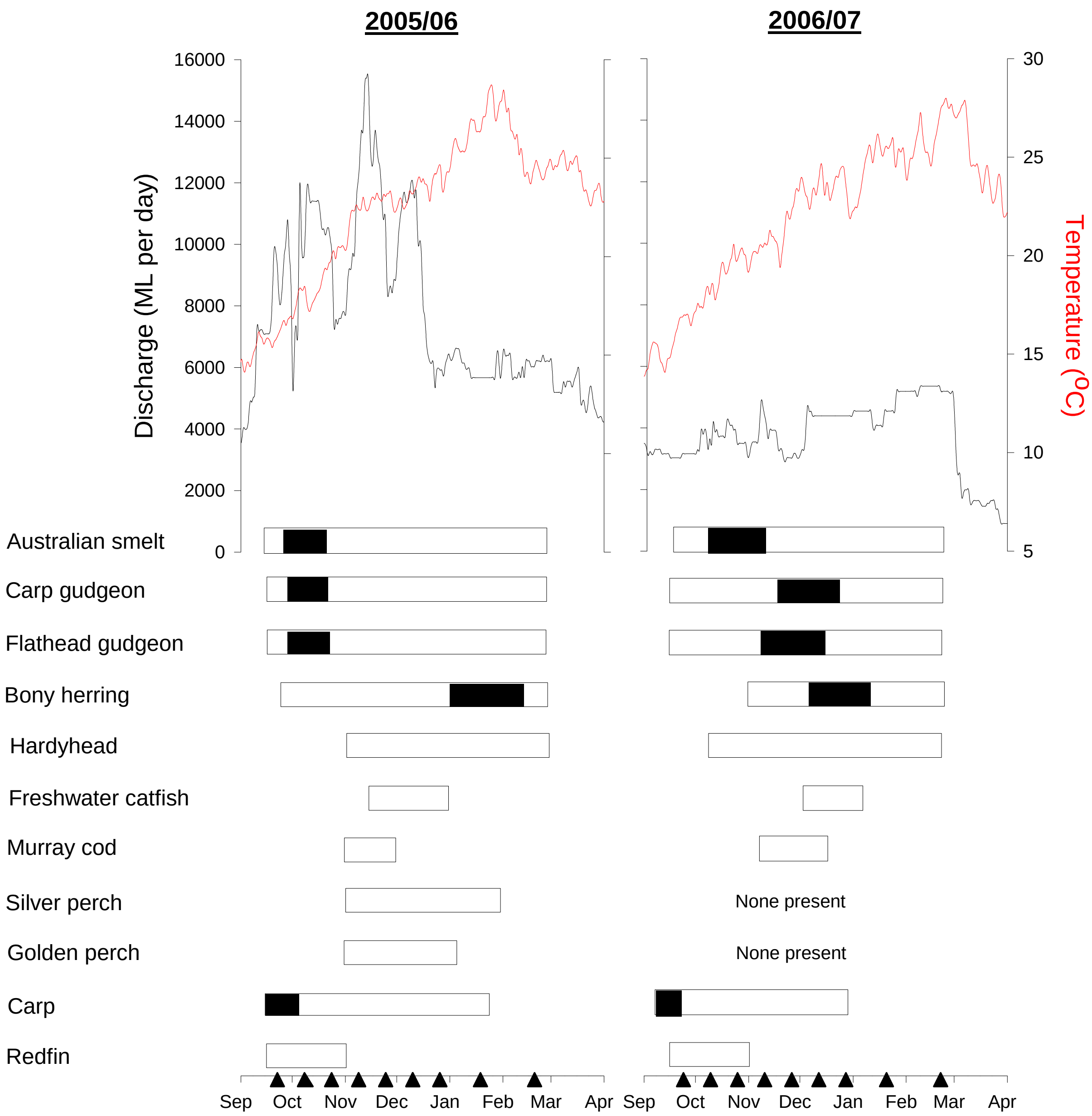


Figure 5. Occurrence of fish larvae at Locks 5 and 6 in the River Murray, South Australia during 2005/06 and 2006/07, plotted with daily discharge (ML per day) across the SA border. Note, Boxes indicate presence of larval fish, black indicates timing of mean peak abundance and arrows indicate actual sampling events. Species collected in low numbers do not have a peak timing allocated.

Table 5. Total catch summary for 2005/06 and 2006/07 sampling events combining Locks 5 and 6, day and night, plankton tow data.

Species	Week beginning (2005/06)										Week beginning (2006/07)									
	19-Sep	10-Oct	24-Oct	07-Nov	21-Nov	05-Dec	19-Dec	23-Jan	20-Feb	Species Total	25-Sep	09-Oct	25-Oct	06-Nov	20-Nov	04-Dec	18-Dec	22-Jan	19-Feb	Species Total
Common native species																				
Australian smelt	211	111	275	356	129	57	72	33	4	**1,248**	776	1,892	2,021	1,500	439	173	44	11	2	**6,858**
Carp gudgeons	219	103	172	404	361	132	232	106	153	**1,882**	9	26	42	155	126	329	273	142	187	**1,289**
Flathead gudgeons	103	109	320	323	201	84	108	114	55	**1,417**	133	156	191	691	583	387	88	200	29	**2,458**
Bony herring	22	0	8	72	71	42	75	299	31	**620**	0	0	0	83	91	917	581	611	179	**2,462**
Hardyhead	0	0	0	1	0	1	0	0	0	**2**	0	0	3	9	4	3	3	0	2	**24**
Iconic species																				
Freshwater catfish	0	0	0	0	32	2	3	0	0	**37**	0	0	0	0	0	3	3	0	0	**6**
Murray cod	0	0	0	7	4	0	0	0	0	**11**	0	0	0	0	0	3	3	0	0	**6**
Silver perch	0	0	0	3	6	4	5	1	0	**19**	0	0	0	0	0	0	0	0	0	**0**
Golden perch	0	0	0	1	9	57	6	0	0	**73**	0	0	0	0	0	0	0	0	0	**0**
Exotic species																				
Redfin perch	1	0	3	0	0	0	0	0	0	**4**	3	4	1	0	0	0	0	0	0	**8**
Common carp	6	11	8	9	2	0	0	1	0	**37**	43	5	1	12	1	0	0	0	0	**62**
Total number of individuals	**562**	**334**	**786**	**1,176**	**815**	**379**	**501**	**554**	**243**	**5,350**	**964**	**2,083**	**2,259**	**2,450**	**1,244**	**1,815**	**995**	**964**	**399**	**13,173**

5.3 Common native species

The four common native species, Australia smelt, flathead gudgeon, carp gudgeon and bony herring, were also the most abundant species sampled in both years. The relative abundances of these species from plankton tows are presented in Figure 6, with accompanying water level and temperature data. Due to the nature of the data, the standard errors are large and therefore should be interpreted cautiously.

Larvae of Australian smelt were collected throughout both of the sampling seasons and at all sites. During 2005/06, relative abundance peaked in early November, directly coinciding with peak water level, and water temperature was approximately 24 °C (Figure 6). In 2006/07, water level was maintained relatively constant throughout the season, relative abundance of larvae was much higher than in 2005/06 and peaked in early October (Figure 6), when water temperature was approximately 19 °C (Figure 6).

Carp gudgeon larvae were also present throughout the entire sampling seasons. In 2005/06 relative abundance peaked in early November, conditions were identical to those for Australian smelt (Figure 6). In 2006/07, relative abundance was similar, although the peak occurred later in the season during early December, water levels were constant during this time and temperature was approximately 22 °C (Figure 6).

Flathead gudgeon larvae were also present throughout the entire sampling seasons. In 2005/06 relative abundance peaked in early November, conditions were identical to those for Australian smelt (Figure 6). During 2006/07 relative abundance was higher, and the peak occurred during early November, water levels were constant during this time and temperature was approximately 21 °C (Figure 6).

Bony herring larvae were also collected throughout both years. During 2005/06 larvae were present throughout the sampling season, with the exception of October below Lock 5, a definite peak in relative abundance occurred during late January (Figure 6). This period coincided with the peak temperature and occurred during stable regulated flow, with no raising of the weir pool. During 2006/07, relative abundance was higher and peak mean abundance occurred during early December, with larvae only being detected in the samples from November onwards (Figure 6). Similarly water level was stable during this time and temperature was approximately 22 °C (Figure 6).

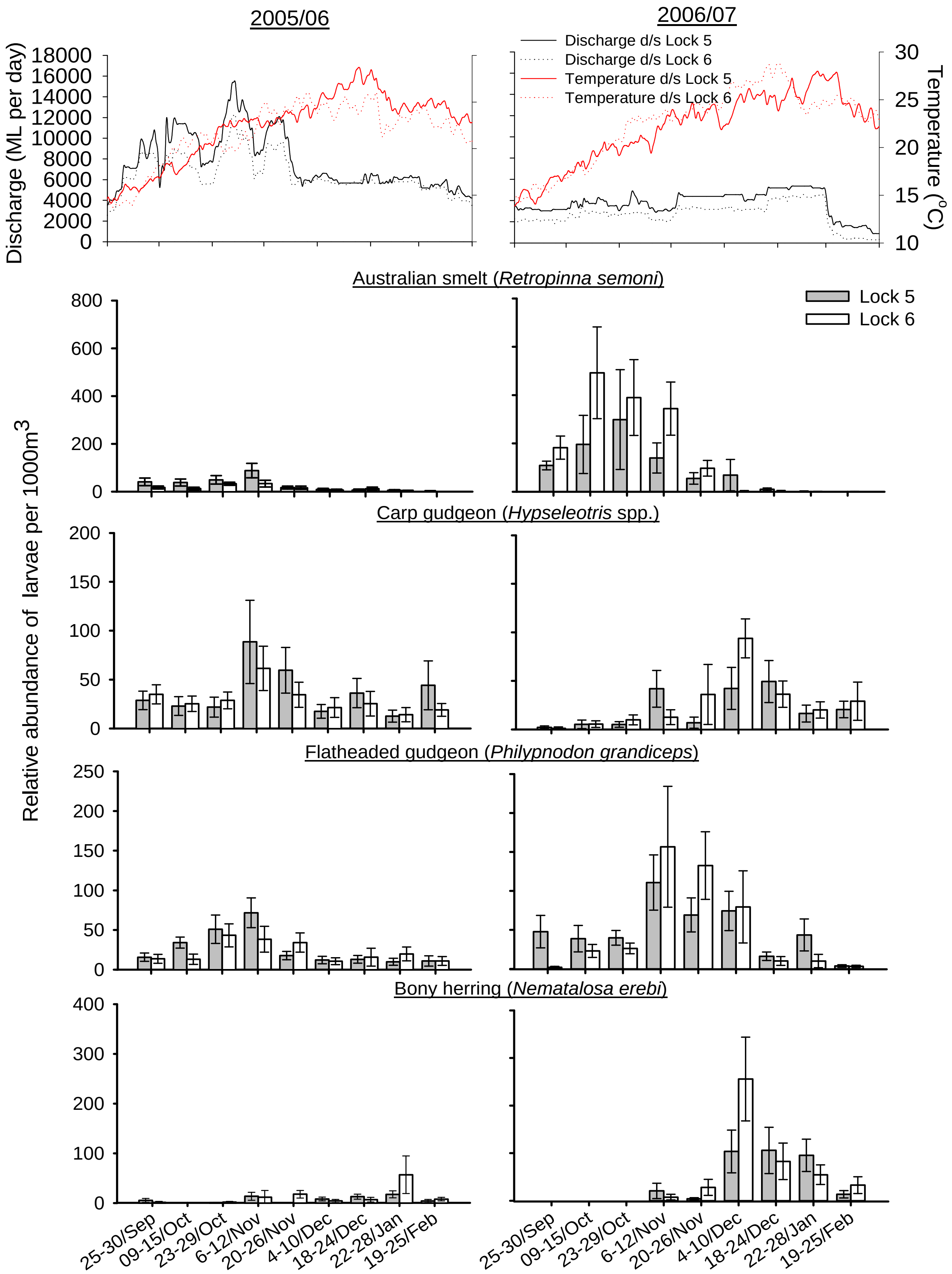


Figure 6. Comparison of common native species fish larvae between the 2005/06 and 2006/07 sampling periods using day and night plankton tow data. Data are presented as relative abundances of fish per 1,000 m³, ± standard error (S.E.) for key species (n = 8). Environmental conditions during this time are presented as relative water level (m AHD) and water temperature (°C) throughout the sampling period. AHD = Level relative to Australian Height Datum, standard pool height D/S Lock 6, 16.3 m AHD, D/S Lock 5, 13.2 mAHD.

5.4 Iconic species

There were differences between the relative abundances and presence/absence of four large bodied iconic species between the two years. With the exception of Murray cod, all iconic species were present in higher relative abundances in 2005/06, when compared with 2006/07 corresponding with the increased discharge and water level raising (Figure 7). Due to the low numbers of individuals collected, and the high standard errors, no further species-specific statistical analysis was performed on the differences between the years for iconic species.

Freshwater catfish larvae were collected in both years, although relative abundance appeared higher in 2005/06. In 2005/06 catfish larvae were collected during November and December; with a peak catch recorded during November (Figure 7). Environmental conditions during this time followed increases in temperature and discharge rates, and temperature during November ranged from 21-25 °C (Figure 7). During 2006/07 larvae were again collected in November and December, discharge rates and water level remained constant during this time and temperature ranged from 23-25 °C (Figure 7).

Murray cod larvae were also collected in 2005/06 and 2006/07, with similar relative abundances (Figure 7). During 2005/06 the arrival of Murray cod larvae occurred during the peak discharge in November, when temperature ranged from 21 to 25 °C. In 2006/07 larvae were collected in November and December, under constant discharge and water level and temperatures between 23 and 25 °C (Figure 7).

Silver perch larvae were collected in 2005/06, but not in 2006/07 (Figure 7). During 2005/06 larvae were present from November through to January, with no definite peak season (Figure 7). The collection of silver perch larvae in November followed the initial increase in flow rates from late September and October, with a temperature increase from 20-22 °C.

Golden perch larvae were also collected in 2005/06 but not in 2006/07 (Figure 7). Golden perch larvae were collected in early November, relative abundance peaked in early December 2005 (Figure 7). The peak of larval golden perch in December coincided with temperatures of approximately 23 °C, and discharges of 11,000 ML per day (Figure 7). Golden perch continued to be collected during January below both locks at a standard length between 30 - 40 mm, these specimens appearing as young-of-the-year were not included in the data set.

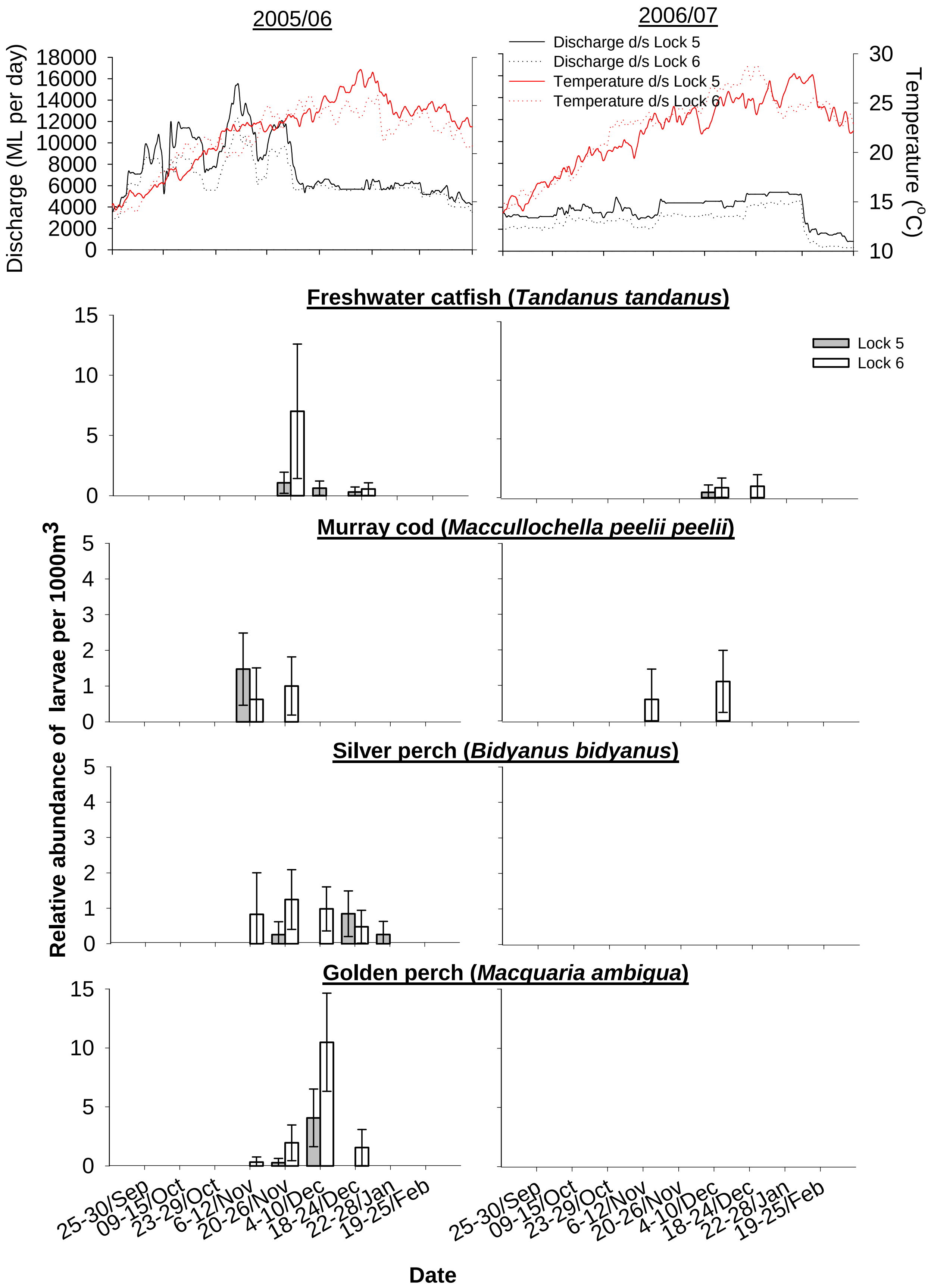


Figure 7. Comparison of iconic species fish larvae between the 2005/06 and 2006/07 sampling periods using day and night plankton tow data. Data are presented as relative abundances of fish per 1,000 m³, ± standard error (S.E.) for key species (n= 8). Environmental conditions during this time are presented as relative water level (m AHD) and water temperature (°C) throughout the sampling period. AHD = Level relative to Australian Height Datum, standard pool height D/S Lock 6, 16.3 m AHD, D/S Lock 5, 13.2 m AHD.

5.5 Exotic species

Carp larvae were present in both 2005/06 and 2006/07 early in the sampling season, late September to late November, (Figure 8). The presence of carp larvae in 2005/06 followed the initial increase in discharge and water level rise at temperatures of approximately 16 °C. Water level remained constant during 2006/07 and temperature was approximately 17 °C (Figure 8).

Redfin perch larvae were collected early in the season (September to November) in both 2005/06 and 2006/07 (Figure 8). In 2005/06 this coincided with the initial increase in water level, however in 2006/07 water level remained constant during this time. Temperature was similar for both years, being approximately 16 ° C.

Due to the low number of individuals collected, and the high standard errors, no further analysis was performed on the differences between the years for exotic species.

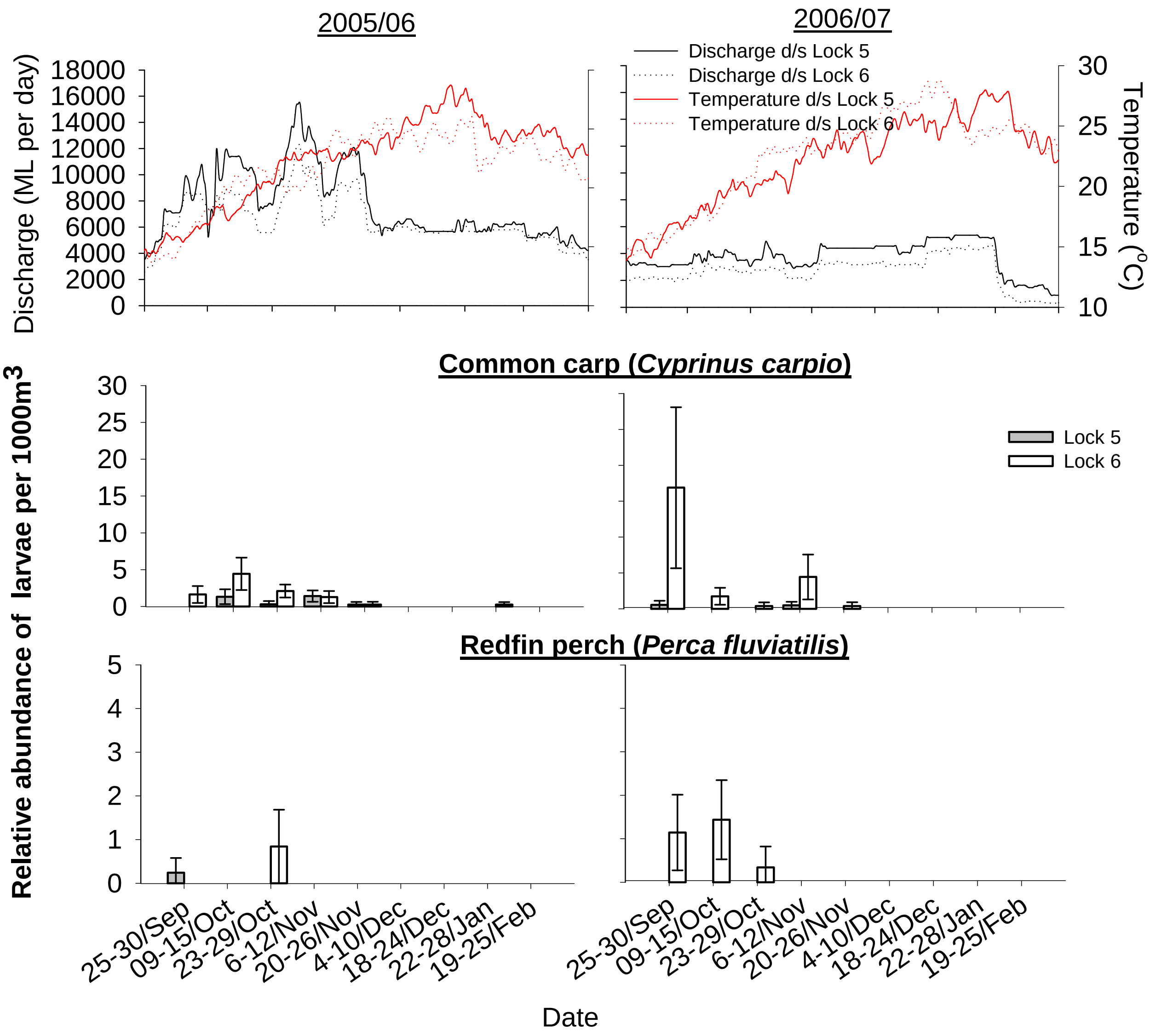


Figure 8. Comparison of exotic species fish larvae between the 2005/06 and 2006/07 sampling periods using day and night plankton tow data. Data are presented as relative abundances of fish per 1,000 m³, ± standard error (S.E.) for key species (n=8). Environmental conditions during this time are presented as relative water level (m AHD) and water temperature (°C) throughout the sampling period. AHD = Level relative to Australian Height Datum, standard pool height D/S Lock 6, 16.3, D/S Lock 5, 13.2.

5.6 Fish assemblage comparisons: between 2005/06 & 2006/07 and between the tail waters of Locks 5 & 6.

Multivariate analyses were performed on the larval fish assemblages (all species identified) to determine if differences could be detected between the years/locks and which species were driving these differences. ANOSIM results indicated no significant difference between Locks 5 and 6 (Global R= 0.018, p = 0.248), however a highly significant difference (Global R 0.127, P= 0.001) in assemblage structure between 2005/06 and 2006/07. Whilst the Global R value was quite small, it still indicates a significant difference between the two years given the high number of replicates used (Clarke and Warwick 2001). Non-metric MDS ordinations of the data displayed some differences/groupings of larval fish assemblages between years (Figure 9). The stress of the solution is low (0.16), allows for confident interpretation of the data (Clarke and Warwick 2001).

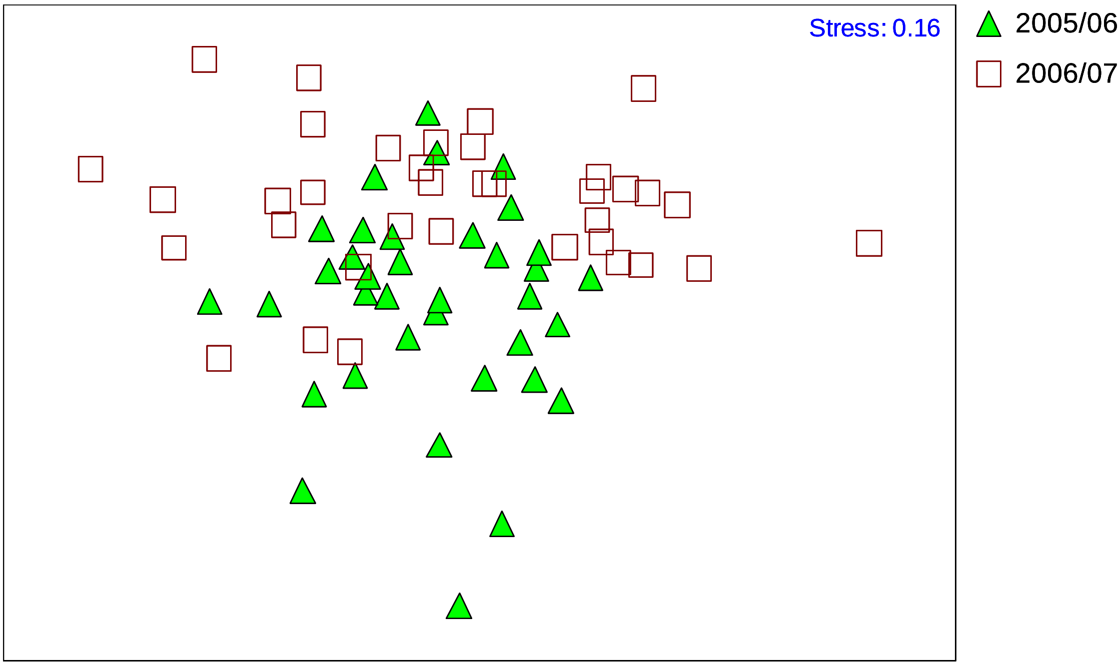


Figure 9. MDS plot (2-dimensional) for the community larval fish assemblages sampled from 2005/06 and 2006/07 (Locks 5 and 6 pooled).

SIMPER analysis determined that the common native species, Australian smelt, bony herring, flathead gudgeon and carp gudgeons, contributed a total of 70% to observed larval assemblage differences between years (Table 6). The fifth species, exotic carp, contributed an additional 8.7% to the differences. All species, except carp gudgeons, were sampled in greater abundance in 2006/07. Murray cod, freshwater catfish, golden perch and silver perch, contributed relatively little to the assemblage differences due to very low abundance of these species. These species, however, are significant due to their ecological, conservation and fisheries value.

Detailed seasonal patterns in the relative abundance of each of the common, iconic and exotic species were reported and compared between years in context of environmental conditions (water temperature and water level) in Sections 5.3, 5.4, 5.5.

Table 6. SIMPER analysis for the comparison of larval fish assemblages between 2005/06 and 2006/07, in the Lower River Murray. Results are based on fourth root-transformed data. Mean abundance is the number of fish larvae per 1,000 m^3 with Locks 5 and 6 data grouped. CR (consistency ratio) indicates species distributions between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between 2005/06 and 2006/07 (shown by ANOSIM) attributable to individual species. A cumulative contribution cut-off of 80% was applied. Mean dissimilarity is expressed as a percentage ranging from 0% (identical) and 100% (totally dissimilar).

Species names	Mean abundance		CR	Contribution (%)	Cumulative contribution
	2005/06	2006/07		Mean dissimilarity = 36.31	
Australian smelt	**43.14**	**265.67**	**1.37**	**24.95**	**24.95**
Bony herring	**19.00**	**89.42**	**1.27**	**21.43**	**46.38**
Flat-headed gudgeon	**48.47**	**98.64**	**1.28**	**12.20**	**58.58**
Carp gudgeon	**66.25**	**48.17**	**1.29**	**11.29**	**69.87**
Carp	**1.50**	**2.72**	**0.89**	**8.7**	**78.58**

5.6.1 Investigations into relationships between larval fish assemblages and environmental parameters

Spearman rank correlation analysis using BIOENV identified that the combination of minimum and maximum temperatures (°C) and maximum relative water level (m AHD) provided the overall best match (ρ_s = 0.339) between environmental variables and the observed differences in larval fish assemblages between 2005/06 and 2006/07 (p=0.01). The best single variable, which explained the observed differences between 2005/06 and 2006/07, was maximum temperature (°C) (ρ_s = 0.298), and the best two variables were maximum temperature (°C) and maximum relative water level (m AHD) (ρ_s = 0.309).

Figure 10a is the MDS ordinations of larval fish assemblages (same as figure 9) showing some separation between 2005/06 and 2006/07. Figures 10b, 10c, and 10d, show the same ordination with superimposed circles representing the minimum temperature (°C), maximum relative water level (m AHD), and maximum temperature (°C), respectively. Figure 10b indicates the separation of the years may have been driven by differences in minimum temperature with distinctly lower values in 2006/07 than those in 2005/06. Similar patterns were detected when matching larval assemblages with maximum relative water level (Figure 10c). Maximum temperature was identified as a significant driving factor for the assemblage difference, although this is not well presented in the bubble plot, with little difference in values between years (Figure 10d).

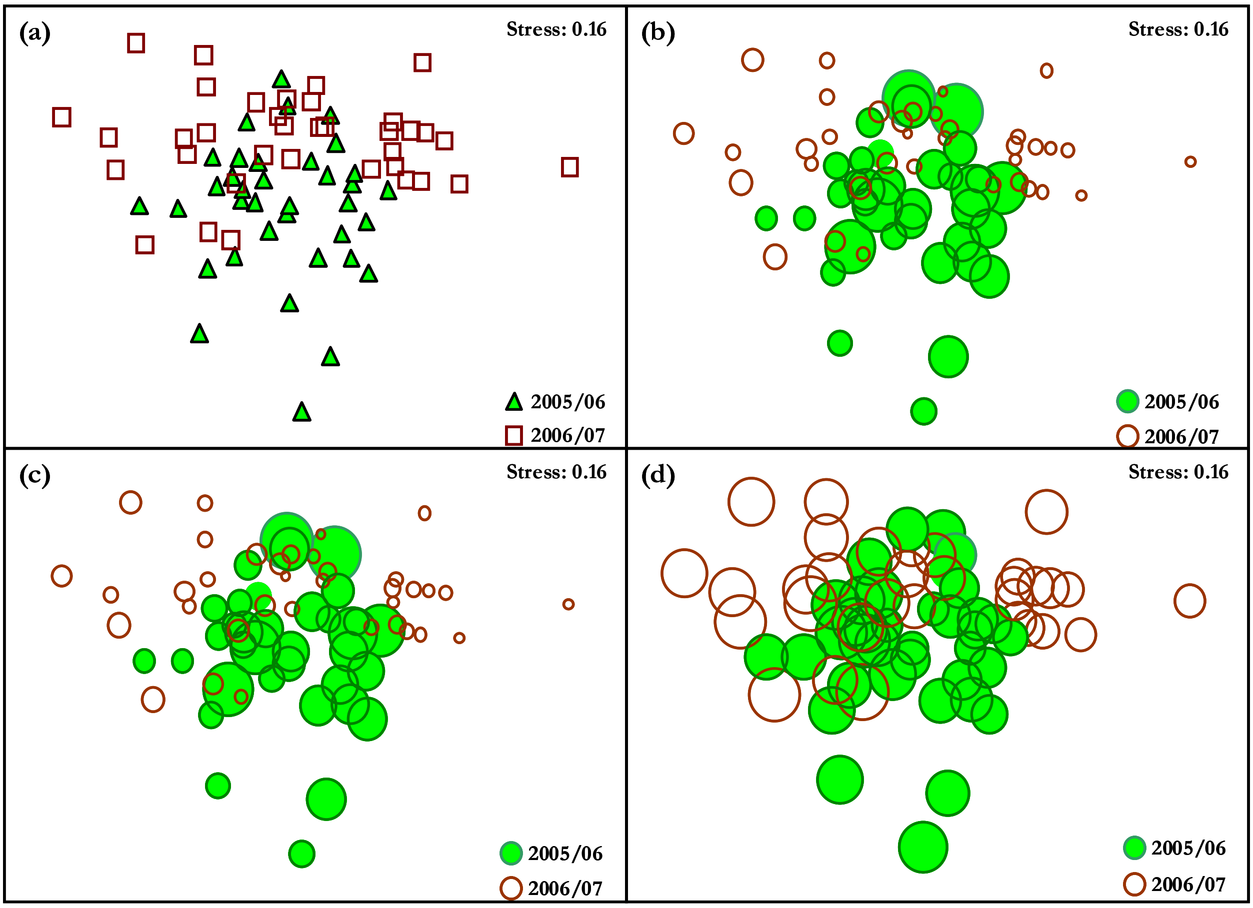


Figure 10. (a) MDS plot (2-dimensional) for the community larval fish assemblages sampled from 2005/06 and 2006/07. Super imposed circles represent the values of (b) minimum temperature °C, (c) maximum relative water level (m AHD) and (d) maximum temperature (°C). Larger circles represent greater values.

5.7 Age estimates for early life stage golden perch collected during 2005/06

During the 2005/06 season the age range of golden perch, including those young-of-the-year collected in January, was 14-63 days, with a mean of 29 (± 1.2 days S.E.) (Figure 11). The minimum ages of golden perch larvae were 14-16 days at a size range of 6-7 mm (Figure 12). These fish were collected below Lock 6 in November and December. The maximum ages were 53 and 63 days, these fish were both collected in January at Locks 5 and 6, respectively. Age-length relationship was linear with 89% of the variation in length correlating to age (Figure 11).

Back dating the ages to spawning time suggests that the greatest spawning frequency occurred between the 05-07/11/2005, with earliest spawning date identified on 20/10/2005 and the latest was on 25/11/2005 (Figure 12). The peak spawning period for golden perch corresponded with the initial increase in water discharge across the SA border (Figure 12).

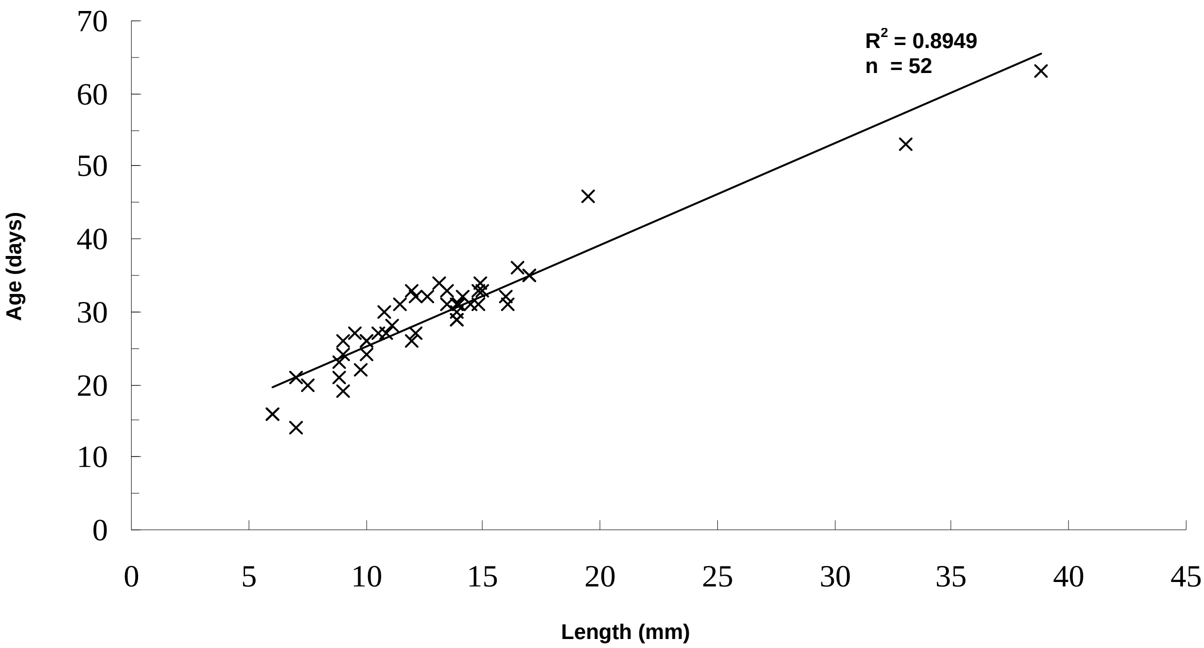


Figure 11. Length-age relationship for golden perch early life stages.

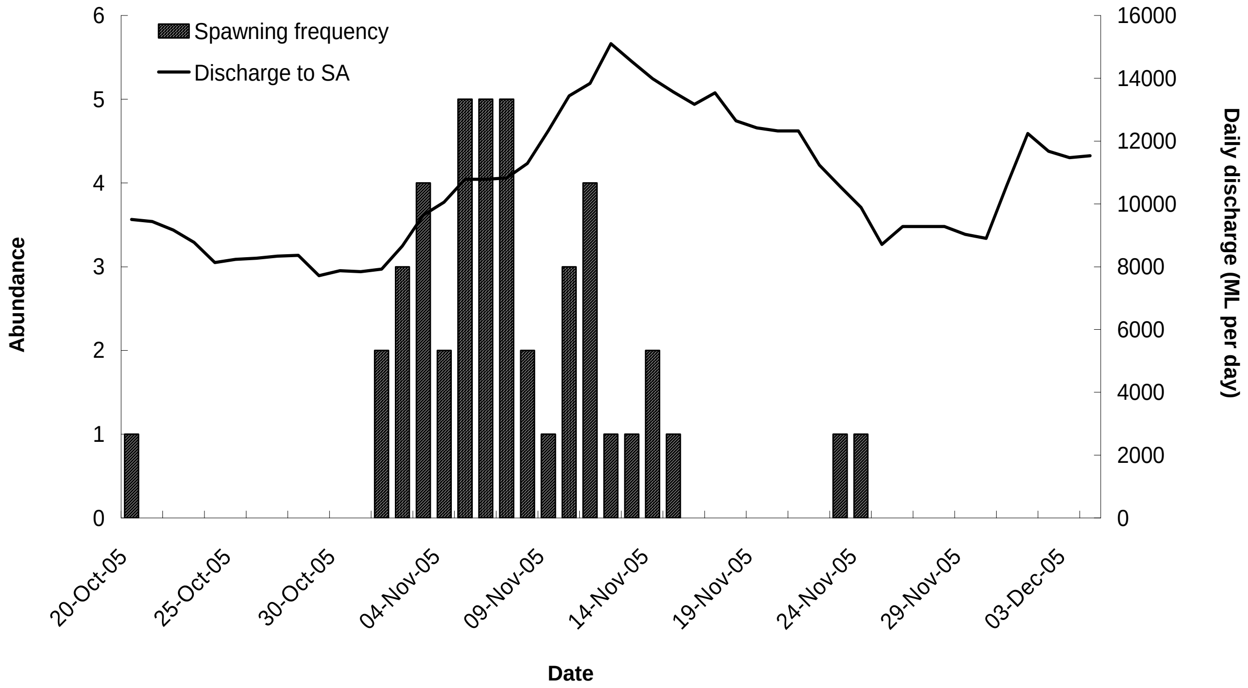


Figure 12. Frequency of back-calculated spawning dates for golden perch collected in 2005/06 (n=52).

6 DISCUSSION

6.1 Floodplain inundation

The natural flow regime of the River Murray in SA has been greatly impacted by river regulation (Maheshwari *et al.* 1995). In 2005/06, due to increased tributary inflows, the Lake Victoria inlet capacity was exceeded, and flow subsequently bypassed Lake Victoria via the Murray, which resulted in an increased discharge to SA. During this period, the discharge followed a similar seasonality to the historical flow regime, starting early in September, peaking during November and continuing to stay above base flow through until the end of December. In 2006/07, the SA section of the River Murray received below standard entitlement discharge; with water being diverted into storage for Lake Victoria. The maximum discharge was 5,190 ML per day during January 2007.

Floodplain inundation has previously been believed to play a major role in the lifecycles of many native fish in the Murray-Darling Basin, by initiating spawning, providing habitat for larvae and juveniles and through increasing the food resource available (Cadawallader 1978; Geddes and Puckridge 1989; Lake 1967c). During the relatively low flow year of 2006/07, even under the maximum discharge (5,190 ML per day), none of the floodplain between Locks 5 and 6 was inundated. The condition differed in 2005/06, through a combination of water level raising and an increase in discharge, a maximum of 254 hectares of the floodplain was estimated to have been inundated between Locks 5 and 6, accounting for about 2% of the floodplain in this area. Under the maximum discharge, without manipulation of water level, only seven hectares of the floodplain would have been inundated, thus, the weir pool raising had a significant effect, potentially accounting for 97 % of the inundation. Although larvae of many native fish do not utilise inundated floodplains as habitat (Humphries *et al.* 1999), this process may benefit subsequent larval survivorship through increasing food availability as a result of nutrient fluxes back into the river channel (Arumugam and Geddes 1987; Geddes and Puckridge 1989; Gehrke 1994; Welcomme 1985).

6.2 Fish species collected as larvae in the main channel of the River Murray, SA

Nine native species, including the iconic species, Murray cod, golden perch, silver perch and freshwater catfish were captured as larvae, and two exotic species, carp and redfin. Results in regard to spawning seasons are consistent with previous studies in this region (Leigh *et al.* 2008; Meredith *et al.* 2002), and the Barmah-Millewa region in the mid Murray (King *et al.* 2007) and further support classifications of early life history modes described by Humphries *et al.* (1999). Understanding timing and duration of spawning events and composition of larval assemblages is particularly important for water management strategies, as it potentially allows management techniques to be implemented at suitable times to benefit spawning and larval survivorship of key native fish species.

6.2.1 Common native species

The most abundant native species collected were the common species, including Australian smelt, carp gudgeon, flathead gudgeon and bony herring. The relative abundance of Australian smelt, flathead gudgeons and bony herring during 2006/07 was higher than 2005/06. These results are in line with those identified by Leigh *et al.* (2008) within the Chowilla Anabranch system, SA and a study by King *et al.* (2007) in the Barmah-Millewa region, mid Murray. These fish are all relatively short lived, 1-3 years with the exception of bony herring, lower trophic level species, which occur in high numbers through out the Murray-Darling Basin (Allen 1989; Hammer and Walker 2004; McDowall 1996). These species are characterised as generalists or low flow recruitment specialists with mode 3a and 3b life history strategies. The LFRH indicates the recruitment of mode 3a and 3b species can occur in the main channel during low flows through habitat specialisation, into still, warm and shallow littoral zones and backwaters (Humphries *et al.* 1999). Although in this instance, where the river is heavily regulated, the main channel proper may provide the necessary characteristics for a successful spawning and recruitment in these species. In the current study, larval fish were abundant in both years for both mode 3a (Australian smelt, flathead gudgeon) and 3b (carp gudgeon) species as defined by Humphries *et al.* (1999). Bony herring have not been classified previously within these modes; however, despite a larger body size their reproductive strategy fits into the classification for mode 3b (Table 2, Humphries *et al.* 1999; Puckridge and Walker 1990). Water temperature has been documented as a possible spawning cue for many of these species, and this was supported in the results from the BIOENV analysis, where maximum temperature was identified as the best single variable matching to larval fish assemblage patterns. With the exception of carp gudgeons, where no significant difference occurred, all of these species responded positively to the low flow conditions in 2006/07, exhibiting greater abundances. This suggests that the above mentioned species respond well to low flow conditions, perhaps due to the high concentrations of appropriately sized prey (Humphries *et al.* 1999) and/or possibly a reduction in species number and abundance of top predator species.

6.2.1.1 Australian smelt

Australian smelt were one of the most abundant species collected as larvae throughout the sampling seasons, abundance was significantly higher in 2006/07 than 2005/06. Australian smelt has a prolonged spawning season in the South Australian section of the River Murray, although there were definite peaks in abundance in both years. There appeared to be a distinct spawning season in both years with peaks occurring early in November 2005 and early October 2006. These results are in line with the results from King *et al.* (2007) in the Barmah-Millewa region during a similar time frame, and Meredith *et al.* (2002) in the Lindsay River during 2001, where a distinct spawning season was identified in early October. Contrastingly, Leigh *et al.* (2008) identified Australian smelt to have a prolonged spawning period with no peaks. In South Australia, a histology study identified that the spawning period for Australian smelt was from August through December, with some residual spawning activity in January (Leigh 2002).

6.2.1.2 Gudgeons

Carp gudgeons were similarly highly abundant throughout the study, and had similar abundances in both years. Present throughout both seasons, they appeared to have a protracted spawning season with some peaks in larval abundance from November through December in 2005/06 and during December of 2006/07. Similar results were identified for the Barmah-Millewa region (King *et al.* 2007). Due to taxonomic difficulties in separating species in the gudgeon genus *Hypseleotris*, these results may be confounded as individual species may have distinct spawning seasons, which when combined suggest a protracted spawning period.

Flathead gudgeon larvae were highly abundant throughout the sampling seasons from September through March, indicating a protracted spawning event, similar to Australian smelt. Larval abundance was higher under low flow conditions in 2006/07 than in 2005/06. In 2005/06, while they were present in higher numbers throughout October and November 2005, there were no distinct peaks. These results are in line with those identified by King *et al.* (2007) from the Barmah-Millewa region. During 2006/07, however, there appeared to be a much more distinct spawning period during November and December, which was more similar to the results from the Lindsay River where a much shorter spawning period was identified from October through December (Meredith *et al.* 2002). These results are also in line with those identified by Leigh *et al.* (2008), although both flathead and carp gudgeons were grouped for analysis so individual results could not be distinguished.

6.2.1.3 Bony herring

Bony herring larvae were collected in high abundances in both sampling seasons, however, abundances were higher during 2006/07 than in 2005/06. The abundance of bony herring larvae peaked during January in 2005/06 and December in 2006/07. Patterns exhibited by bony herring larvae, appearing relatively late in the season, are consistent with previous studies in the Lindsay River (Meredith *et al.* 2002) and the more recent studies in the Chowilla Anabranch (Leigh *et al.* 2008), and coincide with peak daily temperatures and a stable low flow period in both years. This supports suggestions by Meredith *et al.* (2002) that spawning may be cued by either temperature or photoperiod and endogenous rhythms, as predicted by Humphries and Lake (2000).

6.2.2 Iconic species

The iconic species collected were freshwater catfish, Murray cod, golden perch and silver perch. All of these species are State and/or nationally listed threatened species (DEH 2003; EPBC 1999) and/or protected under the South Australian *Fisheries Act* 1982, with the exception of golden perch. For golden perch no formal conservation classification currently exists, however, the commercial fishery was closed in 2003 in SA and golden perch remain to be an important native fish for recreational fishing in the Murray-Darling Basin.

Based on reproductive strategies, the above species can be separated into two distinct life history modes, mode 1 (freshwater catfish and Murray cod) and mode 2 spawners (golden perch and silver perch) (Table 2, Humphries *et al.* 1999). Mode 1 spawners have one spawning event in late spring/early summer, larvae are well developed at hatch and spawning is not believed to be initiated by high flows (Humphries *et al.* 1999), these species were collected in both years of the study. Mode 2 spawners spawn only once between late spring and early autumn and are believed to be able to delay spawning until favourable conditions occur, in the case of golden perch they may resorb gonads if unsuitable conditions persist (Humphries *et al.* 1999). Spawning may be linked to higher flows and possible flooding. In the current study, both golden perch and silver perch were only collected in 2005/06, the higher flow year, in conjunction with the weir pool raising.

6.2.2.1 Freshwater catfish

The collection of freshwater catfish larvae from the main river channel was significant. Larval stages have rarely been observed in the wild. During 2005/06 and 2006/07 larvae of the freshwater catfish were collected from November through December. They ranged in size from 14-24 mm and were estimated to be 23-25 days post hatch (Lake 1967b). Night plankton tows of the pelagic zone were most effective sampling method. Furthermore, the collection of freshwater catfish larvae in the pelagic zone adds support to the suggestion that larval drift may be facilitating downstream dispersal for this species (Zampatti *et al.* 2005).

6.2.2.2 Murray cod

Collection of Murray cod larvae is a significant result as it indicates adult spawning activity in both years. Murray cod were collected as free-swimming larvae throughout November 2005 and November and December 2006. The appearance of free-swimming larvae occurs 21-25 days post fertilisation (Lake 1967b; Rowland 1992). Larvae were collected in day and night samples of the pelagic environment, it is reasonable to suggest that they were still in the drifting stage, and thus, were spawned during late October. Murray cod larvae were collected during November, which was identical to that documented in previous studies (Humphries *et al.* 2002; King *et al.* 2007; Leigh *et al.* 2008; Meredith *et al.* 2002). These results add further support to the growing body of evidence suggesting that Murray cod will spawn at the same time of year regardless of variations in flow discharge (Humphries 2005; Koehn and Harrington 2005; Koehn and Harrington 2006).

Given that collection of Murray cod larvae occurs in all years regardless of discharge rates (Humphries 2005; Koehn and Harrington 2005; Koehn and Harrington 2006), an increase in water level is not required to initiate spawning. Contrastingly, stock assessments of Murray cod have suggested strong year classes associated with years of high flow and flooding in South Australia (Ye *et al.* 2000; Ye and Zampatti 2007). This may be linked to survivorship and recruitment rather than spawning, with higher level of recruitment success in high flow and flood years, where the greatest influence is likely to be the survival of larvae and juveniles (Koehn and Harrington 2006). Given this low flow years may pose a significant threat to Murray cod recruitment.

6.2.2.3 Golden perch and silver perch

Collection of golden perch and silver perch is similarly significant, as larvae of these species are rarely collected in the wild and in SA this is one of the first studies to attempt this. Both species are believed to be stimulated to spawn by flooding (Harris and Gehrke 1994; Lake 1967c; Mackay 1973; Reynolds 1983; Rowland 1983) as prescribed by the flood recruitment model (Harris and Gehrke 1994). Given, the results of more recent studies, however, the factors that drive spawning and larval survivorship are as yet uncertain (Gilligan and Schiller 2004; King *et al.* 2005; Mallen-Cooper and Stuart 2003). Despite this, adult stock assessments have indicated that golden perch have very strong year classes associated with years of high discharge and flooding in SA (Ye 2005). Mallen-Cooper and Stuart (2003) identified that in the middle reaches of the Murray, both golden perch and silver perch had strong year classes associated with moderately variable within channel flows.

Golden perch is believed to have single spawning event between October and March, which has been positively correlated to rises in water level during within channel flows (Gilligan and Schiller 2004; King *et al.* 2005; Mallen-Cooper and Stuart 2003). Golden perch have been documented to resorb eggs if conditions are unsuitable. In the current study, golden perch larvae were initially collected at the sampling sites in early November 2005. This species is considered an obligate drifter and have relatively little ability to regulate larval drift, thus they have the potential to disperse significant distances. Given the age of the larvae sampled (mean of 29 days) and water transit times it is possible that the larvae were spawned in the vicinity of Locks 7 and 8 (pers. comm. Porter 2006). These areas were not influenced by the weir pool manipulation trials; however, they did receive an increase in discharge (given that this area has a wide diversity of off-channel anabranch systems it may benefit more highly from the within channel rises). This supports previous findings that a within channel flow rise may be sufficient to induce spawning for golden perch.

Silver perch showed a prolonged spawning season in 2005/06, from early November to late January. During this period water temperature exceeded 23 ºC, the threshold at which spawning occurs (Clunie and Koehn 2001). The spawning season identified in the current study supports that identified in previous field studies (King *et al.* 2004; Lake 1967c; Mallen-Cooper and Stuart 2003; Merrick and Schmida 1984). Similar to golden perch, spawning in silver perch has been shown to correlate positively to rises in flow and water kevel (Gilligan and Schiller 2004; King *et al.* 2005; Mallen-Cooper and Stuart 2003). The presence of silver perch in 2005/06 but not 2006/07 adds further support to this and indicates that a small within channel rise may be sufficient for spawning and survival of larvae. Like golden perch, silver perch are obligate drifters and may have come from outside the sampling area although age estimates were not conducted for this species.

6.2.3 Exotic species

6.2.3.1 Exotic Carp

Carp larvae were collected in 2005/06 and 2006/07 during the early season (September through November), and we may have missed the very beginning of the spawning season. Meredith *et al.* (2002) also seemed to have missed the majority of the spawning season of carp in the Lindsay region when they commenced sampling in October. In the Chowilla Anabranch study, carp were collected from September through December, and the authors also note that larvae may have been present prior to beginning of the sampling (Leigh *et al.* 2008). King *et al.* (2007) collected carp larvae from October with the peak abundance and patterns differing between the years. Humphries *et al.* (2002), recorded catches of carp larvae from September through January, in the Broken and Campaspe Rivers, Victoria, from 1995-1999. Studies on the histology of adult fish in SA have indicated spawning activity from September through to May (Smith and Walker 2004).

6.2.3.2 Redfin perch

Redfin perch larvae were collected in 2005/06 and 2006/07 from September through October, and we may have missed the very beginning of the spawning season, as many of these were later stage larvae. In the Chowilla anabranch system redfin perch larvae were only collected for a brief period in October and November 2006/07 (Leigh *et al.* 2008). Similar to carp, due to the delay of sampling Meredith *et al.* (2002) had only recorded minimal catch of this species in the Lindsay region during 2001. Humphries *et al.* (2002) similarly recorded a discrete period of collection for redfin perch larvae from September through November each year, in the Broken and Campaspe Rivers, Victoria from 1995-1999. Similarly, King *et al.* (2007) recorded redfin perch larvae annually, with the highest relative abundance in October.

6.3 Effect of water level raising on fish populations

The current study indicated the common native species, such as Australian smelt, flathead gudgeons, carp gudgeons and bony herring, could respond positively to low discharge and stable water level conditions such as those in 2006/07. Collection of the larvae of a range of iconic species, including golden perch, silver perch, Murray cod and freshwater catfish during 2005/06 represents a significant result for native fish populations, particularly as the first two species were only present in 2005/06, suggesting successful spawning. Although through current monitoring, it was not possible to isolate the effect of weir pool raising given it was undertaken in conjunction with an increase in discharge, it is unlikely that raising the weir pool level alone has initiated spawning in any of these key native species.

Change in water level and increased discharge is not believed to induce spawning in wild populations of freshwater catfish (Lake 1967a) or Murray cod (Humphries 2005; King *et al.* 2003; Koehn and Harrington 2005), as they have been shown to spawn in all years independent of flow. The collection of freshwater catfish and Murray cod larvae in both years suggests that the weir pool raising had little effect on spawning. Potential influence on larval survivorship and recruitment success requires further investigation.

Golden perch and silver perch larvae have rarely been collected in the wild, and thus, most of the information available is from experimental studies (Harris and Gehrke 1994; Lake 1967c; Mackay 1973; Reynolds 1983; Rowland 1983). Given the high probability that these fish came from outside the area affected by the weir pool raising it is unlikely that raising the level of the weir pools initiated spawning in either species. As a comparison, golden perch larvae were collected in the Chowilla Anabranch system during 2005/06, which similarly received increased discharge and was minimally influenced by the raising of the Lock 5 weir pool (Leigh *et al.* 2008). However, no larvae of this species were collected during the same period in 2006/07 when flows were relatively stable (Leigh *et al.* 2008). There was some evidence for a low-level of recruitment of golden perch and silver perch in 2005/06, being that young of the year golden perch were collected in January and February 2006 at around 40 mm in the main channel, additionally young of the year golden perch and silver perch were collected in February 2006 at about 55 mm within the Chowilla anabranch system (B. Zampatti unpublished data).

An increase in floodplain inundation was estimated through weir pool raising during the manipulation trial in 2005/06, with an increase of discharge to SA. Previous studies indicated that floodplain inundation may release accumulated nutrients, creating phytoplankton blooms, providing a food source for the survival and growth of larvae and juvenile fish (Arumugam and Geddes 1987; Geddes and Puckridge 1989; Gehrke 1994; Rowland 1992). Therefore, weir pool raising to increase area of floodplain inundated may provide positive effects on larval survivorship for those fish downstream of the area inundated. However, this needs to be treated cautiously as a simple manipulation of water level is not sufficient to reproduce the outcomes of flood pulses (both hydrological and biological) through the surrounding floodplain (Toth *et al.* 1998).

In conclusion, weir pool manipulation is not a replacement for increasing discharge rates. Nevertheless, when used in conjunction with elevated discharge or environmental flow allocations, manipulating weir pool height may have the potential to increase the environmental benefit. However, there may be some negative impacts, for example, increased floodplain inundation may aid the spawning and survivorship of exotic species, through increasing connectivity to off-channel spawning sites. Therefore, further investigation is needed to identify and quantify the ecological outcomes of weir pool manipulation, and different regimes of raising and drawing down of weir pools (timing, duration, rate etc) to maximise ecological benefits.

7 RECOMMENDATIONS FOR FUTURE RESEARCH

- An improved adaptive management process needs to be developed for future weir pool manipulation trials in relation to different discharges to SA.
- Further investigation is needed to identify and quantify the ecological outcomes of weir pool manipulation, through a static raise (i.e. water level raise without coinciding increase in flow discharge) and a raise in conjunction with increased flow.
- Research is needed to study different regimes of raising and drawing down (timing, duration, rate etc) to maximise ecological benefits.
    - For example, timing of manipulations needs to be considered in relation to native and exotic spawning seasons. As exotic species, such as carp and redfin, spawn earlier (August/September) than most native species, a slight delay (from September to October) of weir pool raising may disadvantage the spawning and recruitment of carp but still provide native fish with necessary conditions to boost recruitment.
    - The effect of differing draw down strategies, once the raising is complete, also warrants further research to determine the effects on fish, which may be utilising the inundated floodplain areas as habitat.
- Recruitment studies should be conducted in years following weir pool manipulation trials to further confirm the effects of water level raising on recruitment success.
- The relationship needs to be considered between over bank flows and zooplankton production, as food for larvae, in an effort to time nutrient fluxes back into the river so that appropriately sized prey items are available in sufficient densities to support larval fish communities and facilitating survival and growth of young fish.

8 PERSONAL COMMUNICATIONS

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