Movement of fish, eggs and larvae through the Hattah Lakes environmental pumps

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Winter–spring 2014

Final Report

MDFRC Publication 50

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Final Report prepared for the Mallee Catchment Management Authority by The Murray-Darling Freshwater Research Centre.

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This report was prepared by The Murray-Darling Freshwater Research Centre (MDFRC). The aim of the MDFRC is to provide the scientific knowledge necessary for the management and sustained utilisation of the Murray-Darling Basin water resources. The MDFRC is a joint venture between La Trobe University and CSIRO.

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Report Citation: Brown P, Huntley S, Ellis I, Henderson M, Lampard B (2015) Movement of fish eggs and larvae through the Hattah Lakes environmental pumps. Final Report prepared for the Mallee Catchment Management Authority by The Murray-Darling Freshwater Research Centre and La Trobe University, MDFRC Publication 50/2015 January, 36pp.

Cover Image: (Clockwise from top left) Environmental pumps, sampling fish larvae in Chalka Creek, the outlet from the pumps into Chalka Creek, sampling fish larvae in the Murray River, photomicrograph section through a juvenile Silver perch otolith

Photographer: Braeden Lampard – MDFRC. Fish Aging Services (otolith)

Document history and status

Version	Date Issued	Reviewed by	Approved by	Revision type
DRAFT	19/1/2015	Iain Ellis	Paul Brown	Scientific review
DRAFT	28/1/2015	Mark Henderson	Paul Brown	Readability
DRAFT V3	4/3/15	Michelle Kavanagh	Paul Brown	Copy Edit

Distribution of copies

Version	Quantity	Issued to
DRAFT	1 x Word	Andrew Greenfield, MCMA
DRAFT V2	1 x Word	Vic Hughes, MDBA
DRAFT V2	1 x Word	Louisa Davis, DELWP
Final	1 x PDF	Andrew Greenfield MCMA

Filename and path:	m:\projects\dse_malleecma\tlm\494 & 601- movement of fish, eggs and larvae through the hattah pumps\final report\finalreport_movementoffisheggsand larvae through the hattah pumps.docx
Author(s):	Paul Brown, Scott Huntley, Iain Ellis, Mark Henderson, Braeden Lampard
Author affiliation(s):	The Murray–Darling Freshwater Research Centre and La Trobe University
Project Manager:	Murray–Darling Freshwater Research Centre
Client:	Mallee Catchment Management Authority
Project Title:	**Movement of fish, eggs and larvae through the Hattah pumps part B; Fish movement on Hattah drawdown**
Document Version:	Final
Project Number:	M/BUS/601 & 608
Contract Number:	**MD2846-1, 14.1315**
Purchase Order:	**PPU22237**

Acknowledgements: Thanks to Taylor Pay and David Wood, MDFRC for assistance with the fieldwork; to Andrew Greenfield, Nicholas Sheahan and Peter Kelly at the Mallee CMA for commissioning and supporting the project; to Andrew Keogh at the Murray-Darling Basin Authority for supplying flow statistics; to Andrew Brown and Kyne-Krusic Golub at Fish Ageing Services Pty. Ltd. for the otolith analysis; to Chan Fei Chong at Goulburn Murray Water for updates on pump operations and to Shane Southon and Damian Kerr, Parks Victoria for information, assistance and support during the project.

This project was funded by The Living Murray initiative. The Living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian, Australian Capital Territory and Commonwealth governments, coordinated by the Murray–Darling Basin Authority.

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Glossary

Morphotype Of a single type, defined by shape, i.e. fish eggs that all look the same are a single morphotype.

Sagittal otolith One of three pairs of otoliths, or 'ear bones' present in fish. These act as organs of balance for the fish. They can be used to estimate a fish's age as they grow in micro-increments of one per day leaving a visible trace as concentric rings when a cross section of the otolith is examined under a microscope.

Ichthyoplankton

Plankton is the term used to describe small animals and plants that live freely in the water column; the component of plankton that is made up of fish larvae and eggs is ichthyoplankton.

Entrainment The process of particles (e.g. fish eggs and larvae) becoming swept along with the flow created by a structure; in this case the Hattah environmental pumps.

Impingement The process of objects (e.g. fish) coming into violent and /or sustained contact with something, e.g. with the inlet-screens of pumps.

Executive summary

The present study primarily examines the response of the local fish community to the second of two substantial environmental watering events at the Hattah Lakes that delivered 92 000 ML of water through environmental pumps during winter/spring 2014–15.

An earlier 2013–14 event delivered 61 000 ML of water during spring/summer 2013–14 to inundate an almost completely dry Hattah Lakes system. The two major differences between the present 2014–15 event and the 2013–14 event described above are scale and timing. The 2014–15 watering event surcharged the Hattah Lakes wetlands to over 150% of their capacity resulting in a productivity pulse associated with flooding, and enabling the environmental regulators in Chalka Creek to subsequently be opened returning a substantial proportion of this productivity to the river. This study examines how the fish assemblage passing through the Hattah pumps changes over time (i.e. with season between the two events) and how this assemblage differs from that of the Murray River for the same period. A secondary aspect of this study was to preliminarily describe the response of the fish assemblage within the Hattah Lakes to the recession of water back to the Murray River.

As the Hattah Lakes filled during winter–spring 2014, there were a total of eight sampling events in Chalka Creek and four sampling events in the adjacent Murray River. Fish eggs and larvae were sampled with replicate drift nets, small fyke nets and light traps in each location (creek and river). Two sampling events targeted the recession flows which followed the surcharge filling.

Chalka Creek fish assemblage comprised six native and four non-native species of fish, as well as native freshwater shrimps and yabbies. The Murray River fish assemblage comprised seven native and three non-native species of fish, plus freshwater shrimps and yabbies (crustaceans). Relative abundance of fish and crustaceans in the Murray River was a reasonable predictor of relative abundance in Chalka Creek during environmental watering. However, multivariate analysis showed that there were significant differences between the assemblage structure of fish, and crustaceans sampled in the Murray River (source) and the Chalka Creek (sink). This dissimilarity is largely driven by differences in abundance of crustaceans, Carp gudgeons, Bony herring, and Australian smelt.

The fish assemblage differed between the present environmental watering event and the previous commissioning event. At each event, the fish assemblage in the Murray River was more diverse and abundant than that in Chalka Creek. During the present event, patterns of relative abundance for individual species in the Murray River are not reflected in species' abundances species in Chalka Creek.

Abundance of larvae in the Murray River during this winter–spring survey was low compared to previous studies. Only three species of native fish were recorded as drifting larvae compared to six species during the previous spring–summer survey.

Juvenile Silver perch (n=2) were recorded in Chalka Creek on 22 and 29 July 2014 and analysis of daily increment counts suggested ages of 78 and 74 days corresponding to estimated hatch dates of 29 March and 10 April, respectively. During this period the Murray River upstream of Hattah experienced a small rise in flow while flows in the Murrumbidgee were low and steady. The water temperature during the spawning dates was between 22 and 24 ^{o}C.

Although many fish survived entrainment and transport through the pumps, survival varied by species and may be lower than estimates from other somewhat comparable studies. Estimates of survival (as ratio of live: dead fish in the samples) also varied with distance downstream from the pump outflow.

Based upon these results, recommendations are made on:

- Avoidance of entrainment of unwanted alien invasive species (e.g. Common carp).
- The preferred timing of watering of the Hattah Lakes via the environmental pumps to optimise the nursery potential for native species and reduce risk of entrainment of Common carp.

Knowledge gaps identified include:

- The effect of pump operations on the potential for entrainment-mortality.
- The potential to facilitate the emigration of large-bodied native fish species from the Hattah Lakes under a range of flow conditions.
- Evaluation of the survival trade-off for juvenile fish between “risky-transport” to a fast-growth, wetland nursery habitat; and normal-growth riverine habitat.

1 Introduction

When inundated, the wetlands and floodplain of Hattah Lakes provide a mosaic of important habitat for a variety of native fish species and their different life stages. Historically, flooding occurred almost annually, providing regular fish passage between the Murray River and Hattah Lakes. River regulation has reduced the frequency, magnitude and duration of these floods (Cumming & Lloyd 1993; Souter 2005).

In the 2013–2014 spring/summer commissioning of environmental regulators constructed under TLM Environmental Works and Measures Program (MDBA 2012) restored some of the hydrological balance that has been altered by river regulation. The managed environmental watering event delivered 60 904 ML of water to the Hattah Lakes wetlands and surrounding floodplain, filling previously dry wetlands and inundating some floodplain habitats that had not seen water for ~20 years. The response of the fish communities to this environmental watering event was investigated by sampling the fish assemblage entrained in the 2013–2014 environmental watering and transported into Chalka Creek (and thence into the Hattah Lakes) and comparing it to the assemblage sampled in the adjacent Murray River (Brown *et al.* 2014). While the commissioning event inundated the floodplain allowing fish transported into the lakes to benefit from high productivity pulses associated with flooding; subsequent isolation from the Murray River prevented further lateral connectivity between the productive wetlands and the river channel.

The present study primarily examines the response of the fish community to a second larger environmental watering event that delivered 92 000 ML of water during winter/spring 2014. The two major differences between this event and the commissioning event described above are scale and timing. The 2014 watering event surcharged the Hattah Lakes wetlands to over 150% of their bank-full capacity enabling the environmental regulators in Chalka Creek to be opened returning a substantial proportion of this floodplain productivity to the river – this mimics the 'flood pulse' concept (Junk *et al.* 1989) believed to be one of the key processes that drive productivity in floodplain rivers of the world. The timing of this second filling event during winter and early spring is prior to the main spawning season of most native fish species (Lintermans 2007) so fewer fish eggs or larvae were expected in the source population of the Murray River.

Entrainment in large pumps, such as the environmental watering pumps at Hattah (and as also used throughout the Australian irrigation agriculture industry), has been shown to effect fish through injury and mortality of large and small individuals (medium sized fish are transported relatively unscathed) (Baumgartner *et al.* 2009). Previous studies have identified that pumping water into the Hattah Lakes from the Murray River can establish a "filtered" fish assemblage containing a sub-set of the species present in the donor population (Freestone *et al.* 2014; Vilizzi *et al.* 2013). While "filtering" such an assemblage can be advantageous if it contains desirable native fish species and few non-natives (Vilizzi *et al.* 2013), there have also been occasions where the resulting assemblage was depauperate (Ellis & Wood 2011).

The present study examines how the fish assemblage passing through the Hattah Pumps varies over time (i.e. with season) and how this assemblage differs from that of the Murray River for the same period. A secondary aspect of this study was to preliminarily describe the response of the Hattah Lakes fish assemblage to the recession of water back to the Murray River. That investigation was separately funded and started part way through the present study and is fully described in Appendix A.

2 Methods

2.1 Hydrology

Measured flow through the Hattah environmental pumps and River Murray height data modelled for the pump site was obtained from the Murray-Darling Basin Authority (pers. comm. Andrew Keogh, MDBA).

2.2 Fish community

2.2.1 Sampling designs

As the Hattah Lakes filled, there were a total of eight sampling events in Chalka Creek and four sampling events in the adjacent Murray River (Table 1). Each sampling event was comprised of three consecutive days.

Table 1. Sampling schedule for the eight sampling events

Event	Dates	Chalka Creek	Murray River
1	27–29 May 2014	✓	✓
2	10–12 June 2014	✓	
3	24–16 June 2014	✓	✓
4	8–10 July 2014	✓	
5	28–30 July 2014	✓	✓
6	5–7 August 2014	✓	
7	19–21 August 2014	✓	✓
8	2–4 September 2014	✓	

On each sampling day in Chalka Creek fish, eggs and larvae pumped into the creek from the Murray were sampled with:

- 6 small fyke nets set facing upstream
- 3 drift nets set facing upstream
- 3 light traps deployed in slack water areas.

On each sampling day in the Murray River fish, eggs and larvae comprising the fish assemblage in the source population were sampled with:

- 6 small fyke nets (3 facing upstream and 3 facing downstream)
- 3 pairs of drift nets (each pair consists of 1 top and 1 bottom net to sample the considerably deeper river channel)
- 3 light traps.

At each site nets were set in the afternoon and collected the following day (~ 18 h). Small fyke nets have dual wings (each 2.5 m long x 1.2 m drop), with a first supporting hoop (Ø = 0.4 m) fitted with a square entry (0.15 m x 0.15 m) covered by a plastic grid with rigid square openings (0.05 m x 0.05 m) and 2 mm mesh throughout. Drift nets are 1 m long conical nets with a circular opening (Ø=0.5 m) and a mesh size of 0.52 mm to capture drifting material including fish eggs and larvae (ichthyoplankton). Mechanical flow meters (General Oceanics Pty, Ltd.) were suspended from a bridal in the mouth of each drift net to record water volume filtered. Light-traps were modified quatrefoil traps (Secor *et al.* 1992) illuminated with a 6-hour cyalume© chemical light-stick and shielded by 1 mm mesh to protect captured larval fish from predation.

The sampling site in Chalka Creek was immediately downstream of the environmental pump outflow channel (Figure 1). In The Murray River samples were collected from a reach immediately upstream of the environmental pump inlets (Figure 1).

2.3 Sample processing

For small fyke nets, all catch was identified and counted on site. The first 20 individuals from each species on each day at each site were also measured. Small-bodied fish species were measured standard length (SL, mm) and total length (TL, mm). Large-bodied fish species were measured fork length (FL, mm).

Decapod crustaceans were caught in large numbers in small fyke nets. These were largely a mixture of two species of freshwater shrimp, *Macrobrachium australiense* and *Paratya australiensis* and the occasional yabby (*Cherax destructor*). The two species of freshwater shrimp are difficult to diagnose as juveniles in a field situation and as such were simply recorded as "shrimps", effectively pooling both species into one category.

Drift-net and light trap samples were preserved in ethanol and returned to the laboratory for processing. The contents of drift net and light trap samples were later sorted and juvenile fish, fish larvae and eggs were identified and enumerated.

Two juvenile Silver perch captured in Chalka Creek were sampled for analysis of daily otolith-growth increments to estimate their hatch dates. Otoliths were extracted under a dissecting microscope and glued to a microscope slide where they were polished down to the central point and examined for daily growth increments (Brown & Wooden 2007; Secor *et al.* 1991). Age determination was performed by Fish Aging Services, Pty. Ltd. (www.fishagingservices.com.au).

After week 4 of sampling the status of each fin-fish in the samples counted was noted as ‘alive’ or ‘dead’. During weeks 1–3 this was not noted. Cause of death was not always obvious. However, fish that were dead on collection of the sample and had physical injuries were photographed.

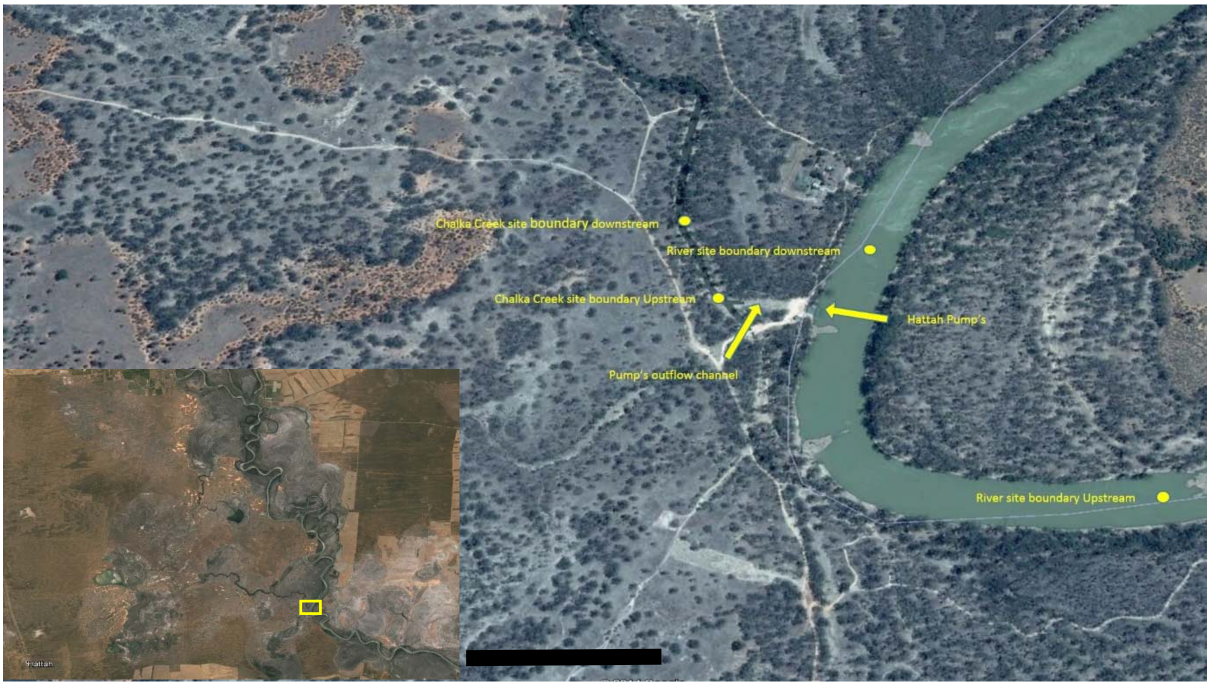

Figure 1. Map showing location of Chalka Creek site and Murray River site sampled in relation to Hattah environmental pumps. Inset shows location in broader context of Murray River reach. Scale bar=500 m.

2.4 Statistical analyses

Given that a pre-existing fish population existed in the Hattah Lakes (e.g. Lake Lockie), we sought to validate the concept that directional nets set in Chalka Creek to capture fish moving with the flow (i.e. downstream) would provide an indication of what was coming through the environmental pumps, rather than what was potentially swimming up Chalka Creek from the lakes. To explore this source-sink relationship between relative abundance of fish in the Murray River (source) population and in Chalka Creek, the ‘sink’ population we used data from weeks 1, 3, 5 and 7 when sampling occurred in both Chalka Creek and the Murray River. The relative abundance of each species in a weekly sample from all gears in the Murray River was investigated as a predictor of relative abundance of that species from Chalka Creek, using least squares linear regression.

Where the data was suitable, (i.e. few tied ranks and sample sizes large enough) the length frequency distributions for each species, of samples from Chalka Creek and the Murray River were compared with a two-sample Kolmogorov-Smirnoff test to determine if they were from the same length-structured population. All above statistical analyses were carried out using R (R Development Core Team 2008).

2.4.1 Multivariate statistics

Multivariate statistical analyses were done using PRIMER v6.0 (Clarke & Warwick 2001) and the add-on PERMANOVA+ (Anderson 2001). For the Chalka Creek site and the Murray River site, catch data for all species and groups (i.e., counts, including fish, fish eggs and decapod crustaceans) were combined from all sampling gear on each date into a single sample. Sample counts were first square root transformed to reduce the dominance of the counts of the very abundant species; then Bray-

Curtis similarity measures were calculated for all pairs of samples. The similarity matrix was used in a non-metric Multi-Dimensional Scaling ordination to produce a 2-D plot describing the dissimilarity in species composition and abundance of samples from the Chalka Creek and Murray River.

The null hypothesis that there *are no differences in community composition among groups of samples*, was tested using a one-way ANOSIM (Clarke and Warwick 2001) with samples grouped by waterway (Chalka Creek or Murray River). The ANOSIM calculates a global-R statistic and uses 999 randomised permutations of sample identity to create a distribution to test whether global-R is significantly different from zero, in which case the null hypothesis can be rejected.

SIMPER analysis (Clarke & Warwick 2001), was used to examine the contribution of each species to average resemblance between sample groups. For Bray-Curtis similarities it determines the contributions to the average Bray-Curtis dissimilarity between pairs of groups of samples. It also determines the contributions to the average similarity within a group.

Using a permutational MANOVA (PERMANOVA (Anderson 2001)), fish relative-abundance data previously reported in Brown *et al* (2014) (not presented here) was re-analysed along with matching data from the present study to test for differences in fish assemblages among two environmental watering events. Note that decapod crustacean abundance data from the present study was excluded from this fish assemblage comparison to make this analysis compatible with the previous dataset which was fish-only. The design used had two fixed factors, *location* (levels=Chalka Creek [C] and Murray River [M]) nested within *season* (levels =Spring-Summer 2013-2014 [S] and Winter–Spring 2014 [W]). As above, abundance data was square-root transformed and resemblance matrix calculated using Bray-Curtis similarity measures.

2.4.2 Estimate of ichthyoplankton entrained

The catch of ichthyoplankton entrained by the Hattah pumps was estimated by using the flow meters within the drift-nets in the Murray River to calculate the volume of water filtered by each net (ML). The catch can then be expressed as individuals (larvae or eggs) caught per megalitre filtered (catch per ML). The daily flow for the environmental pumps at Hattah Lakes was supplied for each day of drift-netting (Andrew Keogh, MDBA). The mean catch (individuals per ML) for each sampling day is multiplied by the daily flow to give an estimate of the mean daily entrainment for ichthyoplankton.

3 Results

3.1 Water delivery

Following the initial commissioning of the environmental pumps and the delivery of 61 GL of water to the Hattah Lakes during the period October 2013–January 2014 a second watering event was implemented to water flood plain habitat at a higher elevation. Pumping recommenced 26 May 2014 and continued for 120 days until 9 September 2014 (Fig 2) delivering a total of 91.969 GL (Pers. comm. Andrew Keogh, MDBA) which surcharged the Hattah Lakes above their 100% full level.

On 15 September, the environmental regulators at Oateys and Messengers Crossing began releasing the surcharged water back to the Murray River (see Appendix 1).

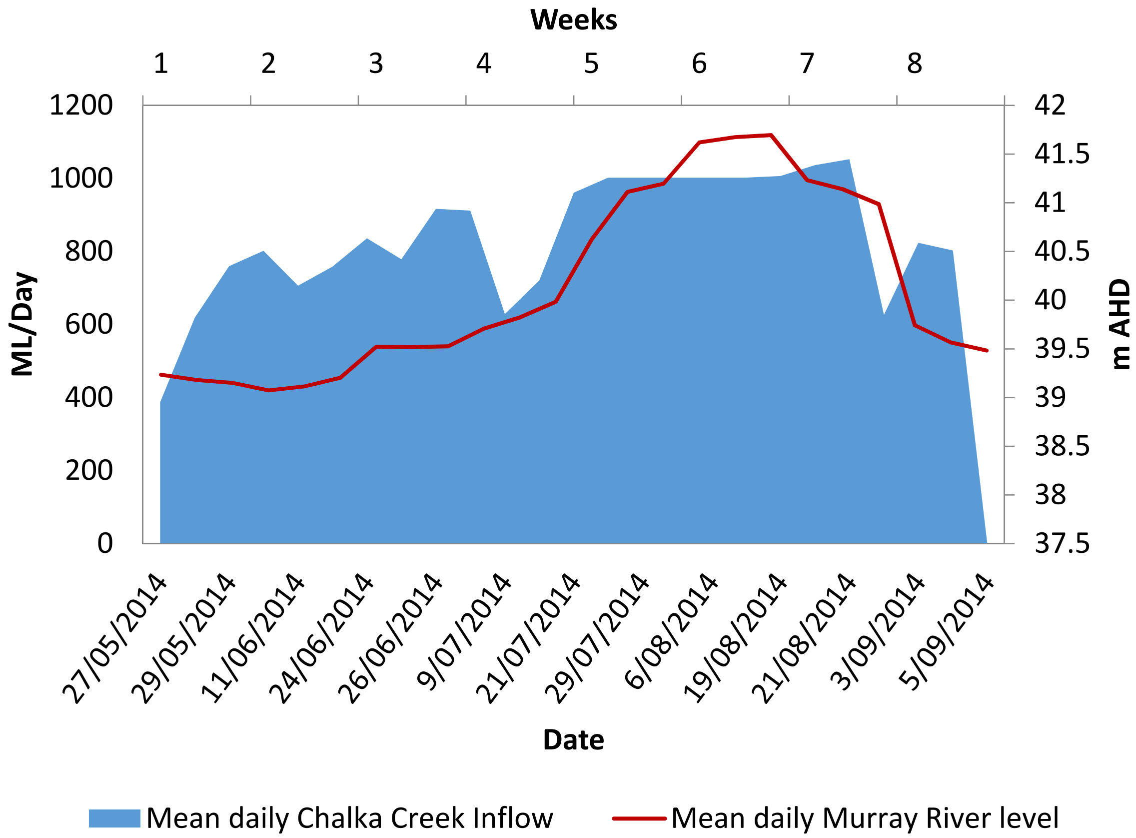

Figure 2. Pumped water volume during environmental watering (solid blue) showing the estimated river height at the pump site (line, m AHD). The approximate height of the pump inlet was 37.5 m AHD (courtesy of Andrew Keogh, MDBA).

3.2 Chalka Creek fish assemblage during environmental watering

The fish (n=685) sampled in Chalka Creek comprised six native (n=626) and four non-native (n=59) species of fish, plus fish eggs (n=12) and freshwater shrimps (n=1228) and a single yabby (Table 2).

Fish eggs were only encountered in the last week of sampling and were of a single morphotype. These were putatively identified as eggs of Australian smelt (*Retropinna* semoni) as adults were simultaneously sampled at peak abundance.

Bony herring (*Nematalosa erebi*), Australian smelt, Carp gudgeons (*Hypseleotris* spp.), Golden perch (*Macquaria ambigua*), Eastern gambusia (*Gambusia holbrooki*) and Common carp (*Cyprinus* carpio), made up the majority of the fish sampled although freshwater shrimp were an order of magnitude more abundant than any species of fin-fish. Other species including Silver perch (*Bidyanus bidyanus*), Un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Goldfish (*Carassius auratus*) and Oriental weatherloach (*Misgurnus anguillicaudatus*), were sampled at a count of five or fewer individuals.

Silver perch (n=4) and Oriental weatherloach (n=5) were recorded in Chalka Creek, but not in the Murray River.

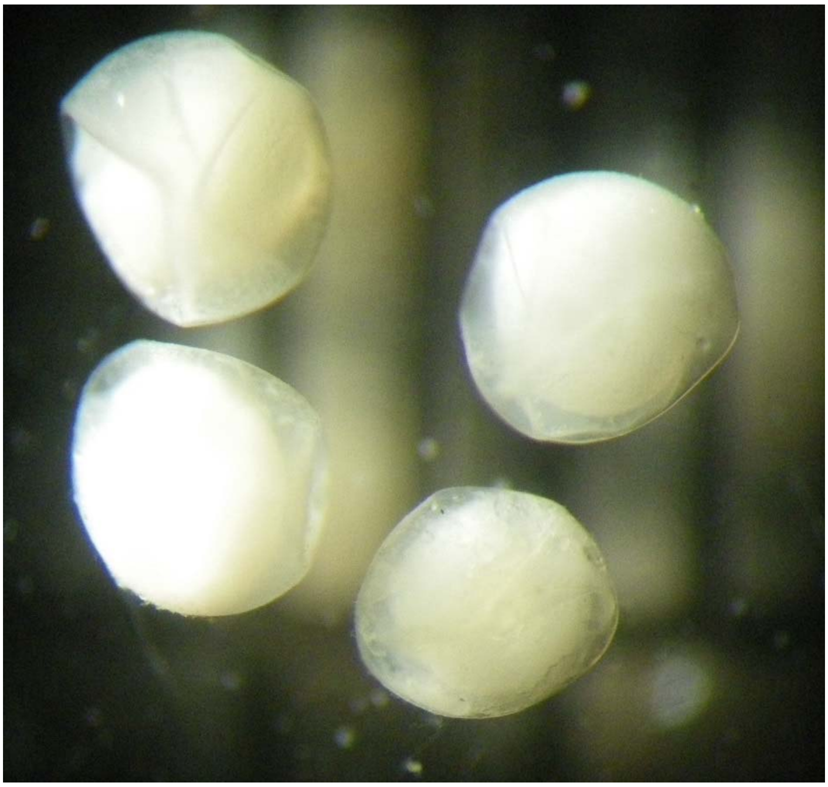

Figure 3. Fish eggs sampled in Chalka Creek during week 8, (2–4 September 2014). Putatively identified as the eggs of Australian Smelt. Adult Australian Smelt were simultaneously sampled at peak abundance. Vertical lines behind eggs are 1 mm ruler divisions. Note these eggs have been fixed in 70% ethanol causing some distortion to the outer membrane.

Table 2. Fish, eggs and decapod crustaceans sampled in Chalka Creek and the adjacent Murray River during environmental watering via the Hattah Pumps, May–September 2014, and using three types of sampling gear.

Origin	Size/Type	Common name	Species	Chalka Creek			Murray River			Total
				Drift nets	Light traps	Small fyke nets	Drift nets	Light traps	Small fyke nets	
Native	**Crustacean**	Freshwater shrimp	*Macrobrachium australiense/ Paratya australiensis*			1228			1595	2823
		Yabby	*Cherax destructor*			1			10	11
	Large-bodied	Bony herring	*Nematalosa erebi*	15		243	9		11	278
		Golden perch	*Macquaria ambigua*			29			2	31
		Silver perch	*Bidyanus bidyanus*			4				4
	Small-bodied	Australian smelt	*Retropinna semoni*	2	1	239	3	1	16	262
		Carp gudgeon	*Hypseleotris spp.*	3	1	87	2	4	572	669
		Flathead gudgeon	*Philypnodon grandiceps*						1	1
		Murray-Darling rainbowfish	*Melanotaenia fluviatilis*						12	12
		Un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*			3			20	23
Non-native	**Large-bodied**	Common carp	*Cyprinus carpio*			12			7	19
		Goldfish	*Carassius auratus*	1		4			2	7
		Oriental weatherloach	*Misgurnus anguillicaudatus*	1		4				5
	Small-bodied	Eastern gambusia	*Gambusia holbrooki*			37			42	79
Fish Eggs		Australian smelt	*Retropinna semoni*	12						12

3.3 Murray River fish assemblage during environmental watering

The fish sampled in the Murray River (n=704) comprised seven native (n=653) and three non-native (n=51) species of fish, plus freshwater shrimps (n=1594) and yabbies (n=10) (Table 2).

Again, freshwater shrimps were the most abundant. Carp gudgeon were the most common fin-fish and other small species such as Eastern gambusia, Australian smelt, Un-specked hardyhead, Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) and Bony herring were sampled in moderate abundance.

Flathead gudgeon (*Philipnodon grandiceps*), and Murray-Darling rainbowfish were sampled in the Murray River but not in Chalka Creek.

Relative abundance of species in the Murray River was a reasonable predictor of relative abundance of species in Chalka Creek during environmental watering. There was a significant linear relationship between the relative abundance of a species in the Murray River samples and that species abundance in the Chalka Creek (Figure 4).

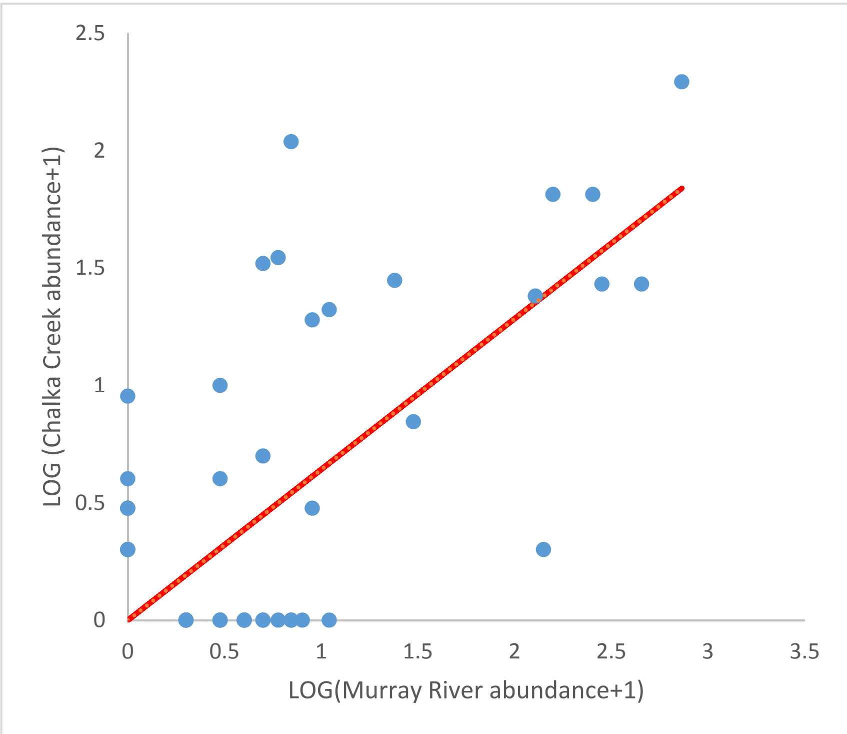

Figure 4. Relative abundance data (LOG transformed) for weeks 1, 3, 5 and 7 when sampling occurred in both Chalka Creek (C) and the Murray River (M). Points are relative abundance data. Line is linear regression C=0.64 × M, (Adj. R^2=0.62, F=79, p<0.001).

3.4 Comparison of source and sink fish assemblages

There were significant differences between the assemblage of fish and decapod crustaceans sampled in the Murray River (source) and the Chalka Creek (sink). The MDS plot below illustrates the dissimilarities between samples of assemblages from Chalka Creek and the Murray River (Figure 5). The one-way ANOSIM test showed that the source and sink assemblages differed significantly at the 0.1% level. Examination of the dissimilarities using a SIMPER test to determine the discriminating species shows that four species groups are principally responsible for over 70% of the difference between source and sink assemblage (Clarke and Warwick 2001); and these are freshwater shrimps, Carp gudgeons, Bony herring, and Australian smelt (Table 3).

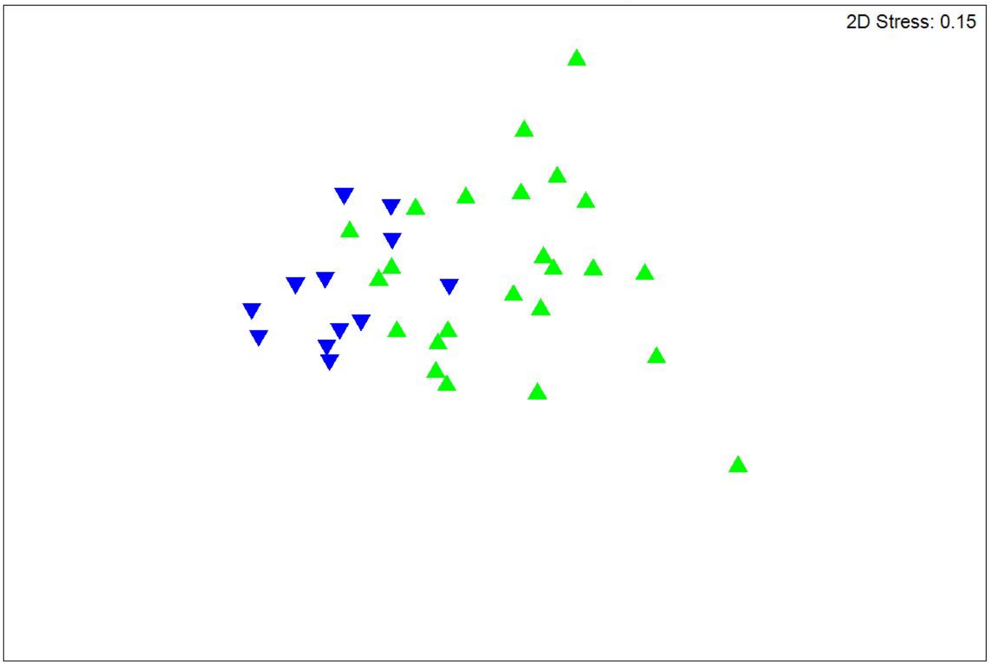

Figure 5. Multi-dimensional scaling (MDS) plot for two groups of samples of fish and decapod crustaceans from Chalka Creek (▼) and the adjacent Murray River (▲). A one-way ANOSIM test showed that groups differed significantly at the 0.1% level.

Table 3. A SIMPER analysis of the significant dissimilarity in diversity of the two groups of samples of fish and decapod crustaceans from Chalka Creek and the adjacent Murray River shows that the dissimilarity is largely driven by differences in *Macrobrachium/Paratya* spp., *Hypseleotris* spp., *N.erebi*, and *R. semoni*, which between them accounted for over 70% of the dissimilarity.

Species	**Chalka Creek**	**Murray River**				
	Mean Abund.	**Mean Abund.**	**Mean Dissimilarity**	**SD Dissimilarity**	**% Contribution**	**Cumulative %**
Freshwater shrimp	6.30	11.01	15.19	1.48	28.20	**28.20**
Carp gudgeon spp.	1.53	6.39	12.61	1.79	23.40	**51.60**
Bony herring	2.23	0.79	5.27	1.08	9.78	**61.37**
Australian smelt	2.43	1.03	4.83	1.18	8.97	**70.34**
Eastern gambusia	0.58	1.54	3.93	1.38	7.29	77.63
Un-specked hardyhead	0.10	0.95	2.43	1.06	4.51	82.14
Golden perch	0.84	0.12	2.20	1.14	4.08	86.22
Murray-Darling rainbowfish	0.00	0.67	1.72	0.89	3.20	89.42
Yabby	0.04	0.54	1.65	0.66	3.07	92.49

3.4.1 Silver perch spawning date

Otoliths from two juvenile silver perch (both 27 mm, TL) were sampled in Chalka Creek on 22 and 29 July 2014. Analysis of daily increment counts suggested ages of 78 and 74 days respectively. Assuming an age of approximately 6 days at first increment formation, similar to Golden perch (Brown & Wooden 2007), the estimated hatch dates correspond to 29 March and 10 April, respectively. During this period the Murray River upstream of Hattah experienced the ascending limb of a rise in flow rate peaking at 8900 ML d^{-1} at Euston weir on 25 March. Flows in the Murrumbidgee were low and steady during this period. The water temperature during the estimated spawning dates was between 22 and 24 °C at Wemen (riverdata.mdba.gov.au).

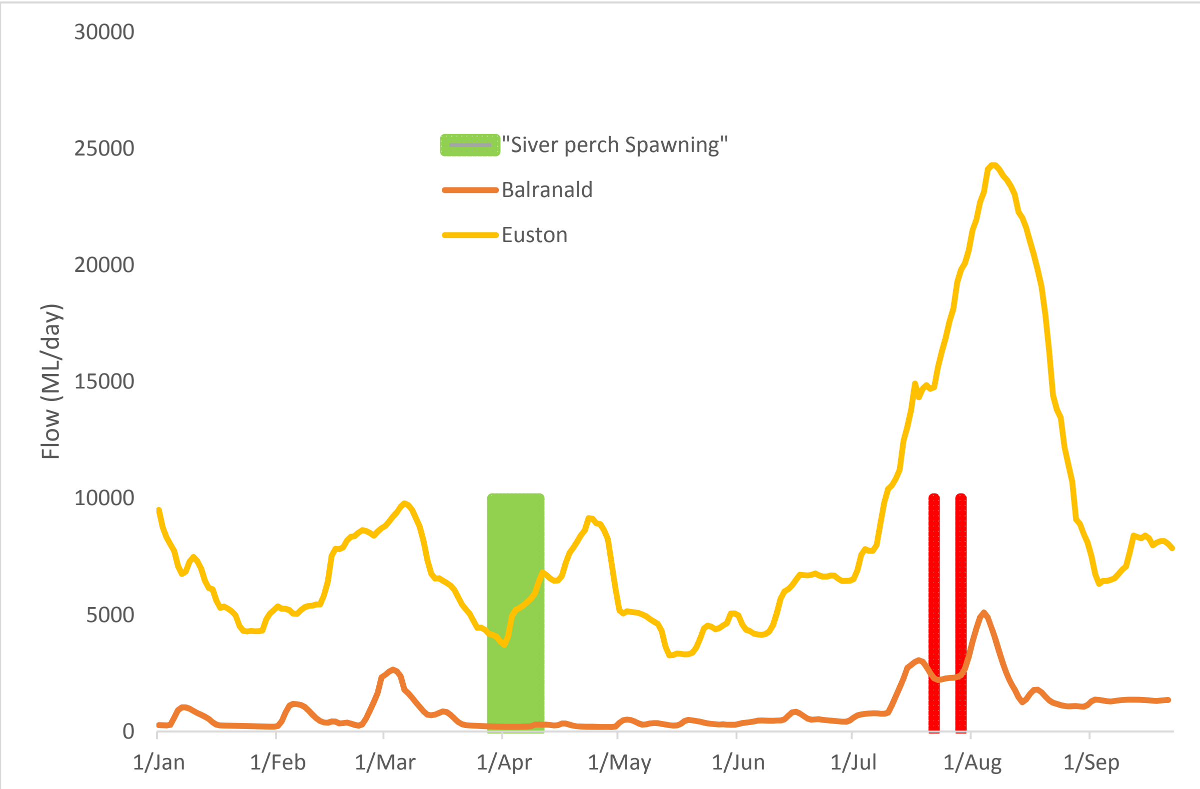

Figure 6. Hydrology of the Murray and Murrumbidgee rivers upstream of Hattah (Euston and Balranald, respectively) during the period including the estimated spawning date (green bar) and capture dates (red bars) for the juvenile Silver perch sampled at Chalka Creek, Hattah.

Figure 7. Photomicrograph of sagittal otolith of juvenile Silver perch (25 mm, SL). Micro-increment counts indicated an age of at least 74-days, suggesting a spawning date in late-March early April.

3.5 Comparison of fish assemblage between seasons

There were significant differences in fish assemblage abundance sampled between the present environmental watering event and the previous commissioning event ('Season', Pperm=0.001) (Table 4, Figure 8). At each event, the fish assemblage sampled at the Murray River sites was significantly different to the assemblage sampled at the Chalka Creek sites ['Chalka vs Murray' (Season), Pperm=0.001] (Table 4, Figure 8).

Table 4. PERMANOVA table of results for design including two fixed factors Season and Location where Season has two levels (Spring-Summer 2013–2014 and Winter-Spring 2014) and Location has two levels (Chalka Creek and Murray River) nested within Season.

Source	Degrees of Freedom	Sum of Squares Error	Mean Squares Error	Pseudo-F	P(perm)	Unique perms
Season	1	26098	26098	17.167	0.001	997
Location(Season)	2	37527	18764	12.343	0.001	996
Chalka vs Murray (Season)	2	37527	18764	12.343	0.001	998
Residual	58	88173	1520.2			
Total	61	1.5882×10^5				

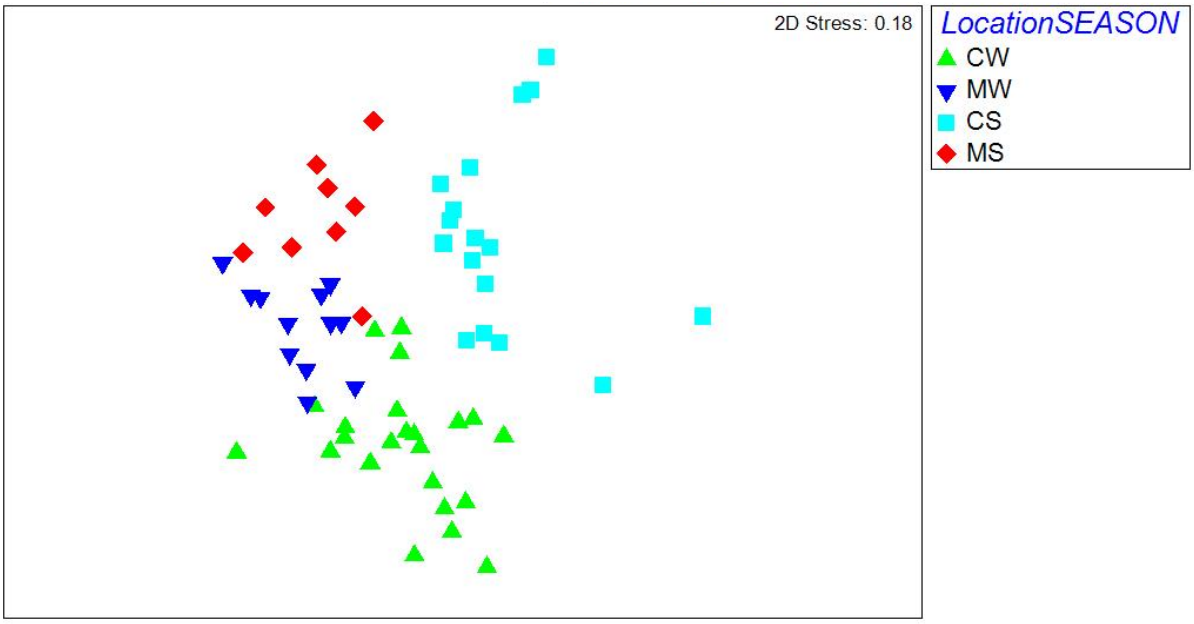

Figure 8. Non-metric Multi-dimensional scaling (MDS) ordination for abundance samples of fish from two locations Chalka Creek (C) and the adjacent Murray River (M) and two 'seasons' Spring–Summer 2013–2014 (S) and Winter–Spring 2014 (W). A PERMANOVA test showed that fish assemblages across locations and seasons differed significantly (P≤0.001) (i.e. C≠M during W or S, and W≠S).

3.6 Temporal patterns in relative abundance of fish eggs and larvae

In apparent contradiction of section 3.3, patterns of relative abundance in the source population of the Murray River are not reflected in abundances of any particular species in Chalka Creek (Figure 9).

Abundance of freshwater shrimp and Carp gudgeons declined steadily over the four Murray River samples over 8 weeks, whereas there was no similar pattern observed in Chalka Creek. Bony herring were sampled rarely in the Murray River and whereas the catches were variable in Chalka Creek they built steadily until week 5; after which they were negligible (Figure 9).

Abundance of Australian smelt steadily increased in Chalka Creek throughout the study; whereas, catches of this species were consistently low in the Murray River. Golden perch were sampled at low abundance in all but one week in Chalka Creek. In contrast the Murray River samples only contained Golden perch in week 1 (Figure 9). Silver perch were recorded only in Chalka Creek (Table 2), in weeks 4–6.

Un-specked hardyhead, Goldfish and Oriental weatherloach were sampled sporadically at low abundance in Chalka Creek. Unspecked-hardyhead were more abundant in the Murray River than in Chalka Creek. Murray-Darling rainbowfish were also recorded at moderate abundance in all Murray River samples but neither they nor Flatheaded gudgeon were recorded in Chalka Creek (Table 2). Australian smelt eggs were only sampled in the last week of sampling (week 8) in Chalka Creek, unfortunately, the Murray River was not sampled in week 8 (Table 2).

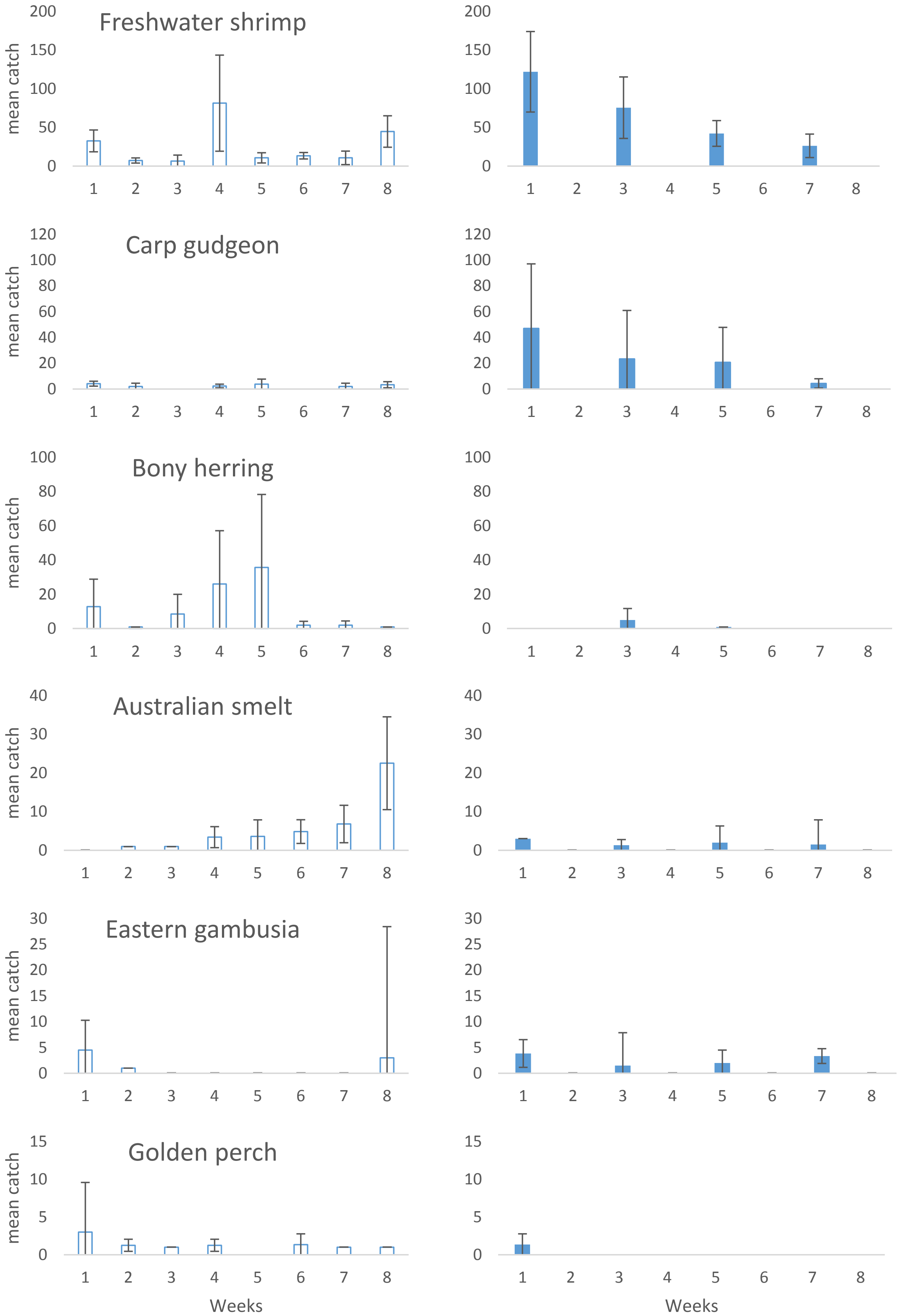

Figure 9. Mean catch (±95% confidence interval) in small fyke-net samples from Chalka Creek (left) and the Murray River (right) during weeks 1-8 of environmental watering via the Hattah pumps. Note Murray River was only sampled during weeks 1, 3, 5 and 7.

3.7 Comparative size distribution of common fish species

For Goldfish, Un-specked hardyhead, Australian smelt, Golden perch and Common carp the sample sizes were too small at either Chalka Creek or the Murray River to provide adequate statistical comparison of the length distributions in samples from source and sink populations.

The length structure of samples of Bony herring and Eastern gambusia in samples from Chalka Creek and the Murray River was the same (D=0.33 p=0.34; D=0.14 p=0.99) (Figure 10). The length frequency of samples of Carp gudgeons from Chalka Creek was different to that of samples from the Murray River (D=0.58, p=0.006) (Figure 10).

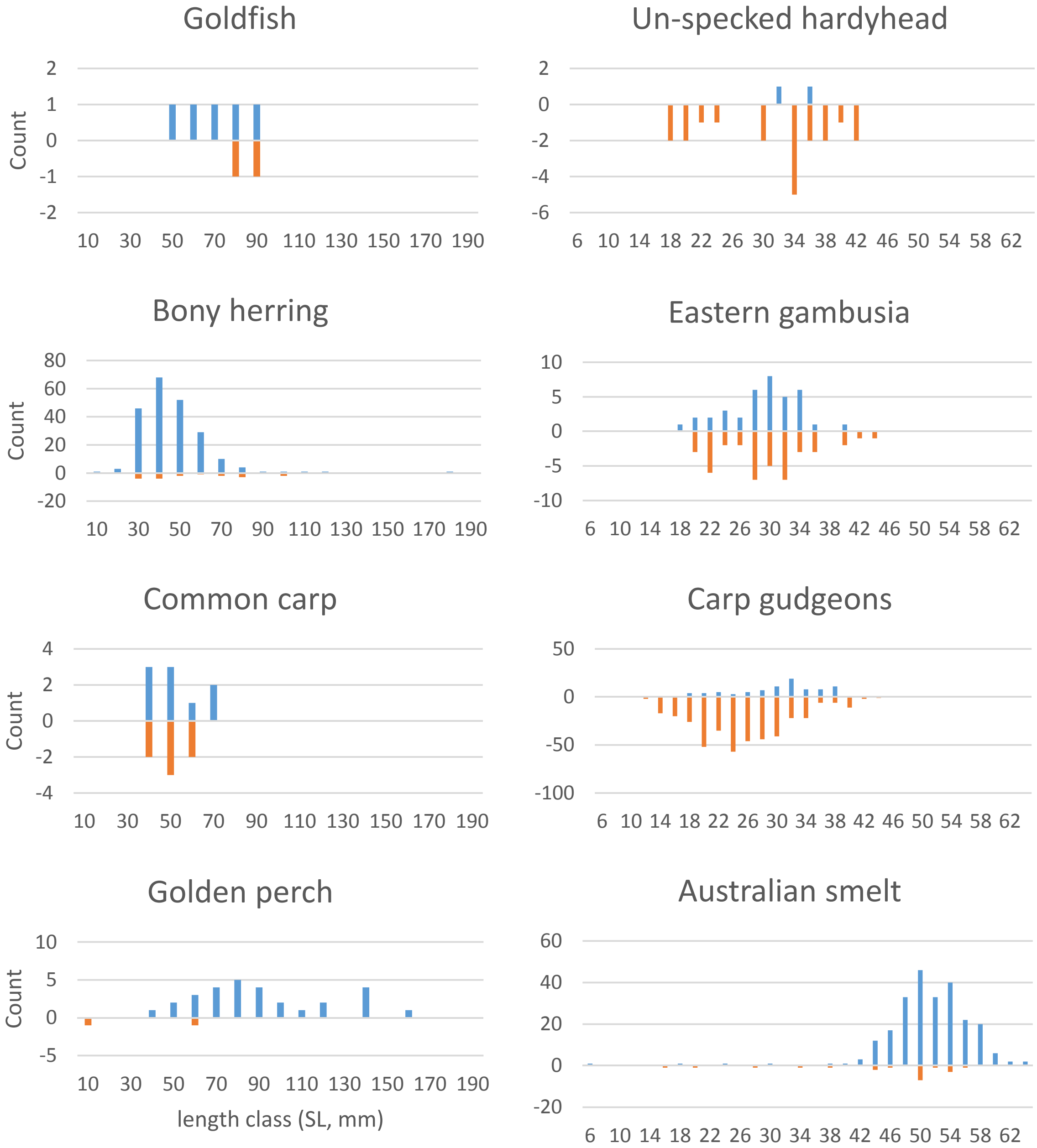

Figure 10. Comparative size frequency distributions for four large-bodied fish species (left) and four small-bodied fish species (right) that were found in both locations. Each panel shows length frequency distribution sampled from Chalka Creek (count) and the Murray River (-1×count, for convenience).

3.8 Estimated daily entrainment of ichthyoplankton

In the Murray River, catches of fish larvae in the drift nets were low. Only three species were caught: Australian smelt, Bony herring and Carp gudgeon, on only two of the ten days sampled. On 21 July an average of 57 larval Bony herring and 0.03 Carp gudgeon larvae were caught per ML. On 20 August an average of 520 smelt larvae per ML were caught. Assuming these catches reflect the likely rate of entrainment on those days this suggests a total estimate of 21,430 larval smelt, 2320 Bony herring and 2 Carp gudgeon entrained by the Hattah environmental pumps.

3.9 Survival rate after entrainment

All the fin-fish sampled from small fyke nets and drift nets in the Murray River were collected alive. Mortality of fin-fish within the samples collected from week 4 (n=650), was only evident in the Chalka Creek samples (n=473 of which 227 were dead) where exposure to, and transit through, the environmental pumps was a possibility for all fish sampled.

In Chalka Creek overall, 48% of individual fish sampled were dead on removal from the net and the percentage of the catch that was dead varied by species:

- 36% Australian smelt (n=233)
- 74% Bony herring (n=159)
- 43% Carp gudgeon (n=51)
- 8% Golden perch (n=12)
- 50% Un-specked hardyhead (n=2)
- 33% Silver perch (n=3)
- 0% Goldfish, Oriental weatherloach and Eastern gambusia (n<5)

Physical injuries were noted on many of the dead fish as shown in (Figure 11), including de-scaling, amputations and bulging eyes (exophthalmia).

The incidence of fin-fish mortality in the small fyke nets decreased with distance downstream from the outflow point of the environmental regulator and also decreasing average water velocity (Figure 12). This suggests that the 48% average mortality rates recorded above from all gear, is likely to be an underestimate. The true overall mortality rate may be closer to the 75% recorded in net 1 closest to the pumps, shown in Figure 12.

Figure 11. Physical injuries such as amputations, de-scaling and exophthalmia were noted in a range of species sampled in small fyke nets from Chalka Creek. Clockwise from top-left; Bony herring, Common carp and a Silver perch; Common carp and a Golden perch; Australian smelt; Australian smelt and Common carp.

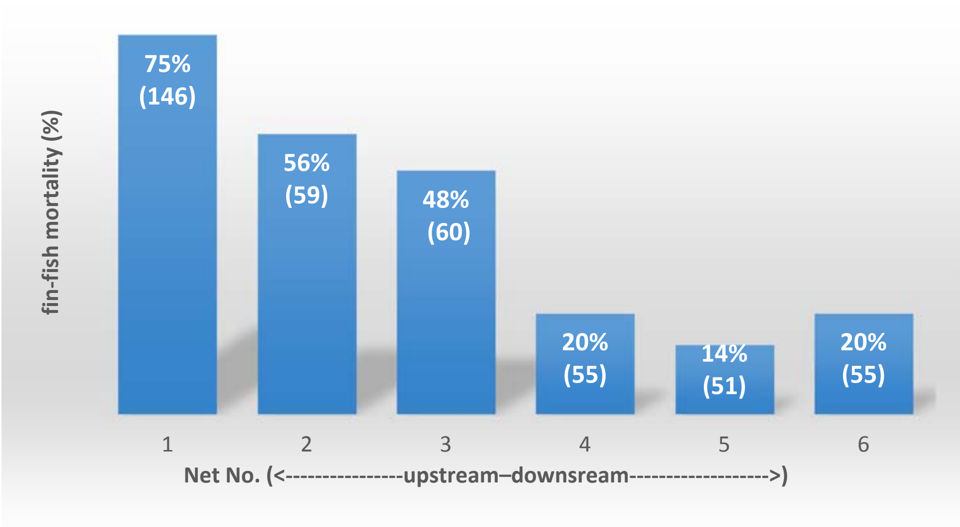

Figure 12. Overall fin-fish mortality rate (% of total sample dead, sample size is in parenthesis). Weeks 4–8, recorded in individual small fyke nets (1–6) where net 1 was positioned closest to the outfall of the environmental regulator and net 6 was furthest downstream (approximately 200 m).

4 Discussion

4.1 Impact of environmental watering on fish assemblage

The present study set out to determine the impact of the winter–spring environmental watering on the Hattah Lakes fish community. While entrainment and transport of fish from the Murray River clearly has a direct effect; this was potentially confounded by still detectable effects from the previous commissioning flows and the fish community that subsequently established within the Hattah Lakes in the intervening period (Freestone *et al.* 2014).

4.1.1 Contrasting fish communities: two successive filling events

Differences between fish assemblage structure observed in spring–summer and winter–spring samples in both Murray River and Chalka Creek locations are driven by multiple factors effecting the source-sink dynamics of the system. Strong seasonal variation in the relative abundance (and hence availability), of fish species in the source population (Murray River) is common. Surveys of freshwater fish in summer generally produce larger and more diverse samples than surveys during winter (Gehrke *et al.* 1995; Harris & Gehrke 1997; King *et al.* 2009a). Abundance of fish larvae generally peaks through spring and summer in the lower Murray River (Vilizzi 2012) and during winter the river presents a relatively depauperate source assemblage of eggs and larvae.

The commissioning environmental watering event (spring–summer 2013–2014) pumped water into dry lakes and so the fish assemblage in the Chalka Creek was only effected by relative abundance in the source population and by the interaction of those fish with the environmental pump infra-structure (e.g. species and size-selectivity, differential survival of entrainment) (Baumgartner *et al.* 2009; Boys *et al.* 2013). During the second environmental watering event, in addition to the source dynamics, selectivity and differential survival discussed above, the fish assemblage in the Chalka Creek was also effected by interaction with the existing established fish fauna in the Hattah Lakes (Henderson *et al.* 2014).

4.1.2 Contrasting fish communities: source and sink

The significant linear relationship between fish relative abundance in the Murray River (source) and Chalka Creek (sink) for the four alternate weeks of the study when the Murray River was sampled (see Figure 4) supports the source-sink concept that broad patterns of relative abundance in Chalka Creek samples are significantly driven by relative abundance in the Murray River. The logical and most likely mechanism for this is the environmental pumps which is also consistent with previous observations (Brown *et al.* 2014). Further evidence of passage through the pumps comes from damaged individuals (see discussion below) and from fish sampled in Lake Kramen channel during winter–spring 2014 (Appendix 1) which was dry before pumping started. However, examination of patterns of relative abundance for individual species, including the full 8 weeks of samples from Chalka Creek, suggests that the Murray River was unlikely to have been the only source of fish sampled in Chalka Creek 'directional nets' at least for some species.

Bony herring juveniles (≤90 mm, SL) and Golden perch juveniles (≤160 mm, SL) occurred more frequently and were more abundant in Chalka Creek than the Murray River. Freshwater shrimp and Carp gudgeons were ubiquitous although both showed declining trends in abundance in the Murray River that were not replicated in the Chalka Creek samples. Bony herring, Golden perch, and Carp gudgeon were common and well dispersed across the Hattah Lakes after the initial (commissioning event) environmental watering (Henderson *et al.* 2014). All three species can respond positively to inflows (Lyon *et al.* 2010; Conallin *et al.* 2011; Koster *et al.* 2014), and are likely to have moved upstream from the lakes towards the environmental pumps at the Messengers Crossing end of Chalka Creek during the second watering event.

Disparity in abundance between source and sink populations of Golden perch, Bony herring and Australian smelt during the winter–spring 2014 period suggest an alternative source other than the Murray River for some of those fish sampled from Chalka Creek. For these species at least it seems likely that the relatively abundant fish sampled in the Chalka Creek at Messengers Crossing could have originated from fish emigrating from the lakes in response to inflows. The size-structure of Golden perch and Bony herring sampled suggests that the majority were less than a year old (Mallen-Cooper & Stuart 2003; Puckridge & Walker 1990). Australian smelt were mainly sampled as adults that may have been older than age-2+ years (Milton & Arthington 1985) although the presence of eggs during the last sample in Chalka Creek suggests that either the population in the Hattah Lakes or the source population from the Murray River, had commenced spawning. Eggs of Australian smelt have been noted as adhesive and demersal (Milton & Arthington 1985), so their presence in Chalka Creek drift samples suggests local origin, perhaps dislodged by the high water velocities at the pump outlet.

The present study also identified a spawning event in early April 2014 for Silver perch, listed as *Critically Endangered* under the EPBC Act (Department of Environment 2015). Based on current knowledge of Silver perch as flow-dependent spawners (Baumgartner *et al.* 2014), the event was likely to have occurred in the Murray River upstream of Hattah Lakes. April is outside the previously recorded spawning season for Silver perch (Lintermans 2007; King *et al.* 2009b) This preliminary evidence suggests that, wetland watering following within-channel flow-peaks as late as April in the lower Murray River may be useful for 'seeding' wetlands with flow-dependent spawning species such as Silver perch.

The invasive species Eastern gambusia may be less likely to be entrained during winter pumping. From week three through to week seven it was absent from Chalka Creek samples while present in the Murray River source population. In some temperate Australian rivers, the species has a seasonal cycle in population abundance related to spring breeding and winter mortality that results in low abundance during winter (Pen & Potter 1991).

4.1.3 Entrainment survival

It is clear that significant numbers of fish have survived entrainment and transport through the Hattah Lakes environmental pumps into Chalka Creek. Evidence from previous studies of the commissioning flow (Brown *et al.* 2014), and from fish surveys of the Hattah Lakes since that flow (Henderson *et al.* 2014), describes a fish community that can only have developed from fish, eggs or larvae transported through the pumps. However, the present study has contributed to the increasing evidence that suggests high mortality rates are a consequence of this transport.

Large diameter pumps have been shown to cause varying mortality-rates to different species and size-classes of fish. Baumgartner *et al.* (2009), reported injury and mortality rates each of approximately 4% for low-flow and high-flow irrigation pumps with a similar fish assemblage to the present study. Although not directly comparable due to many differences in experimental design and pump infrastructure; the rates of mortality determined in the present study are likely to be much higher.

In the present study, nets set close to the pump outfall in high-velocity water caught passively drifting fish (including moribund and damaged/dead fish) and fish swimming actively downstream. Catches from these nets suggests that 14%–75% of fish sampled were dead and/or injured, with the mortality rate varying among species.

The systematic way in which the overall mortality rate decreased with decreasing water velocity and decreasing proximity to the pump-outfall is interesting. One factor that may affect the accuracy of these mortality estimates is differential net-avoidance (Hunter & Wisby 1964). Dead or injured fish are less likely to avoid capture by the net and less likely to escape the net once caught, than live fish. One would expect an interaction between such effects and water velocity, such that higher velocities would reduce net avoidance and escapement for live fish. If so, our estimates of mortality should increase in accuracy with increased proximity to the pump-outflow. Differences in 'behaviour' between fragments of dead fish and actual live fish would be expected and could account for this.

Other factors affecting the accuracy of our mortality estimates include escape from the nets by live fish in comparison to passive-capture of dead fish (Hansen 1944, cited in Patriarche 1968) and the differential availability between live fish and dead fish as the dead ones 'settle-out' or are consumed over increasing distance from the pumps. As net proximity-to-outfall and water velocity decrease, the pieces of dead fish may settle out, or be more likely to be consumed by scavengers, becoming less likely to be trapped by our nets. If so, our estimates of mortality would again be more accurate in close-proximity to the pump outflow.

4.1.4 Hattah Lakes as functioning fish nursery-habitat

Watering the Hattah Lakes via environmental pumps has allowed the establishment of a fish community of both valuable native and unwanted alien species in this system of shallow productive wetlands. Furthermore, during reconnection with the River Murray, native and alien fish transported to and raised in the lakes chose to move back from the lake habitats towards the river. The environmental watering clearly allows the Hattah Lakes to function as a "nursery-environment" for a range of species found within the southern Murray–Darling Basin. However, the importance of these findings at the population-scale is unknown. The mortality of fish during entrainment and transport through pumps has opportunity-costs for the riverine ecosystem (Koehn & Harrington 2005). Investigation of infrastructure operations can lead to understanding of potential reductions in these mortality costs (Boys *et al.* 2013). Such costs are discounted by the likelihood of improved survival of those fish that are successfully transported into the high-quality nursery-environment of the Hattah Lakes (Beesley *et al.* 2014). The discount becomes realised not only when fish emigrate from the Hattah Lakes into the Murray River on a future connecting flow (see Appendix A); but also when fish in the Hattah Lakes contribute to ecosystem services (Chee 2004; Brauman *et al.* 2008; Beschta & Ripple 2009). Fish remaining in the Hattah Lakes contribute to the food-web by providing food for piscivores, by regulating water-quality through top-down zooplankton dynamics, or even by contributing nutrients to the drying bed of a lake. The "importance" question is really one of balancing this discount, with the opportunity-cost of similar contributions that the entrained fish, eggs and larvae could make to the system outside the Hattah Lakes. When there is insufficient science to inform otherwise, such value-comparisons are often as much about social and political perspectives as they are ecological ones. Meanwhile, improved understanding of this balance can be achieved by learning all we can about comparative population dynamics and survival of fish in floodplain–lake and riverine habitats and the lateral movement of fish between such habitats under a variety of flow conditions.

4.1.5 Knowledge gaps and recommendations

The difficulty in attributing observations from the present study to effects of entrainment or lake-effects highlights why the impacts of environmental watering on fish community at the Hattah Lakes are probably best evaluated through stratified lake-fauna surveys (Henderson *et al.* 2014).

Mitigation of entrainment mortality

- Investigate effect of pump operations on potential for entrainment mortality. Are there ways of running the existing pumps to minimise mortality of entrained fish?
- Investigate potential for fatal or damaging impingement of fish on inlet screens. Do the existing screens cause fish approaching the pump-inlet to become 'stuck' across the mesh of

the screen? If so, can the pumps be run in ways to minimise this and can screens be used that exclude native fish of the size that are least likely to survive passage?

Movement of large-bodied alien and native fish

- Investigate potential for movement of Golden perch, Silver perch, Murray cod, Bony herring and Carp into and out of the Hattah Lakes during a range of flow conditions. Do large-bodied native fish and/or Carp, emigrate from the Hattah Lakes with outflowing water through the Messengers or Oateys regulators during draw-down? Does inflowing water from the pumps stimulate movement of large-bodied fish up Chalka Creek from the Hattah Lakes to accumulate at Messengers Crossing? If so, can the pumps and regulator be operated together to facilitate emigration for these accumulated fish? Future investigations of these movements should be comprehensive to allow consideration of a range of potential variables (season, antecedent conditions in source and sink, hydrological effects etc.)

Avoidance of entrainment of unwanted alien invasive species

- Recommendation 1: If objectives are weighted towards avoiding the entrainment of Carp and Eastern gambusia then environmental watering during the winter, as in the present study, is recommended. If spring–summer watering is required then avoid pumping high densities of drifting carp larvae into the Hattah Lakes by temporarily ceasing pumping during in-channel Murray River flow peaks. Particularly avoid the second of a series of such flow peaks if they occur from late August–December (Brown *et al.* 2014).

Optimise "nursery-potential" of Hattah Lakes through environmental watering

- Recommendation 2:
    - Filling empty wetlands: Evidence from the impact of the commissioning environmental watering event (Brown *et al.* 2014) along with the present study supports the Spring–Summer timing of any "filling event", such that a rich assemblage of egg, larval and small fish are entrained and transferred to the Hattah Lakes. In combination with recommendation 1, this may achieve strong inclusion of native fish species while minimising carp entrainment (Ellis *et al.* 2014).
    - Topping up wetlands: Environmental watering designed to add to already inundated wetlands can be timed during the Winter–Spring; this reduces the risk of high densities of Carp being entrained and added to the wetlands.

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Appendix A: Investigation of fish movement with respect to the draw-down phase of 2014 Hattah Lakes Environmental Watering

Introduction

Two managed watering events have inundated the wetlands and floodplains of Hattah Lakes since spring 2013, with 60 904 ML and 91 969 ML of water being delivered respectively (Brown *et al.* 2013, Brown *et al.* 2015) via the Hattah Lakes environmental pumps. Both events were monitored for fish entering the Hattah Lakes system confirming a 'filtered' fish assemblage of fish, larvae and eggs (Brown *et al.* 2014, Vilizzi *et al*. 2013).

This present study examines the response of the 'filtered' fish community to a drawdown event as water recedes from the inundated floodplains and lakes through Chalka Creek and returned to the Murray River. It was anticipated that native fish species would respond by returning to the main river channel after experiencing a higher growth rate in the productive floodplain system. The 2014 watering event surcharged the Hattah Lakes wetlands to over 150% of their capacity. The high water level enabled the environmental regulators in Chalka Creek to be opened returning a substantial proportion of this water, and the productivity it contained, to the river. This strategy mimics the 'flood pulse' concept (Junk *et al.* 1989) believed to be one of the key processes that drive productivity in floodplain rivers of the world.

Coinciding with the drawdown of Hattah Lakes was the pumping of Lake Kramen (see Figure hydrograph), which is achieved by the use of one of the seven main Hattah Lakes environmental pumps. Lake Kramen was dry previous to this pumping thus providing a perfect opportunity to replicate (on a smaller scale) the first 'Movement of fish, eggs and larvae through the Hattah Lakes environmental pumps' project. We can seek to measure the same 'filtered' assemblage of fish that was achieved by the first Hattah Lakes environmental pumps report (during which Chalka Creek and the Lakes were dry) and compare the results.

Methods

Site information

The sampling sites at Messengers regulator were immediately downstream of the environmental pump outflow channel and immediately below the Messenger regulator (Murray River side) (Figure 1 of the main report).

The sampling site at Oateys regulator was approximately one kilometre downstream of the regulator. Kramen channel was also surveyed. This connection channel to Lake Kramen can be filled by one of the seven Hattah Lakes environmental pumps.

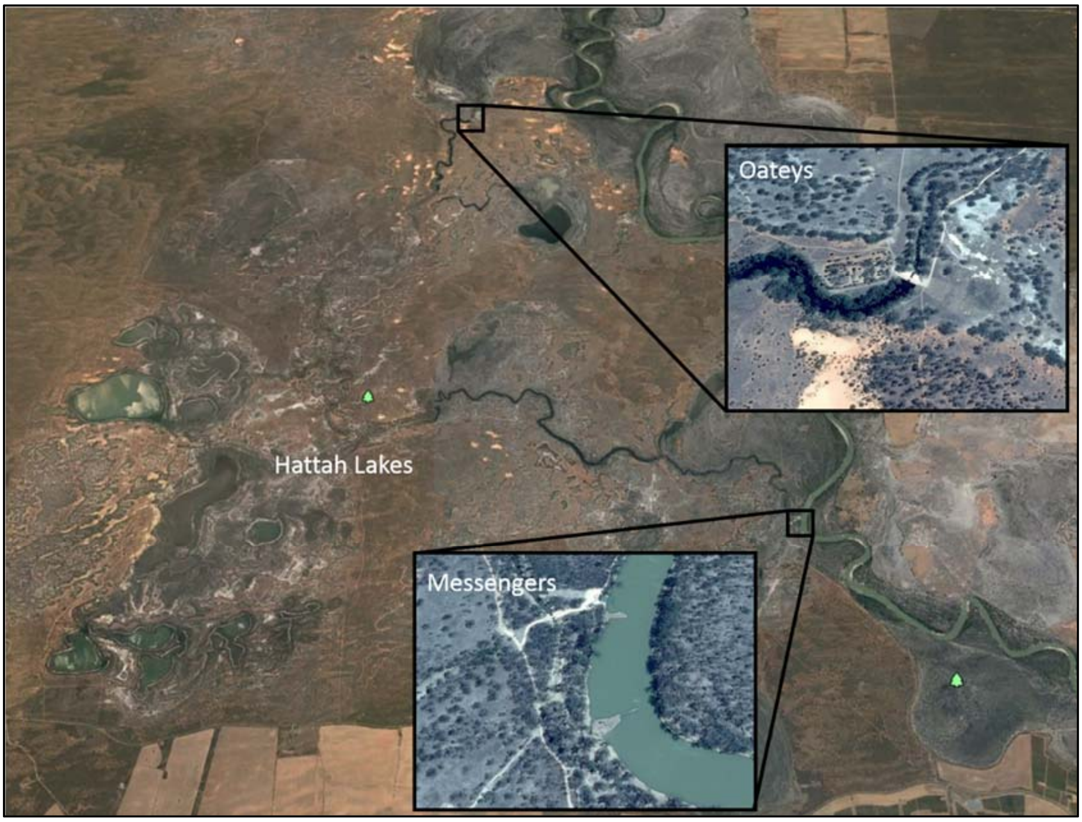


Figure 1A. Map showing location of Messengers regulator (bottom inset) and Oateys regulator (top inset).

Hydrology

Modelled data of outflowing water through each regulator as lake levels recede is depicted in Figure 2A. Due to erosion of the Messengers outflow channel banks, flow was halted on 26 September 2014 while repair work was carried out. Outflows recommenced on 17 November 2014.

Modelled inflow data for Lake Kramen is depicted in Figure 3A. Lake Kramen and its inflow channel were dry prior to filling.

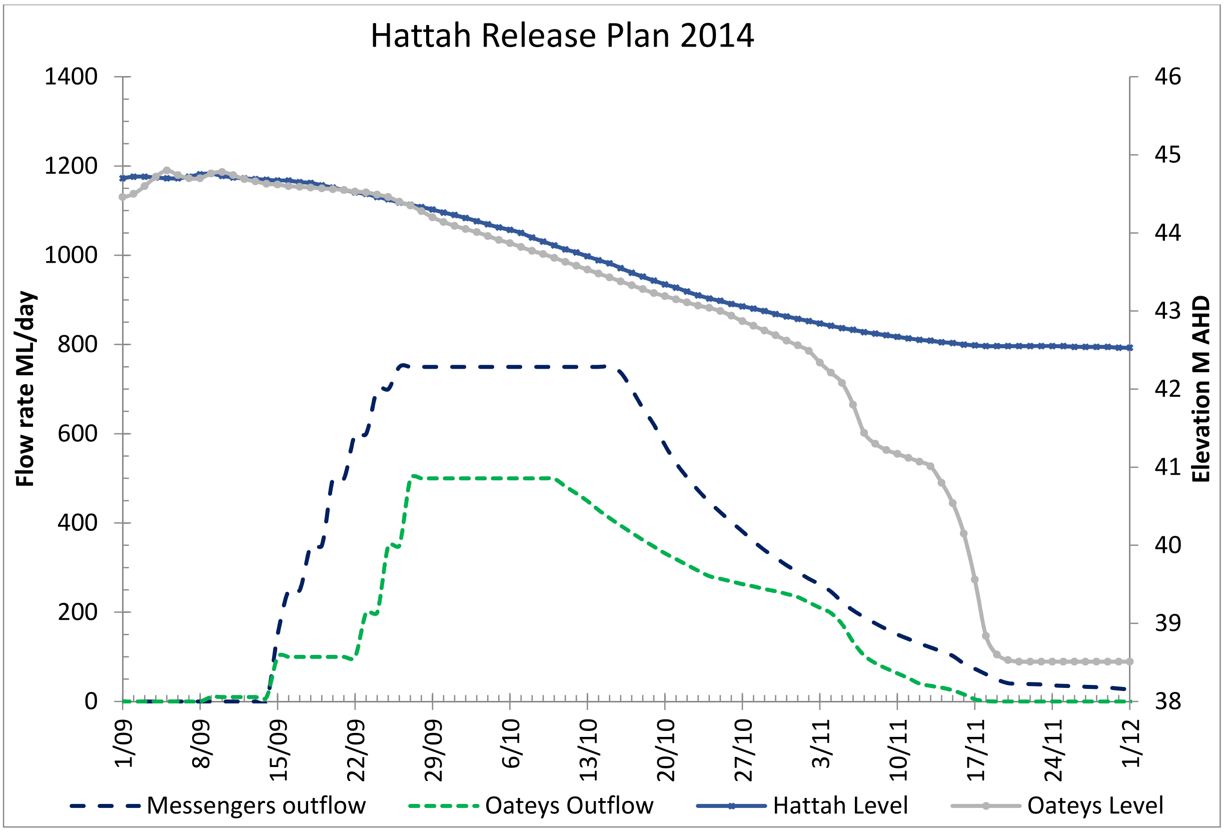


Figure 2A. Modelled hydrograph depicting the intended release of water from surcharged levels at both Messengers and Oateys regulators (source: Mallee CMA).

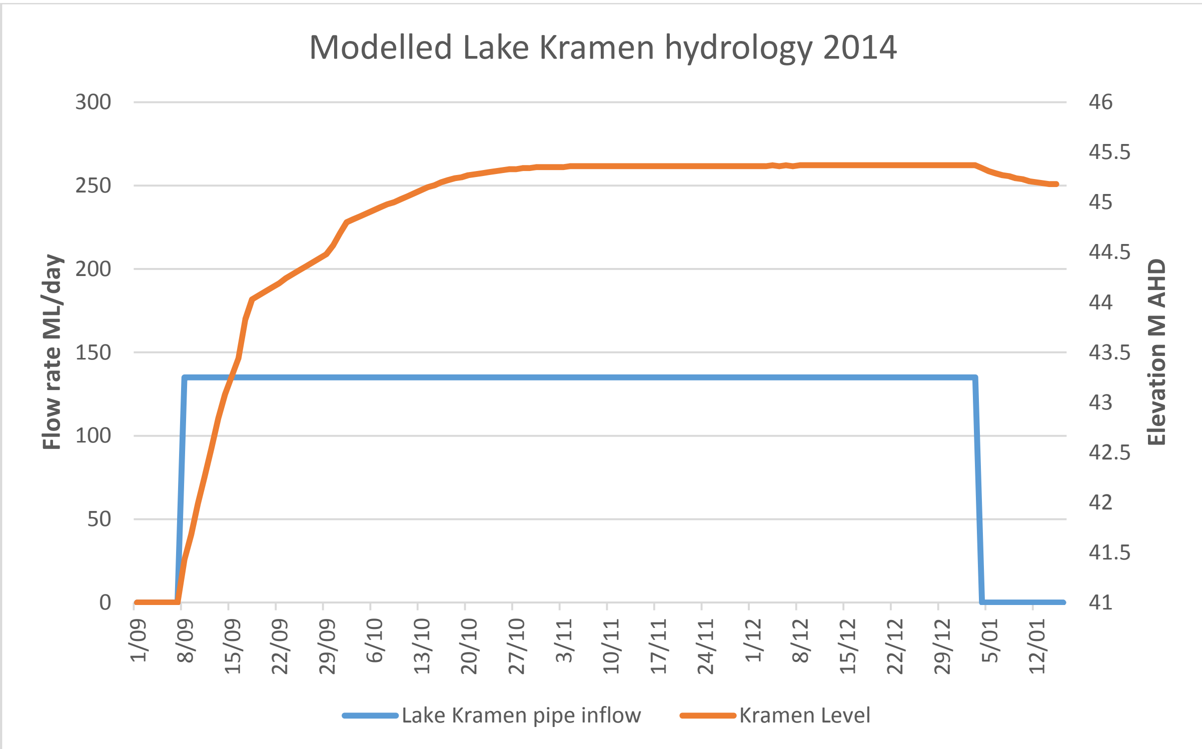


Figure 3A. Modelled hydrograph depicting the intended pumping of water into Lake Kramen channel and subsequently Lake Kramen (source: Mallee CMA).

Fish community

Messengers and Oateys regulator sampling designs

As the Hattah Lakes drawdown commenced, there were a total of two sampling events at Messengers, Oateys and Kramen regulators to identify basic fish assemblage.

On each of two sampling events, at each site, dual wing fyke nets were set to intercept adult and juvenile fish moving with, or against, the flow at either site.

The first sampling date occurred on 17 September shortly after each regulator was opened and sampled fish **both** entering and leaving the Hattah Lakes.

Sample 1 at Messengers regulator:

- Three large fyke nets: two upstream (in Chalka Creek, one facing up, one facing down) and one downstream of Messengers regulator (facing down), flow velocity permitting.
- Four small fyke nets: two upstream (one facing up, one facing down) and two downstream of Messengers Regulator (one facing up, one facing down, flow velocity permitting).

Sample 1 at Oateys regulator:

The water took longer to arrive at the Murray River due to the position of the regulator further upstream from the Murray River than the Messengers regulator, so the initial sampling only focused on fish **leaving** the Hattah Lakes (i.e. there can be no fish moving upstream from the Murray until the drawdown water connects with it).

- One large fyke net: downstream of the regulator, facing upstream.
- Two small fyke nets: downstream of the regulator, facing upstream.

Due to erosion complications the drawdown of Hattah Lakes was interrupted and the second sampling event had to be pushed back to 26 November.

Sample 2 at Messengers:

- Three large fyke nets: two upstream (one facing up, one facing down) and one downstream of Messengers Regulator (facing down), flow velocity permitting.
- Four small fyke nets: two upstream (one facing up, one facing down) and two downstream of Messengers regulator (one facing up, one facing down), flow velocity permitting.

Sample 2 at Oateys:

- Two large fyke nets, downstream of the regulator, one facing upstream and one facing downstream.
- Four small fyke nets downstream of the regulator, two facing upstream and two facing downstream.

Kramen pump sampling designs

On each of the two sampling events for Messengers and Oateys regulators, fyke and drift nets were set to intercept fish, eggs and larvae moving into the Lake Kramen channel and eventually the lake itself. At each site nets were set in the afternoon and collected the following day (~ 20 h set time).

- Three small fyke nets downstream of the pump and regulator, facing into the flow.

- Three drift nets downstream of the pump and regulator, facing into the flow.

Large fyke nets have two netting wings (8 m x 1.5 m) attached to the first supporting hoop (Ø= 0.55 m) with a mesh funnel opening diameter of 0.32 m, and 28 mm-stretched mesh throughout. Small fyke nets have dual wings (each 2.5 m long x 1.2 m drop), with a first supporting hoop (Ø = 0.4 m) fitted with a square entry (0.15 m x 0.15 m) covered by a plastic grid with rigid square openings (0.05 m x 0.05 m) and 2 mm mesh throughout. Drift nets are 1 m long conical nets with a circular opening (Ø=0.5 m) and a mesh size of 0.52 mm to capture drifting material.

The sampling sites at Messengers regulator were immediately downstream of the environmental pump outflow channel (creek side) and immediately below the Messengers regulator (river side). The sampling sites at Oateys regulator was immediately below the regulator (river side). The sampling sites at Kramen was immediately below the pump outflow channel for Lake Kramen channel.

Sample processing

All catch was identified and counted on site. The first 20 individuals from each species on each day at each site were measured. Large-bodied fish species were measured to standard length (SL, mm) and total or fork length (TL/FL, mm) depending on species and weighed. Small-bodied fish species were measured to standard length (SL, mm).

Decapod crustaceans were caught in large numbers in small fyke nets. These were largely a mixture of two species of freshwater shrimp, *Macrobrachium australiense* and *Paratya australiensis* and the occasional yabby (*Cherax destructor*). The two species of freshwater shrimp are difficult to diagnose as juveniles in a field situation and as such were simply recorded as “shrimps” and “yabbies”, effectively pooling both species into one category.

Lake Kramen drift net samples were preserved in ethanol and returned to the laboratory for processing. The contents of drift net samples were later sorted and juvenile and larval fish identified and enumerated.

Results

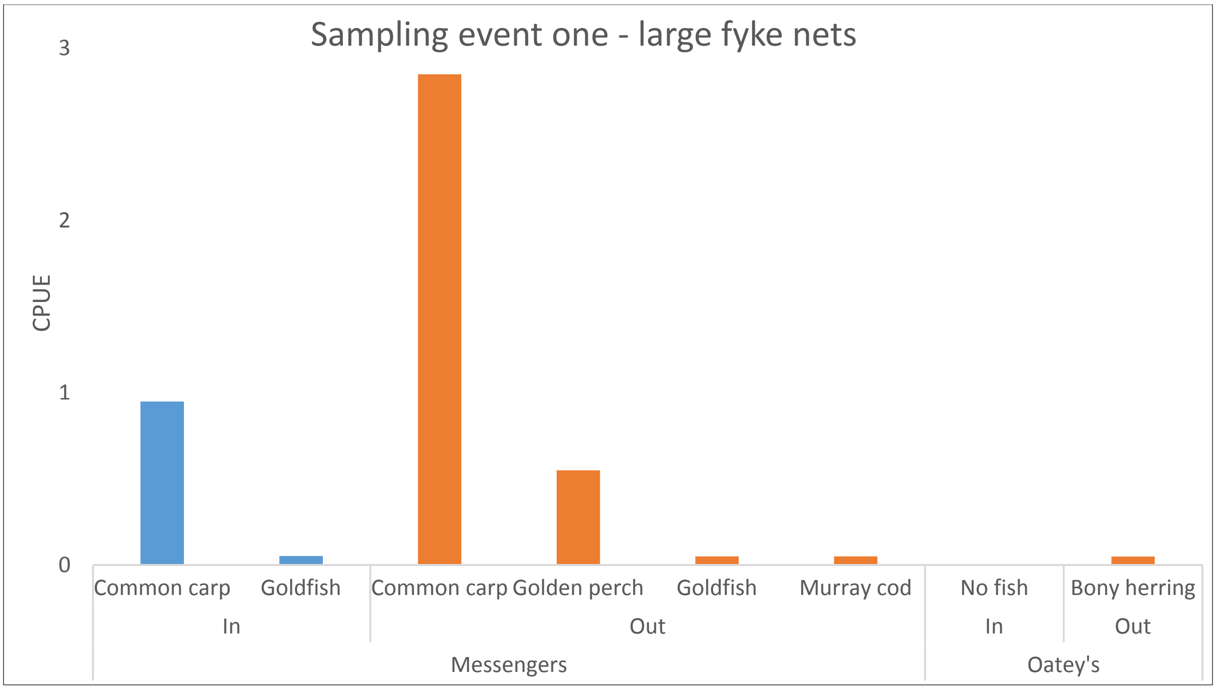
Fish assemblage during recession of environmental water

Fish (n=966) sampled during the environmental water recession at Hattah Lakes comprise seven native (n=191) and four non-native (n=775) species, plus Freshwater shrimp (n=15) and Yabbies (n=10) (Table 1A).

Both native and non-native fish expressed a greater affinity to moving out of the system with the direction of flow (Figures 4A & 5A). For some species (i.e. Golden perch) all of the fish sampled were moving back to the Murray River (Figure 16), whilst for Australian smelt almost all were sampled trying to enter the system against the direction of flow (Figure 5A).

Table 1A. Fish and decapod crustaceans sampled during the recession of water back to the Murray River via Messengers and Oateys regulators, September–November 2014, and using two types of sampling gear.

Origin	**Size/type**	**Common name**	**Species name**	**In**		**Out**		**Total**
				Large fyke nets	**Small fyke nets**	**Large fyke nets**	**Small fyke nets**	
Native	**Crustacean**	Freshwater shrimp	*Macrobrachium australiense/ Paratya australiensis*		15			15
		Yabby	*Cherax destructor*		1	3	6	10
	Large-bodied	Bony herring	*Nematalosa erebi*			2		2
		Golden perch	*Macquaria ambigua*			11	1	12
		Murray cod	*Maccullochella peelii peelii*			1		1
	Small-bodied	Australian smelt	*Retropinna semoni*		57		2	59
		Carp gudgeon	*Hypseleotris spp.*		11		101	112
		Flathead gudgeon	*Philypnodon grandiceps*		1		1	2
		Un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*				3	3
Non-native	**Large-bodied**	Common carp	*Cyprinus carpio*	53	8	57	391	509
		Goldfish	*Carassius auratus*	1		1		2
		Oriental weatherloach	*Misgurnus anguillicaudatus*	2	4		4	10
	Small-bodied	Eastern gambusia	*Gambusia holbrooki*				254	254



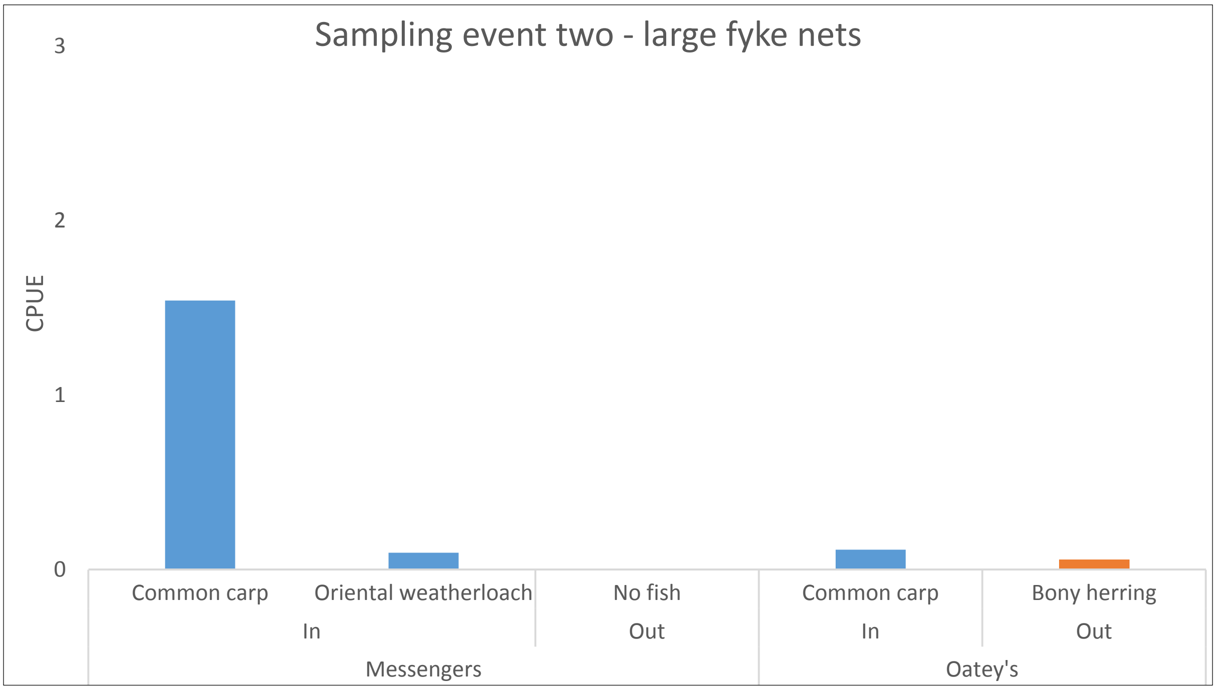
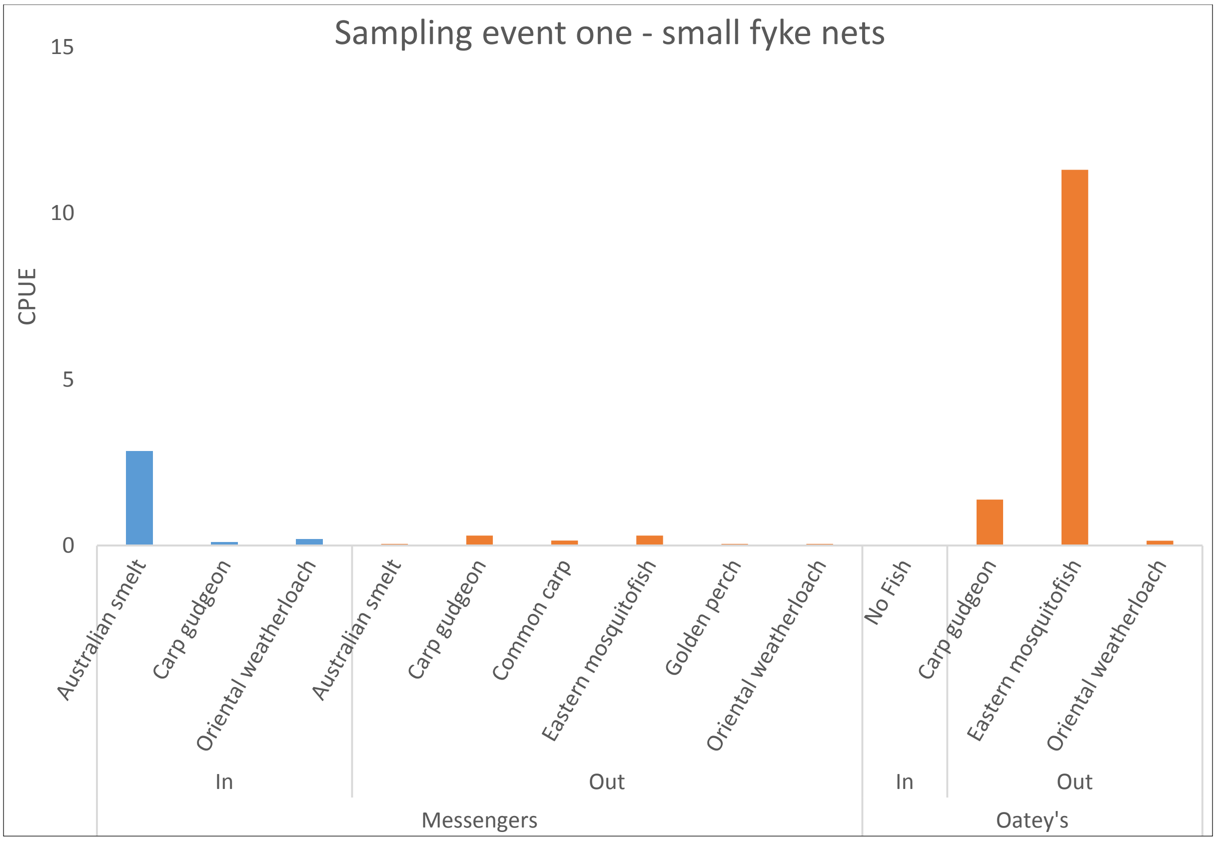


Figure 4A. Direction of large-bodied fish movement at each regulator on two sampling occasions. CPUE represented as fish per hour per net.



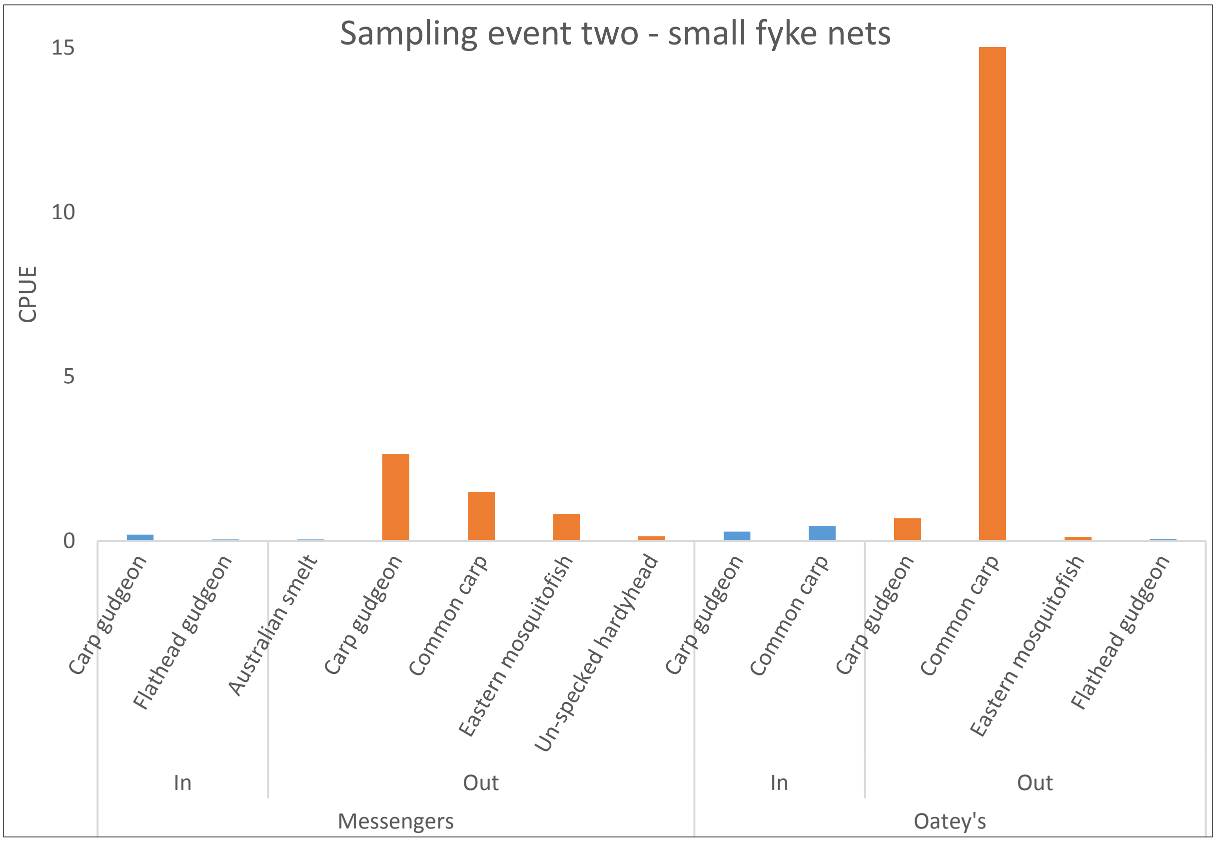


Figure 5A. Direction of small-bodied fish movement at each regulator on two sampling occasions. CPUE represented as fish per hour per net.

Kramen channel fish assemblage during environmental watering

Fish (n=466) sampled during the environmental watering of Lake Kramen comprise three native (n=463) and two non-native (n=3) species, plus Freshwater shrimp (n=10) and Yabbies (n=29) (Table 2A).

Australian smelt were the most common species detected and Common carp and Goldfish, the only non-native species sampled, were the least common (Table 2A).

Table 2A. Fish and decapod crustaceans sampled in Kramen channel during environmental watering via the Hattah Lakes environmental pumps, September–November 2014, and using two types of sampling gear.

Origin	Size	Common name	Species name	In		Total
				Drift nets	Small fyke nets	
Native	**Crustacean**	Freshwater shrimp	Macrobrachium		10	10
		Yabby	Cherax destructor		29	29
	Large-bodied	Golden perch	Macquaria ambigua		3	3
	Small-bodied	Australian smelt	Retropinna semoni	41	405	446
		Carp gudgeon	Hypseleotris spp.	1	13	14
Non-native	**Large-bodied**	Common carp	Cyprinus carpio		1	1
		Goldfish	Carassius auratus	2		2

Survival after entrainment (Lake Kramen)

As mentioned in the main report there was evidence of mortality due to transit through the environmental pumps (Figure 6A).

Figure 6A. Physical injuries such as amputations, de-scaling and exophthalmia were noted in a range of species sampled in small fyke nets from Chalka Creek. Left to right; Goldfish and Australian smelt.

Discussion and conclusion

Impact of environmental water recession on fish movement

This present study reflects a short survey conducted as a preliminary investigation into whether native fish would return to the main river channel after strong growth within the Hattah Lakes. Receding water prompted some movement of native and non-native species and the majority was *with* the flow back into the Murray River.

Contrasting fish communities: events one and two

Large-bodied fish

The native species Golden perch, Murray cod and Bony herring were only detected moving out of the lake system into the main river channel. While these species were only caught in low numbers (Table 1A) these preliminary results suggest that a key response to recession flows of large-bodied native fish in the Hattah Lakes is movement back to the Murray River after high growth rates within the productive inundated lake system.

Non-native Common carp exhibited bi-directional movement during both events at Messengers and during event two at Oateys. Juvenile carp were detected with small fyke nets moving out at both survey locations. The increased movement of adult Carp into the lake system on a drawdown event could be manipulated to trap and extract Carp through pest management operations (Brown & Gilligan 2014; Stuart 2013; Stuart & Conallin 2009).

Small-bodied fish

Native Carp gudgeon also moved out of the lakes and into the main river channel along with very low numbers of Un-specked hardyhead. Australian smelt were observed moving in from the Murray River to the lakes which is consistent with observations of mass movements upstream at Murray River fishways (Stuart *et al.* 2008). Australian smelt may have been attracted by the higher flow rate exiting Chalka Creek during their migration upstream.

Non-native Eastern gambusia were also observed moving out in high numbers with the flow back into the main river channel. This occurred mostly at Oateys regulator which may represent a difference in either the water quality or antecedent conditions of both ends of Chalka Creek.

Environmental watering of Lake Kramen

Water can be delivered through Kramen channel to Lake Kramen by diverting one of the seven environmental water pumps at Hattah Lakes. Similar to the commissioning of the Hattah Lakes environmental pumps (spring–summer 2013–2014), environmental water was pumped into a dry Kramen channel and lake. Therefore the fish assemblage present could only be supplied from the Murray River via the pump. These results further support that the environmental pumps do provide passage for fish. The standard lengths of the three Golden perch that survived the passage through the pumps were 120 mm, 118 mm and 74 mm. The two larger fish are twice the size of perch caught from the first commissioning event (Brown *et al.* 2014) and are the largest specimens of native fish known to have survived passage through the Hattah Lakes environmental pumps.