Assessment of fish movement to and from Margooya Lagoon upon re-connection to the Murray River.

Iain Ellis and Leigh Pyke

Murray-Darling Freshwater Research Centre,
Lower Basin Laboratory
P.O. Box 3428, Mildura Vic. 3502

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Iain Ellis and Leigh Pyke
The Murray Darling Freshwater Research Centre, Lower Basin Laboratory

For further information contact:

Iain Ellis
Murray-Darling Freshwater Research Centre
PO Box 3428 Albury NSW 2640
Ph (03) 50514050
Fax (03) 50236248
e-mail: i.ellis@latrobe.edu.au

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Executive Summary

The Mallee Catchment Management Authority (Mallee CMA) contracted the Murray-Darling Freshwater Research Centre (MDFRC) to assess the movement of fish into or out of Margooya Lagoon when the regulator between the lagoon and the Murray River was opened during April 2010. Additionally, the growth rate of golden perch and silver perch within this wetland were examined.

Most native fish movement through the Margooya Lagoon regulator was directed out of the wetland (or at least out of the inlet creek), although it was restricted to small bodied species (predominantly carp gudgeon, and unspecked hardyhead). No juvenile golden perch or silver perch (which had been recorded in Margooya Lagoon in December 2009 and April 2010 surveys) were observed exiting the wetland to the Murray River. More juvenile carp were recorded entering the wetland than exiting the wetland when the regulator was opened. One adult carp, too large to pass through the carp exclusion screen fixed to the regulator structure, was recorded outside of the regulator, and was attempting to move into the wetland.

Dissolved oxygen concentrations in the shallow inlet creek of Margooya Lagoon were persistently below 3mg. l^{-1} prior to the regulator being opened and remained at around this concentration during the week following the opening of the regulator. Low dissolved oxygen concentrations were considered likely to act as a deterrent to fish passage, given that few fish species are able to tolerate prolonged exposure to dissolved oxygen levels below 3mg.L^{-1}.

The accumulation of debris such as leaf litter, small branches, and cumbungi within the inlet/outlet channel to Margooya Lagoon creates a physical barrier to the movement of fish into or out of the wetland. Removal of this debris from the inlet creek would increase the likelihood of fish movement into and out of Margooya Lagoon while also increasing the flow rate from the wetland through the inlet/outlet creek when the regulator is opened. This action is likely to improve dissolved oxygen concentrations by physical mixing of the water column during the wetland drawdown.

Between the timing of the second MDFRC survey of Margooya Lagoon (December 2009) and the timing of the present study (April 2010), golden perch and silver perch in Margooya Lagoon were estimated to have grown by an average of 1mm in length per day, demonstrating the suitability of newly inundated wetlands as a nursery habitat for these species. Following 3-4 months inhabiting the newly inundated wetland, juvenile golden perch and silver perch were small enough to negotiate the carp exclusion screen on the inlet/outlet regulator and were thus able to migrate from the wetland into the Murray River if inclined to do so when the regulator was opened. However, there was no observation of either species actively moving out of the wetland during this investigation.

We present here a series of conceptual models to suggest potential fish movement scenarios between the river and wetland under three different riverine flow conditions (two filling and one wetland drawdown). The timing of wetland filling events to coincide with elevated river flow levels is considered more likely to facilitate movement of larval and early juvenile (young of the year) golden perch and silver perch from the river channel into the wetland habitat (Scenario 1). The timing of re-connection events to occur when river levels are again elevated may cue juvenile native fish to move out of the wetland, while also facilitating further colonisation by larvae and juvenile fish from the river (Scenario 2a). The timing of re-

connection events to occur when water level in the wetland are considerably higher than in the river (> 20 cm) will provide more substantial head difference between the river and the wetland. The greater flow rates to the river from the wetland this will induce may provide a cue for native fish to move out of the wetland (Scenario 2a). These latter two scenarios would be expected to promote movement of 0+ golden and silver perch from Margooya Lagoon back to the river channel, and could be tested if Margooya Lagoon were refilled via pumping (surcharged), prior to re-opening the regulator. Such intervention would establish a significant head difference between the wetland and the river prior to draw-down. These scenarios could be applied to geomorphically similar wetlands to Margooya Lagoon along the Murray River floodplain, potentially enhancing native fish recruitment within the region via provision of appropriate nursery habitats, such as was observed to occur within Margooya Lagoon during this study.

Introduction

Margooya Lagoon is a floodplain wetland in the Lock 15 Weir Pool located in the Beggs Bend State Forest 12km south-east of Robinvale. The wetland is approximately 30 hectares in size and up to 2 metres deep at full supply level.

Off-channel habitats such as Margooya Lagoon are important for fish populations because of the increased habitat diversity offered by floodplains, with heightened survival, feeding and reproduction opportunities (Junk *et al.* 1989, Lyon *et al.* 2010). Closs *et al.* (2005) demonstrates that wetlands of the Murray-Darling system support a variety of native fish species, sometime species of conservation significance, highlighting the importance of these systems for conserving fish biodiversity.

The Mallee Catchment Management Authority (Mallee CMA) is currently managing hydrological regimes of Margooya Lagoon via the control of a regulator fitted with a carp exclusion screen located on the inlet/outlet creek (close to the Murray River). Prior to installation of the regulator, the hydrology of the wetland had been altered from ephemeral (alternating between dry and wet phases) to almost permanent inundation and connection to the Murray River above the lock and Weir 15 at Euston.

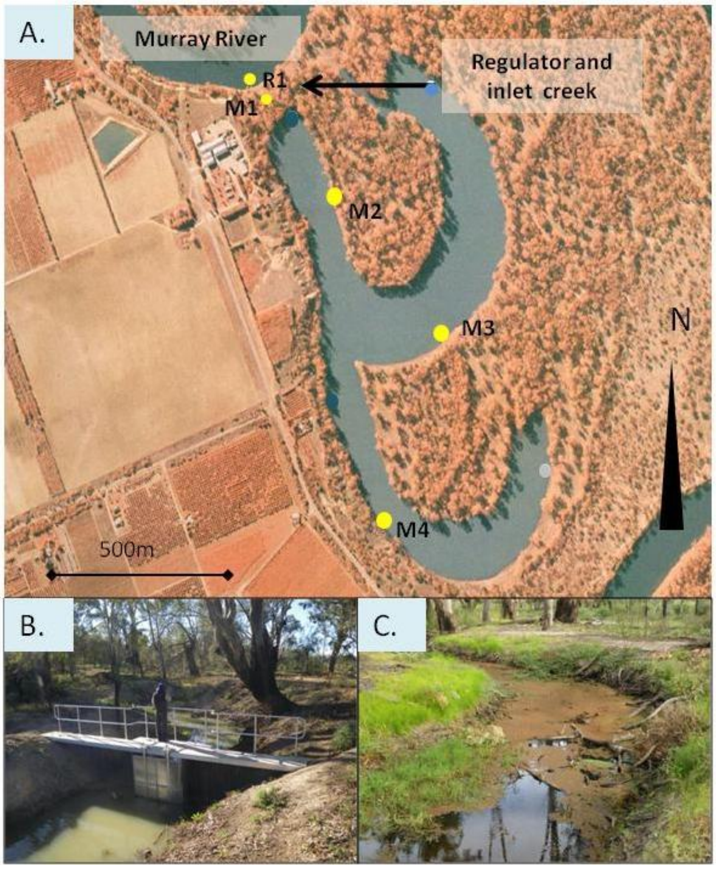

Figure 1. (A) Margooya lagoon with sample sites indicated; (B) regulator on the inlet creek; (C) the defined channel of the inlet creek.

Margooya Lagoon and has experienced a managed dry phase throughout most of 2009 (Figure 1). The regulator was opened and water began filling the lagoon in October 2009 via the small creek at the northern end of the wetland. The regulator is fitted with a carp exclusion screen (mesh width of 35 mm), restricting passage through the regulator to fish of a girth generally less than 35mm.

On 22 October 2009 a survey of the fish community in the inlet creek and partially-filled wetland was conducted (Chapman *et. al* 2009). Due to low river levels during October 2009, the regulator was closed and Margooya Lagoon was surcharged via pumping directly from the Murray River into the inlet creek. A second survey was conducted in December 2009 when the wetland was full (Ellis *et. al* 2009) which indentified juvenile golden perch (*Macquaria ambuigua*) and silver perch (*Bidyanus bidyanus*) in Margooya Lagoon. Silver perch is listed and under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act 1988). The presence of juvenile golden perch and silver perch in Margooya Lagoon during the summer survey indicated that larvae or early juveniles of these species had entered via the pump or through the carp exclusion screen prior to pumping. No large bodied predatory fish which could eat juvenile golden perch and silver perch were present in Margooya Lagoon at this time.

It is generally recognised that elevated flows and discharge induces spawning in golden perch and silver perch (King *et al.*2010; Mallen-Cooper and Stuart, 2003). The Murray River demonstrated elevated (but within bank) flows during late November and early December 2009 (Figure 2). These elevated flows appear to have stimulating these species to spawn in the river channel, with larvae and/or juveniles subsequently transported into Margooya Lagoon.

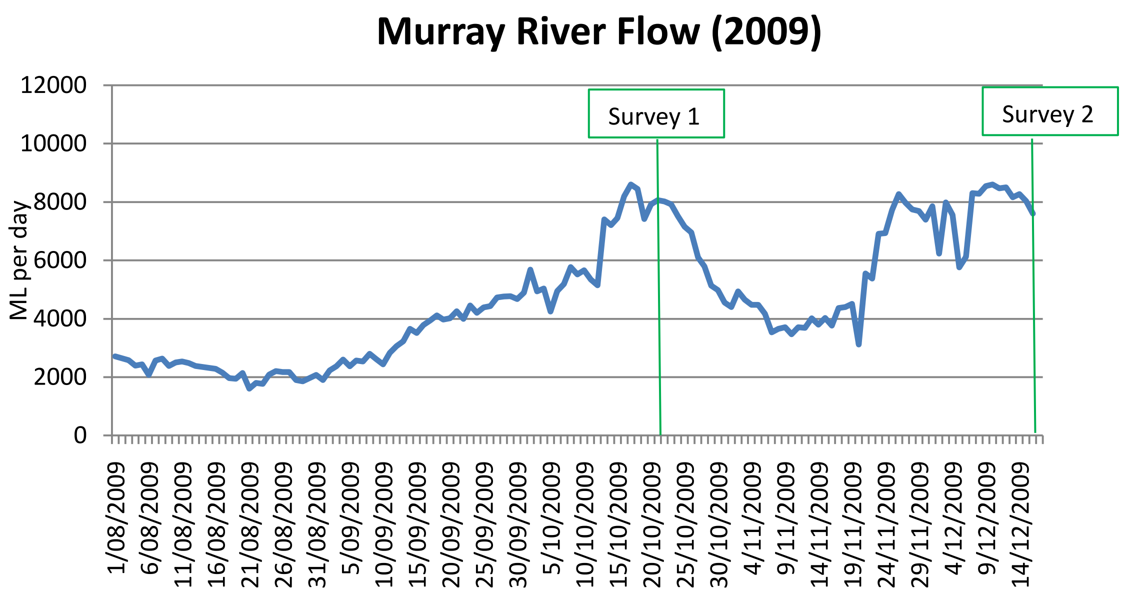

Figure 2. Murray River flows from June to December 2009, with dates of the first two MDFRC surveys of Margooya indicated in green.

An abundance of aquatic vegetation, zooplankton and other food resources (tadpoles and macro-invertebrates) were noted in Margooya Lagoon during December 2009 (Ellis *et. al*

2009), providing early juvenile fish with an abundant food supply and thus an ideal nursery environment in which to develop.

Improving lateral connectivity between floodplain nursery habitats such as Margooya Lagoon and the Murray River is important for fish populations as floodplains provide feeding and nursery zones (Closs *et al.* 2005 ; Mallen-Cooper 2001), and fish community structure, functioning and subsequent fishery production can relate to river–floodplain connectivity (Junk *et al*. 1989).

This study assessed fish movement through the regulator when reconnection to the Murray River was imposed, as well as the survival and growth of juvenile golden perch and silver perch in Margooya Lagoon. The information collected here complements that of existing monitoring programs (water quality, macro-invertebrates and vegetation), and provides recommendations for future management and monitoring of Margooya Lagoon.

Objectives

The objectives of this MDFRC survey were to:

1. Carry out surveys during April 2010 to assess movement of fish species into or out of Margooya Lagoon when the regulator was opened.

2. Collect information regarding the growth rate of golden perch and silver perch (which had been recorded as juvenile cohorts within Margooya Lagoon in December 2010).

3. Conduct surveys using standard methods to allow comparison with past and future surveys.

4. Provide recommendations for management of Margooya Lagoon and suggestions for further work.

Methods

Component 1 – Wetland survey

Prior to the opening of the Margooya Lagoon regulator (13 April 2010, Day 0), the water quality and fish community at six sites in Margooya Lagoon were surveyed. These sites were located in the inlet creek just 'outside' the regulator (R1), in the inlet creek just 'inside' the regulator (M1), and three sites within the open water habitat of the lagoon proper (M3, M4 and M5) (Figure 1). Sample sites coincide with sites used in previous surveys (Ellis *et. al* 2009, Chapman *et. al* 2009).

Water Quality

Water quality data was collected at each site during each survey using a U-52 multi-probe (Horiba Ltd, Australia). Temperature (°C), pH, turbidity (NTU), electrical conductivity ($\mu S.cm^{-1}$) and dissolved oxygen ($mg.L^{-1}$) were recorded at a depth of 0.2 m below the water surface. Measurements were taken between 9 am – 5 pm. Parameters were compared to suggested guidelines as described by ANZECC & ARMCANZ (2008).

Fish and turtles

At each site two large mesh fyke nets (LFN), two small mesh fyke nets (SFN) were deployed overnight (Table 1). Nets were set to include a diversity of structural habitat (open water, vegetation and woody material) to increase the probability of sampling a range of species and size classes.

Component 2 – directional surveys

To examine directional movement to or from the wetland "Directional" surveys of fish in Margooya Lagoon inlet creek both inside and outside the regulator were conducted **after** the regulator was opened on 14-15 April 2010 (Day 1-2) and 20-22 April 2010 (Day 7-8). Diagrams of the directional netting in the inlet creek are demonstrated in Figure 3. On Day 1 a double winged large mesh fyke net (DFN) and a SFN were deployed overnight to block the entire inlet creek **inside** the regulator, to assess fish movement into the wetland from the Murray River. The DFN were set to catch large-bodied fish, while smaller species passed through these and were captured in the fine-mesh SFN, thus the nets so that the nets would collect the majority of fish sizes and species. This process was reversed the following night (Day 2) with DFN and SFN deployed **outside** the regulator to assess fish movement out of the wetland to the Murray River. The same 'directional survey' methodology was repeated on Day 7 and 8, a week after the regulator was opened.

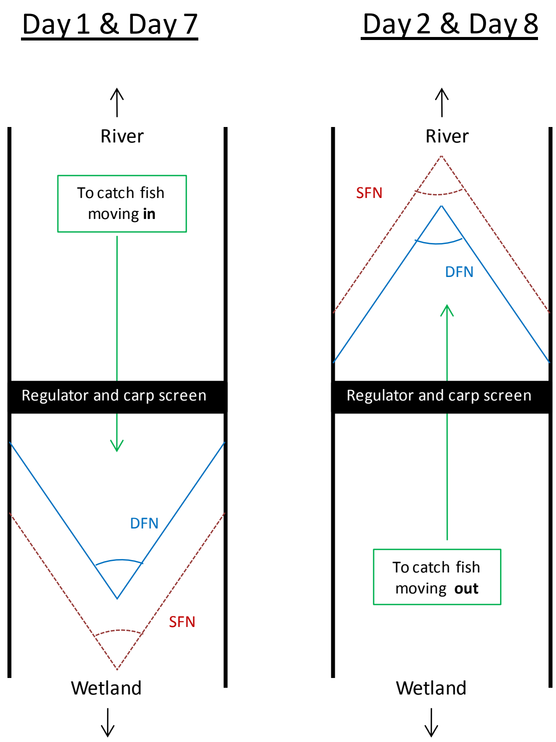

Figure 3. Directional net placement in the Margooya Lagoon inlet creek.

Large fyke nets (LFN) had a central wing (8 m x 0.65 m) attached to the first supporting hoop (∅ = 0.55 m) with a mesh entry of 0.32 m, and stretched mesh size of 28 mm. The Directional large fyke nets (DLFN) had two wings (8 m x 1.5 m) attached to the first supporting hoop (∅ = 0.55 m) with a mesh entry of 0.32 m, and stretched mesh size of 28 mm. Small fyke nets (SFN) had dual wings (each 2.5 m x 1.2 m), with a first supporting hoop (∅ = 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). Each SFN had a stretched mesh size of 2 mm. All nets were set in the afternoon and collected the following morning. The cod-end of LFN and DFN was suspended out of the water by use of floats to avoid mortality of captured air-breathing animals.

Table 1. Sample dates and number of each gear type used during the April 2010 surveys prior to (Component 1) and after (Component 2) opening of the regulator.

Site	Sample Date	Before of after opening of regulator	Day	Number of SFN	Number of LFN	Number of DFN
R1 (River)	13/04/2010	Before	Day 0	2	2	
M2	13/04/2010	Before	Day 0	2	2	
M3	13/04/2010	Before	Day 0	2	2	
M4	13/04/2010	Before	Day 0	2	2	
M5	13/04/2010	Before	Day 0	2	2	
R1	19/10/2009	After	Day 1/2	2	2	1
M2	19/10/2009	After	Day 1/2	2	2	1
R1	22/10/2009	After	Day 7/8	2	2	1
M2	16/12/2009	After	Day 7/8	2	2	1

Fish identifications followed McDowall (1996) and Lintermans (2007). Carp gudgeon were identified to genus level only (i.e. *Hypseleotris* spp.) owing to the current taxonomic uncertainty at the species level (Bertozzi *et al.* 2000). All fish captured were counted. Standard lengths (SL to the nearest 1.0 mm) were recorded for a sub-sample of 15 individuals of each species from each net to allow interpretation of species size-class frequency. The width (head width) for juvenile silver perch, golden perch, carp and goldfish was recorded to determine if the fish were small enough to pass through the carp exclusion screen on the Margooya Lagoon inlet/outlet regulator (screen mesh size 35mm).

Netting catch data was standardised to 20 net hours per wetland, allowing a comparison of taxa richness and abundance between wetlands. All native fish were returned alive to the point of capture while exotic species were euthanized by immersion in Aqi-S following ACEC guild lines. Fauna classified as by-catch in netting surveys (freshwater yabbies, shrimp and turtles) were identified and counted before being returned to their point of capture. Ethics approval was obtained prior to sampling through La Trobe University Animal Ethics Committee (Permit No. AEC07-20-MD-V2).

Results

Water Quality

Mean Water quality measurements for the three recent MDFRC surveys of Margooya Lagoon are presented in Table 2. Mean water quality measurements at each site during Component 1 of the April 2010 survey are presented in Table 3. Mean turbidity in Margooya Lagoon during the April 2010 surveys was higher than in the December 2009 survey, although it was considerably lower to that recorded in October 2009 directly after inundation of the wetland had begun and was comparable to those recorded in other local Mallee wetlands (Ellis. *et al.* 2009 Ho. *et al.* 2004). The mean pH of Margooya Lagoon during the April 2010 surveys was greater than that recorded in the October and December 2009 surveys, but was within the range reasonably expected according to the guidelines of 6.5-8 as described by ANZECC & ARMCANZ (2000).

Electrical conductivity (EC) recorded in Margooya Lagoon during April 2010 was higher that that recorded in December 2009 but below the suggested maximum of 2,200 µS cm^{-1} @ 25ºC for Lowland River systems (ANZECC & ARMCANZ 2008). The mean temperature in Margooya Lagoon was also within the suggested range (ANZECC & ARMCANZ 2008), and it should be noted that water temperature will fluctuate on a daily and seasonal basis.

Dissolved oxygen (D.O. mg L^{-1}) concentrations were recorded between the hours of 11:00 and 17:30. The mean DO of Margooya Lagoon during Component 1 of the April 2010 surveys was greater than that recorded in the December 2009 survey. DO was greater than the recommended minimum concentrations for freshwater ecosystems of 6 mg L^{-1} (ANZECC, 2000) at all sites except in the inlet creek (Site M2). The DO at Site M2 was 0.6 mg L^{-1} prior to opening of the regulator (13 April 2010), and remained below 2.5 mg L^{-1} throughout the remaining surveys in Component 2 of this survey (Table 3).

Table 2: Mean water quality measurements for Margooya Lagoon with mean measurement from previous MDFRC surveys included for comparison.

Survey Date	Turbidity (NTU)	EC (uS.cm-1)	pH	Temperature (ºC)	DO (mg/L)
22/10/2009	177.1	298.8	7.0	24.6	9.1
16/12/2009	3.0	133.2	6.8	29.0	3.9
14/04/2010	58.3	175.8	7.7	18.2	7.0

Table 3: Water quality measurements at each site in Margooya Lagoon during the April 2010 survey.

Date	site	Turbidity (NTU)	EC (uS.cm-1)	pH	Temperature (ºC)	DO (mg/L)
14/04/2010	R1	57	98	8.5	19.9	8.6
14/04/2010	M2	7	184	6.9	16.8	0.6
14/04/2010	M3	80	170	7.5	17.9	8.3
14/04/2010	M4	80.1	169	8.8	19.8	11.0
14/04/2010	M5	66	180	7.6	18.3	8.2

Fish Communities

A total of 2967 fish from eight species (6 native and 2 exotic) were captured in Component 1 of the April 2010 survey of Margooya Lagoon, conducted just prior to opening of the regulator on (Table 4). For comparison, the total catch data for the Site R1 (outside the regulator and directly connected to the Murray River) is presented separate from the sites inside the regulator. The exotic Mosquitofish or Gambusia (*Gambusia holbrooki*) was the most abundant species recorded in the April 2010 survey followed by native carp gudgeon (*Hypseleotris spp*) and unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*). Juvenile golden perch (n=5) and silver perch (n=17) were again recorded throughout Margooya Lagoon having previously been recorded in the earlier December 2009 survey.

Standardised total fish catch (20 x LFN/SFN soak hours) for Margooya Lagoon is presented in Table 5. A greater relative fish catch was recorded in the April 2010 survey than in the previous MDFRC surveys. This is attributed to an increase in the abundance of Gambusia in particular, as well as carp gudgeon and unspecked hardyhead at all sites in the wetland (Figure 4). No introduced common carp (*Cyprinus carpio*) or goldfish (*Carassius auratus*) were recorded in the April 2010 survey, although both species had been present in the December 2009 survey; and were both present in the river adjacent to the billabong at the time of the April 2010 survey.

Table 4. Total fish catch for Component 1 of the April 2010 survey of Margooya Lagoon with Site R1 (connected to the Murray River) presented separately, Shaded cells denote exotic species.

Common name	Scientific name	Autumn 2010	River site (R1)
		14/04/2010	14/04/2010
Australian smelt	*Retropinna semoni*	4	0
Bony herring	*Nematalosa erebi*	16	0
Carp gudgeon	*Hypseleotris spp.*	1028	3
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	238	13
Golden perch	*Macquaria ambigua*	5	1
Silver perch	*Bidyanus bidyanus*	17	0
Murray cod	*Muchullochella peeli peeli*	0	0
Gambusia (Mosquito fish)	*Gambusia holbrooki*	1651	99
Common carp	*Cyprinus carpio*	0	1
Goldfish	*Carassius auratus*	0	1
Oriental weatherloach	*Misgurnus anguillicaudatus*	4	0
	total	**2963**	**2963**

Table 5: Standardised fyke net (catch per 20 net hours) catch for each survey. Shaded cells denote exotic species.

Common name	Scientific name	22/10/2009	16/12/2009	14/04/2010
Australian smelt	*Retropinna semoni*	0.0	0.2	0.5
Bony herring	*Nematalosa erebi*	0.0	0.2	2.2
Carp gudgeon	*Hypseleotris spp.*	9.6	12.2	133.8
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	0.0	0.0	31.3
Golden perch	*Macquaria ambigua*	0.0	1.3	0.7
Silver perch	*Bidyanus bidyanus*	0.0	2.0	2.4
Murray cod	*Muchullochella peeli peeli*	0.0	0.0	0.0
Common carp *	*Cyprinus carpio*	0.0	7.7	0.0
Gambusia (Mosquito fish) *	*Gambusia holbrooki*	1.9	0.3	218.1
Goldfish *	*Carassius auratus*	0.2	1.4	0.0
Oriental weatherloach *	*Misgurnus anguillicaudatus*	0.2	3.5	0.5
	total	**12.0**	**28.8**	**389.5**

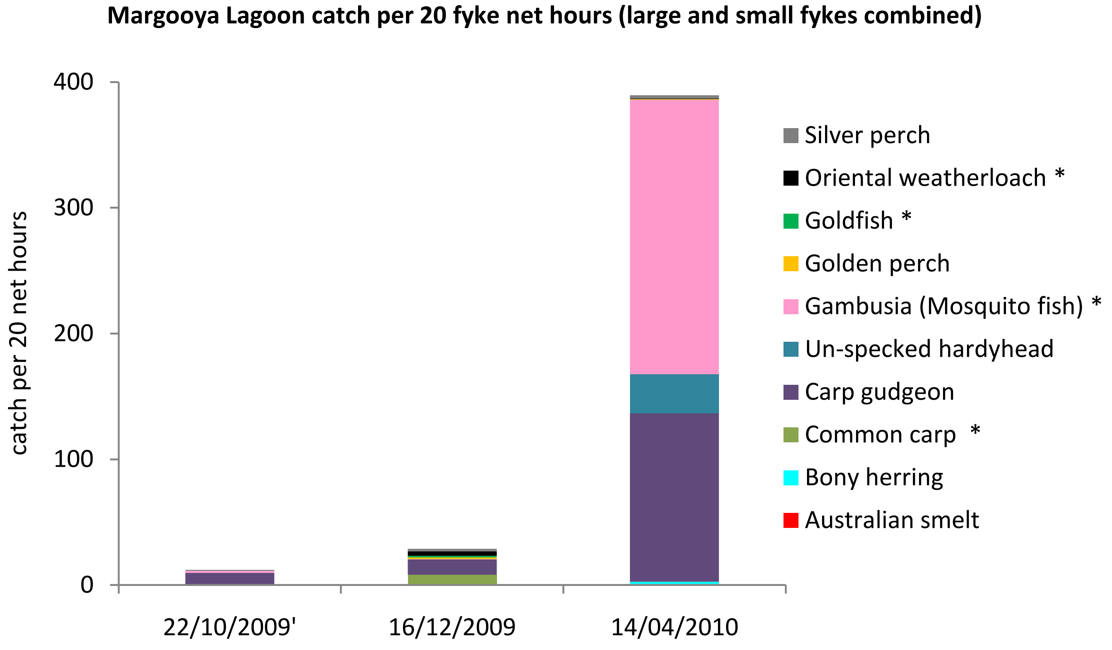

Figure 4. Total standardised fish abundance (catch per 20 net hours, LFN and SFN combined) for all species caught in Margooya Lagoon in the October 2009, December 2009) and April 2010 surveys. * denotes exotic species

Size-class frequency distributions

Small-bodied fish

The size-class frequency distribution for small bodied fish species in the three surveys of Margooya lagoon are shown in Figure 5. Strong cohorts of juvenile carp gudgeon (15-25 mm SL) were recorded in the April 2010 survey indicating recent breeding events (Figure 5). The Gambusia population in Margooya Lagoon was dominated by small adult fish (15-30 mm SL). Australian smelt were only recorded in low abundance in the December 2009 and April 2010 surveys with the population represented only by juvenile individuals in the former (20-35 mm SL), and adults in the latter (45-55 mm SL).Small adult unspecked hardyhead were recorded in the April 2010 survey fish (20-30 mm), having been absent in earlier MDFRC surveys.

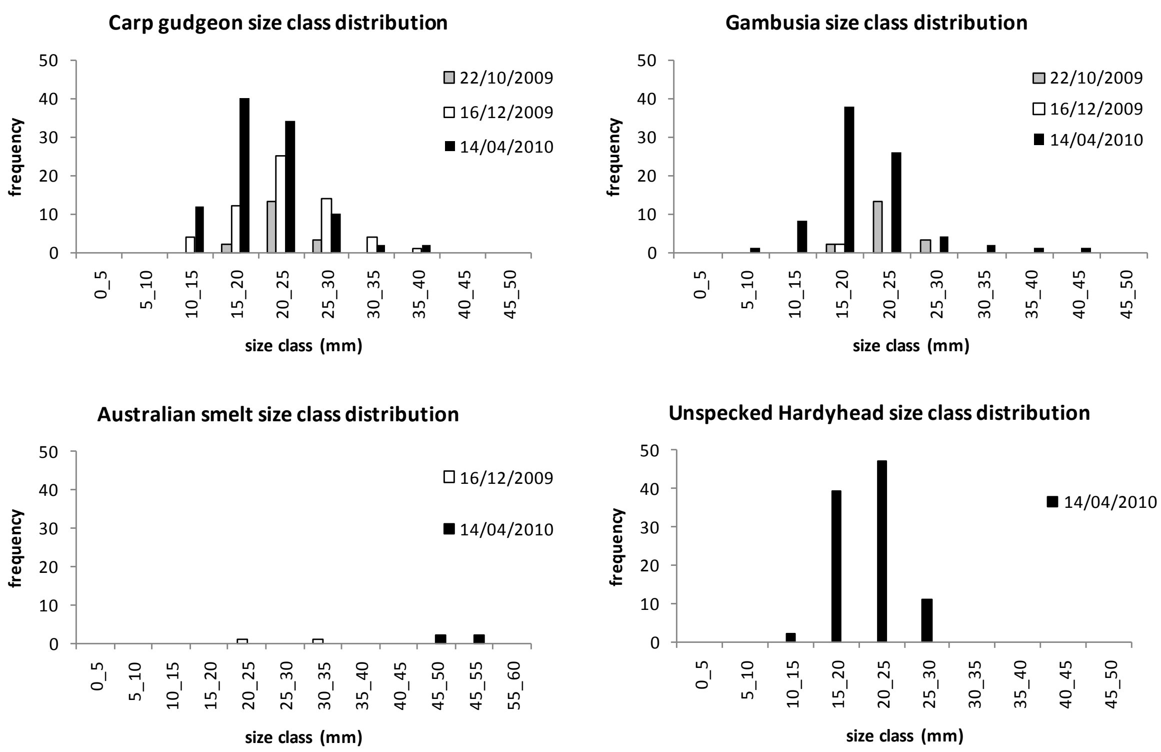

Figure 5. Size frequency distributions for small-bodied fish species captured in netting surveys of Margooya Lagoon.

<u>Large-bodied fish</u>

The size-class frequency distribution for the larger bodied fish species captured in netting surveys in Margooya Lagoon is included in Figure 4. There were no large bodied native fish recorded in Margooya Lagoon prior to the surcharge pumping in October/November which filed the Lagoon.

A cohort of golden perch ranging from 137-182 mm SL was present in Component 1 of the April 2010 survey. These golden perch had been recorded in the December 2009 survey ranging from 20-35 mm SL.

A cohort of silver perch ranging from 130-180 mm SL was present in Component 1 of the April 2010 survey. These silver perch had been recorded in the December 2009 survey ranging from 15-35 mm SL.

A larger size class of bony herring (>140 mm SL) were recorded in Component 1 of the April 2010 survey than the smaller individual (<100mm SL) which were recorded in December 2009.

Only large Oriental weatherloach (>100mm) were recorded in the April 2010 survey. Smaller size classes had been recorded in the inlet creek of Margooya Lagoon in October 2009, and throughout the wetland in the December 2009 survey.

A single small carp (< 80 mm SL) was recorded inside the regulator in the inlet creek in Component 1 of the April 2010 survey. Only larval Carp (< 10mm) had been recorded in the

October 2009 survey of Margooya Lagoon, whilst juvenile and adult Carp and Goldfish were recorded throughout the wetland in the December 2009 survey.

A single small goldfish (<50 mm SL)was recorded inside the regulator in the inlet creek in Component 1 of the April 2010 survey, despite larger size classes being recorded I earlier surveys.

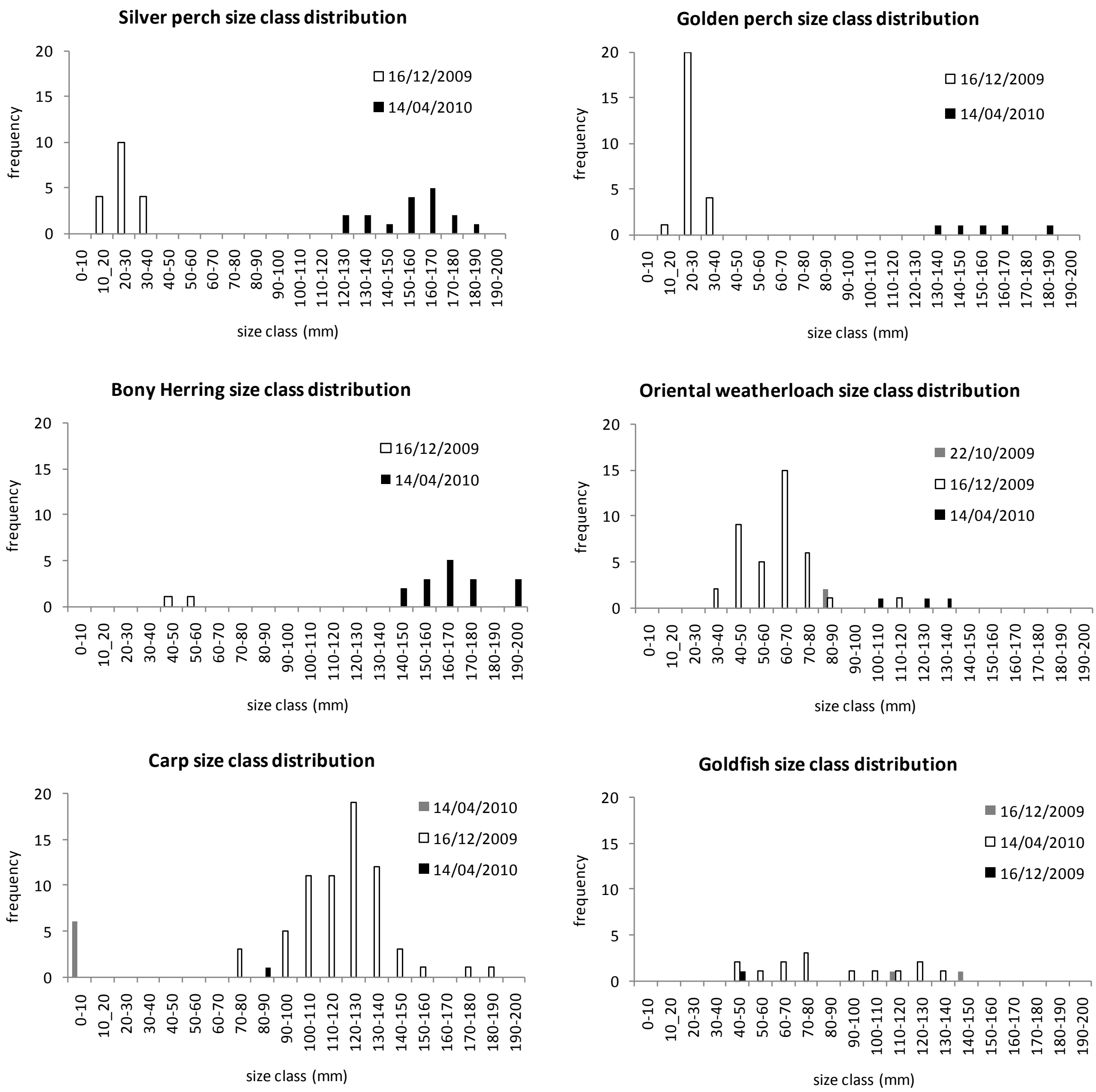

Figure 4. Size frequency distributions for large-bodied fish species captured in netting surveys.

Growth of golden perch and silver perch

The average size of golden perch and silver perch captured in the December 2009 and April 2010 surveys in terms of standard length and weight (±1 standard error) are represented in Table 5. Standard lengths of juvenile golden perch and silver perch in the two surveys are represented graphically in Figure 5.

Table 4. Mean length and weight (± 1 standard error) of golden perch and silver perch captured in the December 2009 and April 2010 surveys of Margooya Lagoon.

		Mean length (SL)	Mean weight (g)	Mean head width (mm)
Golden Perch	16/12/2009	28.8 (± 0.9)	0.7 (± 0.1)	
	14/04/2010	158.0 (± 7.4)	115.4 (± 20.3)	26.8 (± 1.5)
Silver Perch	16/12/2009	25.3 (± 1.3)	0.7 (± 0.1)	
	14/04/2010	156.7 (± 4.0)	89.9 (± 7.5)	25.8 (± 0.9)

Between 16 December 2009 and 14 April 2010, the average size of golden perch increased in length by 113 mm (SL) and by 115g in weight. This represents an average daily growth rate of fish in this cohort of 1.1mm in length (SL) and 0.96g in weight between the two surveys. In the same period the average size of silver perch increased by 131mm (SL) and by 9g in weight (Figure 4, and figure 5). This represents an average daily growth rate of fish in this cohort of 1.1mm and 0.7g between the two surveys.

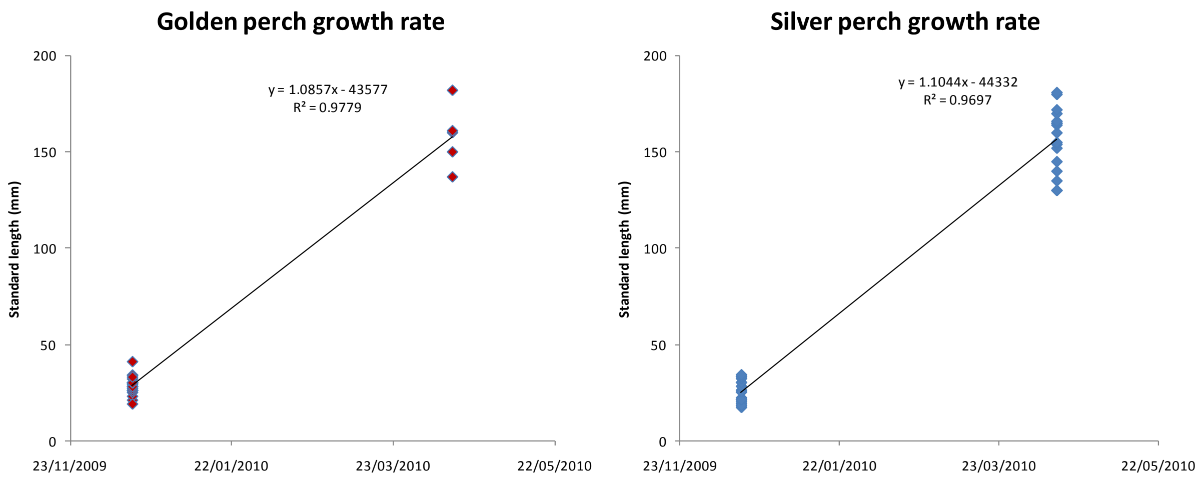

Figure 5. Growth of juvenile golden perch and silver perch in Margooya Lagoon (± 1 SE).

The greatest width (head width) for juvenile golden perch and silver perch captured in the April 2010 survey was recorded to determine if the fish were small enough to pass through the carp exclusion screen on the Margooya Lagoon regulator should they be inclined to do so. The mean head width of golden perch in April 2010 was 26.8mm with a maximum of 31mm, whilst the mean head width of silver perch in April 2010 was 25.8mm with a maximum of 31mm. Based on these maximum head widths, we can assume the juvenile golden perch and silver perch were small enough at the time the regulator was opened to pass through the carp exclusion screen (mesh size 35 mm), into the Murray River if inclined to do so.

Additional vertebrate fauna

Turtles

All three species of turtle known to inhabit the Murray River system were recorded in Margooya Lagoon in the April 2010 survey (Table 5). Although Broad-shell turtles (*Chelodina expansa*) and Eastern Long-necked turtles (*Chelodina longicollis*) had been recorded in earlier surveys, the survey in April 2010 was the first to detect Murray River turtles (*Emydura macquarii*).

Table 5. Turtle species abundance in each survey of Margooya Lagoon.

Common Name	***Scientific Name***	**22/10/2009**	**16/12/2009**	**14/04/2010**
Broad-shelled turtle	*Chelodina expansa*	0	8	1
Eastern Long-necked turtle	*Chelodina longicollis*	2	4	8
Murray River turtle	*Emydura macquarii*	0	0	2

Fish movement to/from wetland after opening of regulator

Table 6 demonstrates the total catch in the directional netting surveys conducted in the Margooya Lagoon inlet creek, either side of the regulator, to assess fish movement in to or out of the wetland. Standardised data for the abundance of each species moving into or out of the wetland are included in Appendix 1.

Table 6. Total catch in directional netting surveys of Margooya Lagoon inlet creek.

Date	Day of Experiment	site	Directional of fish movemnet	Carp gudgeon	Un-specked hardyhead	Golden perch	Silver perch	Goldfish	Common carp	Gambusia (Mosquito fish)	Oriental weatherloach	total
14/04/2010	Day 0	M2	no movemnet - regulator closed	0	0	0	0	0	0	460	0	**460**
14/04/2010	Day 0	R1	no movemnet - regulator closed	3	13	1	0	1	1	99	0	**118**
15/04/2010	Day 1	M2	in to wetland through regulator	113	3	0	0	2	10	296	2	**426**
16/04/2010	Day 2	R1	out of wetland through regulator	2192	35	0	0	2	0	212	0	**2441**
21/04/2010	Day 7	M2	in to wetland through regulator	25	0	0	0	1	7	24	0	**57**
22/04/2010	Day 8	R1	out of wetland through regulator	33	0	0	0	0	2	66	0	**101**

The standardised results of the assessment of fish movement to and from Margooya Lagoon are presented in Figure 7. Prior to opening the regulator (Day 0) the only fish species present in the Margooya Lagoon Creek inside the regulator (Site M2) was Gambusia. Gambusia was also the most abundant species recorded in the Margooya Lagoon Creek outside the regulator, although unspecked hardyhead and carp gudgeon were also present in low numbers. One juvenile carp and one juvenile goldfish were also recorded outside the regulator.

The day after the regulator was opened (Day 1) 296 Gambusia and 113 carp gudgeon were recorded on the inside of the regulator (Site M2) and were assumed to be moving **into** the wetland, as well as 10 carp, 2 goldfish, 3 unspecked hardyhead and 2 Oriental weatherloach (426 fish in total). One adult Carp too large to pass through the regulator carp exclusion screen was also observed outside the regulator (Site R1) attempting to move into the wetland.

On Day 2 when the direction of the netting was reversed a greater number of fish were recorded on the outside of the regulator (Site R1) moving **out** of the wetland than had been recorded moving in on Day 1. In total, 2192 carp gudgeon, 212 Gambusia, 35 unspecked hardyhead and 2 goldfish were recorded moving ‘out’ of the wetland on Day 2 (2441 fish in total).

On Day 7 when the directional netting surveys were repeated a week after the regulator was opened, 24 Gambusia, 25 Carp gudgeon, 7 Carp and 1 Goldfish were recorded on the inside of the regulator (Site M2) and were assumed to be moving i**nto** the wetland (57 in total). On Day 8, when the direction of the netting was reversed, 66 Gambusia, 33 carp gudgeon, and 2 carp were recorded on the outside of the regulator (Site R1) moving **out** to the wetland (101fish in total).

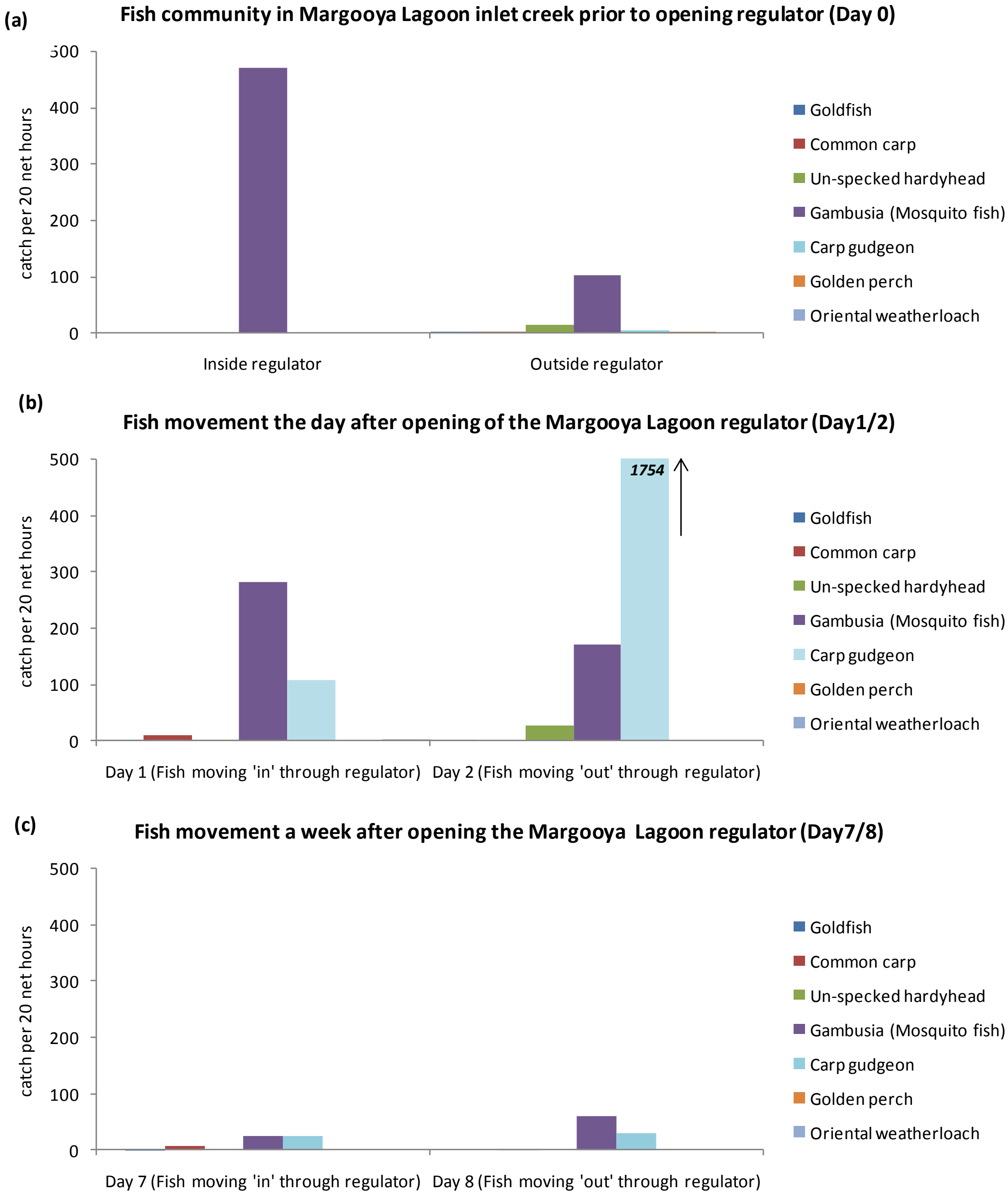

Figure 7. Standardised fish abundance **(a)** captured either side of the Margooya Lagoon regulator on Day 0; **(b)** moving ‘in’ and ‘out’ of Margooya Lagoon creek on days 1 and 2 after opening of the regulator; and **(c)** moving ‘in’ and ‘out’ of Margooya Lagoon creek on days 7 and 8 after opening of the regulator. Catches are standardised to 20 net hours. Note that catch of carp gudgeon on Day 2 greatly exceeds the vertical scale in this diagram, and as such is indicated numerically.

Discussion

Removal of a wet-dry cycle prevents the propagation of many plant and animal species, eventually shifting the aquatic community structure to that typical of a permanent wetland. Pressey (1986) classified the geomorphology of wetlands like Margooya Lagoon as lentic channel forms. This includes "sections of former river channels or anabranches which no longer function as major routes for flow through the system and distributary channels which disperse high flows within the confines of the recent floodplain".

Drying of a wetland promotes nutrient transformation and the consolidation of sediments, and allows for the establishment of terrestrial plant species which provide habitat and nutrients for aquatic biota upon re-inundation. The re-inundation of dry sediment often triggers the release of a pulse of carbon, phosphorous and nitrogen into the water column, increasing primary productivity (Baldwin and Mitchell, 2000, Zukowski *et al.*, 2003, Scholz and Gawne 2004). This in turn increases macrophyte growth, providing food, habitat and breeding opportunities for species at higher trophic levels including macro- and micro-invertebrates, fish, frogs and turtles. This post inundation response was demonstrated by Margooya Lagoon (Ellis *et al.* 2009).

Matching this pulse in production with seasonal spawning patterns of native fish has the potential to confer significant benefit to native fish recruitment success (Scholz and Gawne 2004). Lyon *et al.* (2010) suggests that lateral fish movements approximated water level fluctuations. That is, as water levels rise, fish leave the main river channel and moved into newly flooded off-channel habitats; and on falling levels fish move back to the permanent riverine habitats.

Water Quality

The mean pH, electrical conductivity, turbidity and temperature of Margooya Lagoon during the April 2010 survey were within the guidelines suggested by ANZECC & ARMCANZ (2000). Dissolved oxygen (DO) concentrations at all sites was above the lower level of 6mg/L recommended by ANZECC & ARMCANZ (2000), except the inlet creek site M2, at which DO concentrations were persistently below 3mg. l^{-1} both before the regulator was opened (Day 0), and in the week following the opening of the regulator (Day 1-8). The low DO is likely due to increased biological and chemical oxygen demand. Breakdown of organic matter by aerobic bacteria in aquatic systems consumes oxygen. Large amounts of organic matter in the water column (known as organic loading), can cause dissolved oxygen concentrations to drop with a lack of flow to remove matter compounding the phenomenon. A dense layer of submerged and emergent aquatic macrophytes, particularly *Azolla* sp., would also reduce light penetration and mixing within the inlet channel, thus reducing in-stream photosynthetic production of dissolved oxygen.

Although aquatic DO concentrations fluctuate diurnally, the low DO concentrations recorded in inlet creek of Margooya Lagoon is likely to act as a deterrent to fish passage. Few fish species can tolerate prolonged exposure to dissolved oxygen levels below 3mg.L^{-1}, especially large bodied or more active fish with a higher oxygen demand (NSW Fisheries 2000).

Fish Communities

The carp exclusion screen appears to have prevented adult Carp from entering the wetland, thus allowing aquatic macrophytes to emerge and create dense cover for native fish species. The absence of Carp also promoted the consolidation of wetland sediments, and emergence of abundant phytoplankton and zooplankton, providing excellent nursery habitat for larval and juvenile fish.

Elevated river flows are frequently reported to induce spawning in golden perch and silver perch (King *et al.* 2009; Mallen-Cooper and Stuart, 2003). The Murray River demonstrated elevated flows during November and December 2009, which appears to have stimulated golden perch and silver perch to spawn in the river channel (Clayton Sharpe, personal communication). The presence of juvenile cohorts of golden and silver perch in Margooya Lagoon in the December 2009 survey indicated that larvae of these species entered via the pump (or through the carp exclusion screen prior to pumping).

These juvenile golden perch and silver perch were again detected in Margooya Lagoon in April 2010. The growth of these juvenile fish (a rate of approximately 1mm per day since December 2009) is indicative of the suitability of Margooya Lagoon as a nursery habitat for native fish. This is consistent with other hypothesis and research findings which suggest off-channel habitats provide important nursery environments for fish species (Junk *et al.* 1989, Lyon *et al.* 2010; Closs *et al.* 2005), and demonstrates that managed watering events in floodplain wetlands can contribute to the conservation of native fish biodiversity.

Fish movement though the Margooya Lagoon regulator

Our results suggest the majority of fish movement through the Margooya Lagoon regulator during this assessment was directed "out" of the wetland (or at least out of the inlet creek). This result is consistent with previous findings, where fish move back to the permanent riverine habitats on falling off channel levels (Lyon et al. 2010). Most fish moving out were small bodied natives (predominantly carp gudgeon, with small numbers of unspecked hardyhead).

Conversely, more exotic fish (carp and Oriental weatherloach) were recorded moving "in" to the wetland than there were moving "out" during this assessment. Gambusia were recorded moving both directions, and their dominance both inside and outside the regulator prior to re-connection suggest they may be largely resident in the inlet creek itself, as well as in the wetland and riverine environment adjacent. These exotic fish movements are also consistent with previous studies which suggest in draw-down coinciding with high temperatures in summer and autumn, native fish will move away from shallow warm water, where as exotic species such as *Gambusia* and carp tend to remain and potentially perish via stranding (Zampattii *et al.* 2004).

There was no observation of silver perch or golden perch moving out of Margooya Lagoon in April 2010 survey, despite all captured individuals exhibiting a maximum girth smaller than the mesh size of the carp exclusion screen on the inlet/outlet regulator (i.e. < 35mm). This failure to leave the wetland is most likely due to a combination of three factors:

1. **Insufficient movement cue:** The head difference between the wetland and the river at the time that the regulator was opened was less than 10 cm and only a small volume of water was drawn from the wetland after opening of the regulator. Mallen-Cooper (2004) suggests an initial drop (i.e. a head difference) of 10-20 cm should provide a cue for large bodied species to leave the wetland, while small bodied species are likely to continue to leave as it dries further. The small flow observed upon opening of the regulator may therefore have been insufficient to stimulate golden perch and silver perch to leave the wetland.

2. **Low dissolved oxygen:** The dissolved oxygen (DO) concentrations in the inlet creek were persistently low (as low as 0.6 mg. l^{-1}). Few fish species can tolerate prolonged exposure to dissolved oxygen levels below 3mg.L^{-1} (NSW Fisheries, 2000) and as such may have avoided passage through the inlet creek.

3. **Barriers to movement**: At several locations within the inlet/outlet creek, physical obstructions to fish passage, specifically accumulations of large woody debris and aquatic vegetation (particularly *Cumbungi* spp.) were observed following the opening of the inlet/outlet regulator (Figure 8). Jones and Stuart (2004) recognised that dense areas of fallen timbre combined with shallow sandbars/benches may prevent fish from moving out of the waterbodies they occupied. Shallow habitat in the inlet/outlet creek may also present a barrier to fish movement through increasing potential exposure to predators. Small fish may experience a trade-off between staying amongst habitat during falling flows, and the increased chance of being eaten by a predator while migrating to another habitat (Jones and Stuart, 2004). As such there maybe less risk associated with staying in a wetland such as Margooya Lagoon for smaller individuals.

Figure 8. Margooya Lagoon inlet creek showing constrictions/barriers created by woody debris and vegetation, as well as thick surface vegetation.

Recommendations

Filling events

- Timing the re-filling events to coincide with elevated river flow levels is more likely to facilitate movement of native fish into the wetland from the river channel.

- Filling events in spring and summer are likely to produce a greater ecological response as they are likely to coincide with the natural reproductive patterns of many native aquatic organisms.

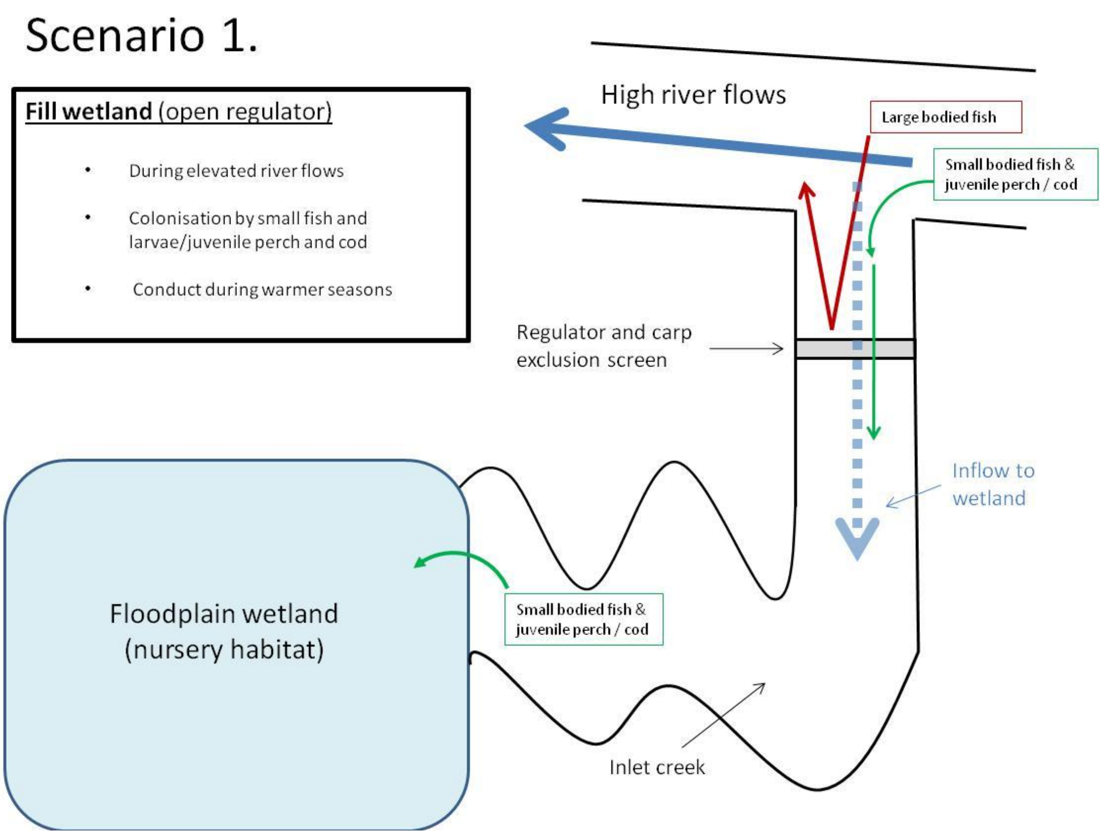

Figure 9. Conceptual Scenario 1 – expected fish movement during filling of wetlands during elevated river flows.

Re-connection events

Opening the regulator within 3-4 months of first filling would allow native fish (which have colonised the wetland), to return to the main river channel before growing too large to pass through the carp exclusion screen. However, reconnection could occur during different river flow scenarios, incurring differing fish responses.

1. Reconnecting during elevated river flows

   Re-opening of the regulator when river flows are elevated will potentially infer multiple benefits in terms of fish passage:

   - In-flows of fresh river water may stimulate the movement of native fish back into the river system.

   - Inflows may again facilitate movement of native fish into the wetland (from the river channel).

   - If the draw-down coincides with high temperatures in summer and autumn, native fish will generally move away from shallow warm water, where as exotic species such as Gambusia and carp tend to remain and potentially perish via stranding (Zampattii et al. 2004).

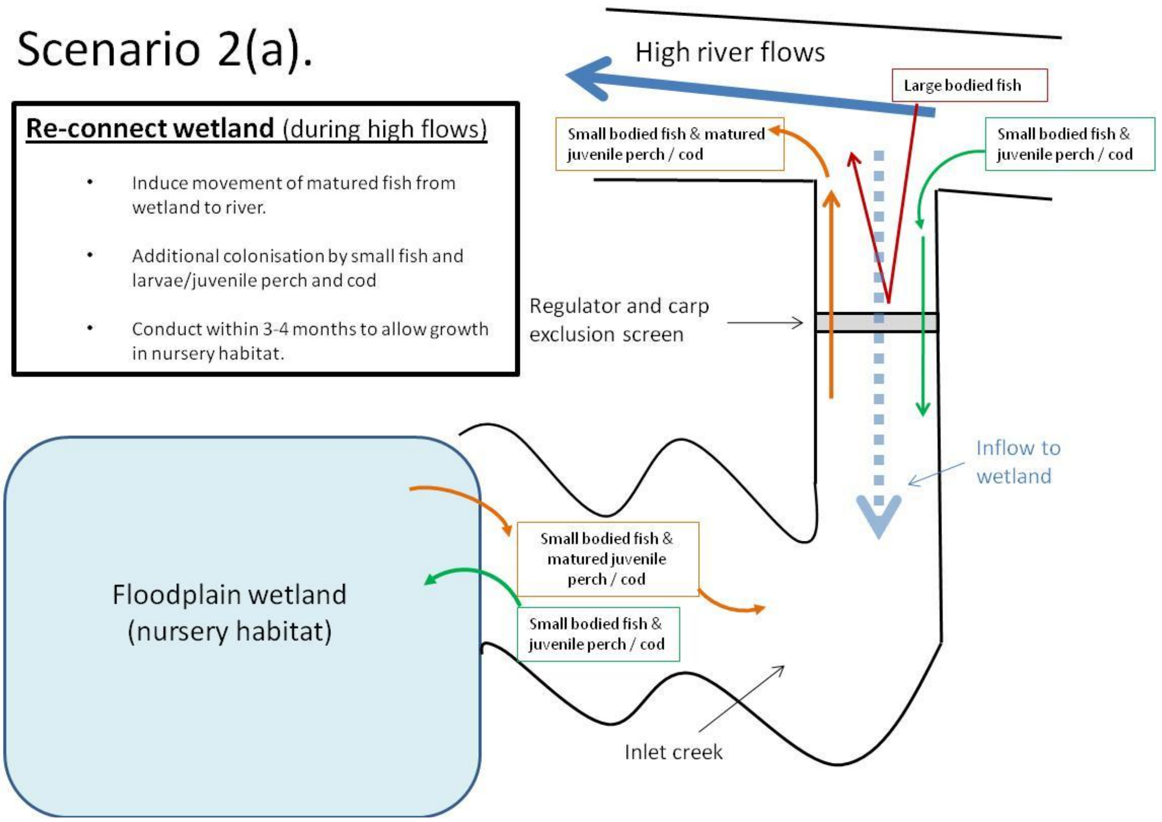

Figure 10. Conceptual Scenario 2(a) – expected fish movement when reconnecting a wetland during elevated river flows.

2. Reconnecting during low river flows

This assessment was conducted when river flows were low, and little head difference between the wetland and the river existed. Although the opening of the regulator during this assessment did result in movement of small native fish from the wetland, it did not induce the movement of juvenile Golden and Silver perch from wetland, increasing the risk of stranding for these developing fish.

The impacts of a managed drawdown and drying phase on these native fish may be minimised by:

- Timing the draw-down event (open the regulator) to occur when water levels in the wetland are considerably higher than the river. Mallen-Cooper (2004) suggest s an initial drop of 10-20 cm should create greater out-flow to the river due to differences in water level, and provide a cue for native species to leave the wetland.

- Further, imposing a managed draw-down when river flows are already low would increase the head difference between the wetland and the main river channel, and the resulting decrease in water level may be sufficient to stimulate native fish to move out of the wetland and reduce stranding.

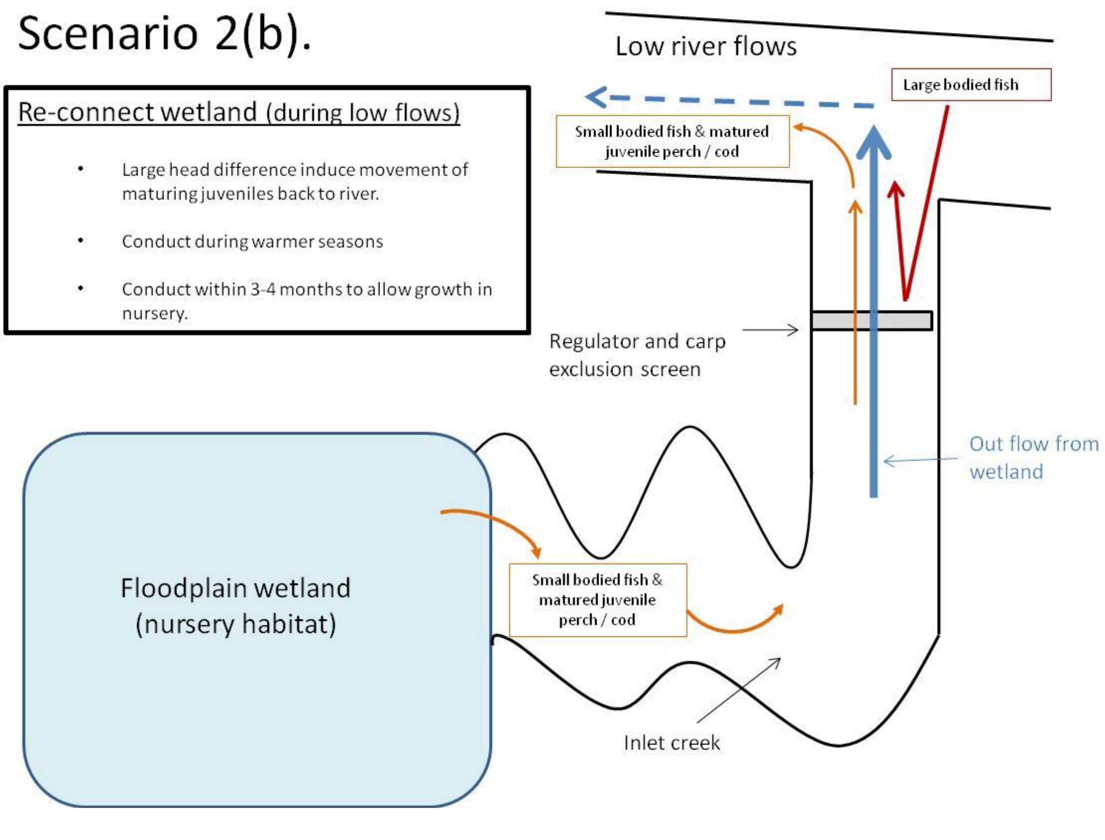

Figure 11. Conceptual Scenario 2(b) – Expected fish movement when reconnecting a wetland during elevated river flows.

Removal of creek blockages

Removal of physical blockages to movement at locations where it creates a barrier within the inlet/outlet creek is likely to increase the opportunity for movement of fish into and out of the wetland both through the provision of unimpeded passage, and also by increasing the flow rate through the inlet creek when the regulator is opened. Removal of blockages is also likely to reduce the instances of deoxygenating in corridors for fish movement such as the Margooya Lagoon inlet channel.

Additional research

Surcharging Margooya Lagoon (closing the regulator and filling via pumping) will create three important research opportunities:

1. to assess fish movement into the inlet creek (from the open water in the wetland) whilst the wetland is being pumped full, it may be possible to determine if fresh flows entering the wetland induce native fish in the wetland to move towards the river, as suggested in Scenario 2(a).

2. to determine if native fish are stimulated to migrate into the main river channel through the carp exclusion screen upon opening of the inlet/outlet regulator when a significant head-difference is apparent as in scenario 2(b). An initial drop (i.e. a head difference) of at least 10-20 cm should provide a cue for large bodied species to leave the wetland, while small bodied species are likely to continue to leave as it dries further (Mallen-Cooper, 2004).

3. By validating the models suggested here for fish movement in Margooya Lagoon, fish movement within other lentic channel wetlands of the Murray River floodplain could be modelled ; enhancing the management of important fish species throughout the Mallee CMA region.

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Appendix 1

Standardised data (catch per 20 net hours) for the abundance of each species moving into or out of Margooya Lagoon.

Date	Day of Experiment	site	Directional of movemnet	Carp gudgeon	Un-specked hardyhead	Golden perch	Silver perch	Goldfish	Common carp	Gambusia (Mosquito	Oriental weatherloach
14/04/2010	Day 0	M2	no movemnet - regulator closed	0	0	0	0	0	0	472	0
14/04/2010	Day 0	R1	no movemnet - regulator closed	3	13	1	0	1	1	102	0
15/04/2010	Day 1	M2	in to wetland	108	3	0	0	2	10	282	2
16/04/2010	Day 2	R1	out of wetland	1754	28	0	0	2	0	170	0
21/04/2010	Day 7	M2	in to wetland	25	0	0	0	1	7	24	0
22/04/2010	Day 8	R1	out of wetland	30	0	0	0	0	2	60	0