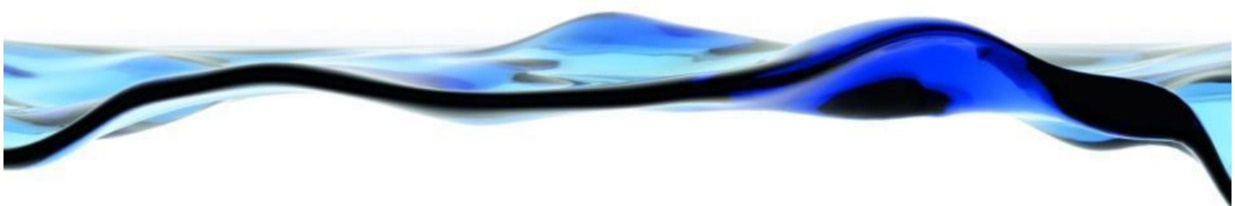
The Response Patterns of Wetland Fish Communities Following Prolonged Drought and Widespread Flooding

Thwaites, L. and Fredberg, J.

June 2014



Goyder Institute for Water Research

Technical Report Series No. 14/9

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia. The Institute will enhance the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

The following Associate organisation led the preparation of this report:

Enquires should be addressed to: Goyder Institute for Water Research
Level 1, Torrens Building
220 Victoria Square, Adelaide, SA, 5000
tel: 08-8303 8952
e-mail: enquiries@goyderinstitute.org

Citation

Thwaites, L. A. and Fredberg, J. F. (2014). *The response patterns of wetland fish communities following prolonged drought and widespread flooding.* Goyder Institute for Water Research Technical Report Series No. 14/9

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This study was part of the Murray Flood Ecology Project, which was funded by the Goyder Institute for Water Research. We wish to thank field staff from SARDI and the Natural Resources South Australian Murray-Darling Basin staff who assisted during the fieldwork, Dr Qifeng Ye for guidance and support throughout the implementation of the project and landholders who generously provided access to the projects wetlands. Finally, thanks to the SARDI reviewers and Dr Karl Hillyard (DEWNR) for improving early versions of this report.

EXECUTIVE SUMMARY

Off-channel floodplain habitats (i.e. wetlands, backwaters and anabranches) have long been recognised as important habitats for the flora and fauna of the Murray-Darling Basin (MDB). Ecologically, they are sites of high primary and secondary production, and contain diverse flora and fauna. Many riverine species are wholly or partially dependent on wetlands for food, shelter or habitat during some part of their life cycle, and they may act as a key source of dispersive offspring to the broader catchment. The wetland fish assemblages in the lower River Murray are some of the most diverse, and often include a large proportion of fish species with conservation significance. This highlights that healthy wetland habitats are integral for the rehabilitation of native fish populations.

Between 1996 and 2010 the MDB experienced one of the most severe droughts on record, termed the 'millennium drought'. The effects of this drought were particularly pronounced in the heavily regulated lower River Murray between 2007 and 2010. For example, inflows over lock 1 (Blanchetown) were reduced to lower evaporative loss in the barrage weir pool. This resulted in insufficient flows over lock 1 to maintain pool levels resulting in the drying of several previously permanently inundated off-stream habitats. During summer/autumn 2010-11, heavy rainfall throughout much of the southern MDB resulted in widespread flooding and the inundation of wetland habitats that had completely dried during the drought period. As the response of wetland fish communities within the lower River Murray to prolonged drying and re-wetting had not been evaluated, the flood event presented a unique opportunity. This project compared the autumn post-flood fish assemblages at 12 selected wetlands (three above, and nine below Lock 1; Blanchetown, SA) with before-flood data from the baseline surveys which occurred in 2005/06. This project aimed to build on previous and current research to determine the response patterns of various fish species following drought, focusing on the role that drying and re-wetting may have for a range of fish species (i.e. native vs. invasive, large-bodied vs. small-bodied).

A total of 4653 fish from 17 species, including 12 native species and five invasive species, were captured during autumn post-flood sampling (2012). Carp gudgeons and bony herring were the most abundant native species, while common carp and eastern gambusia were the most abundant invasive species. In comparison with the autumn before-flood baseline survey (2005-2006), there was a decrease in the total number of fish captured, a decrease in the total number of species recorded and a shift in the relative proportions of native and invasive species. Of the 12 wetlands sampled, six shifted from a native dominated fish assemblage to a post-flood invasive dominated assemblage. The overall change in the autumn post-flood fish assemblage was driven by a decrease in the relative abundance of native carp gudgeon, flathead gudgeon and invasive eastern gambusia and an increase in the relative abundance of common carp. The shift in the relative proportions of these small, medium and large-bodied species is associated with their specific life history strategies and changes in the available aquatic habitat and hydraulic regime (i.e. flow, drying, rewetting) resulting from both the prolonged drought and subsequent flooding.

Common carp displayed the greatest positive response to the flood with significant increases in relative abundance within seven of twelve wetlands. Given that common carp displayed the greatest response within the first year post-flooding, a similar response may be expected during future floodplain/wetland inundation. This will require careful management in order to disadvantage carp, while minimising impact and maximising benefits for native species (e.g. carp screens vs. native fish passage).

Further monitoring is required to evaluate the long-term response of native and invasive species to both natural and human induced inundation of individual floodplains/wetlands (i.e. timing and duration of off-channel fish movements). This monitoring should aim to determine the long-term persistence of both native and invasive species associated with the recent flooding event (i.e. aging, frequency distributions, etc).

INTRODUCTION

Background

Wetlands are off-main channel or floodplain habitats (ephemeral or permanent) including billabongs, swamps, backwaters, flood-runners and small/shallow natural lakes (MDBC 2005). Ecologically, they are sites of high primary and secondary production, and contain diverse flora and fauna. Many riverine species are wholly or partially dependent on wetlands for food, shelter or habitat during some part of their life cycle, and they may act as a key source of dispersive offspring to the broader catchment (Nichols and Gilligan 2004; Wilson 2005). Economically, wetlands fulfill various ecosystem services including the mitigation of floods (i.e. floodwater storage, reduction, attenuation), water supply, salinity interception, and pollutant reduction and water purification by filtering-out dissolved nutrients, fertilisers and pesticides.

Thirty-two fish species occur, or are known to have occurred, within wetlands of the Murray-Darling Basin (Closs et al. 2005; Smith and Hammer 2006). Five of these species are introduced invaders and 27 are native, including 11 species of regional conservation significance. The highest diversity of wetland fishes (88% of all species) occurs in the South Australian Murray-Darling Basin where diadromous species (congolli, *Pseudaphritis urvillii*; common galaxias, *Galaxias maculatus*; and small-mouthed hardyhead, *Atherinosoma microstoma*) contribute to species richness (Closs et al. 2005; Smith 2006; Smith and Hammer 2006). Of the introduced invaders, common carp (*Cyprinus carpio*), eastern gambusia (*Gambusia holbrooki*), redfin perch (*Perca fluviatilis*), and goldfish (*Carassius auratus*) all may be abundant in wetland habitats, but carp often dominate the biomass and are implicated in causing the greatest environmental impacts (Smith 2006).

The fact that many wetlands contain rare and threatened fish species, sometimes in high numbers, highlights the importance of healthy wetlands for the maintenance of species/biotic diversity. Rehabilitating wetland fish communities requires careful management of existing human-induced threats to wetlands, which include altered hydrological regimes, introduced invasive species, salinisation, eutrophication, habitat destruction and grazing (Smith and Fleer 2007). Some threats are more of an issue at the wetland or reach scale (grazing, eutrophication and to some extent, salinisation), but altered hydrological regimes and invasive species are intimately related, and both are problematic at the catchment scale (Gehrke et al. 1995). The threat to wetland fish communities can be compounded or potentially ameliorated (at least in the short-term) by natural events including drought and flood.

The relative importance of floodplain inundation for the spawning and recruitment of native species is a subject of ongoing research (e.g. Junk et al. 1989; Humphries et al. 1999). For example, Humphries et al. (1999) proposed the “low flow recruitment” hypothesis which attempts to explain why some species spawn during the warmest months and lowest flows and how they are able to recruit under these conditions within the main river channel. The authors speculate that inundated floodplains may not provide ideal habitat for fish spawning and recruitment due to varying spatial and temporal degrees of connectivity, potentially lethal concentrations of leachates, low levels of dissolved oxygen and varying densities of prey items (see Humphries et al. 1999). In addition, it is possible that large floods that coincide with spawning periods may cause higher than normal mortality by displacing eggs, embryos and larvae from nesting and nursery areas (Humphries et al. 1999). However, Junk et al. (1989) proposed the flood pulse concept which hypothesizes that the predictable inundation of floodplain habitats is key to the maintenance of species/biotic diversity and for the production of food and animal biomass (including fish i.e. spawning and recruitment). Indeed, flooding is considered essential for stimulating primary and secondary production through nutrient release which ultimately enhances recruitment in fish communities (Junk et al. 1989; Ribeiro et al. 2004; Balcombe and Arthington 2009).

Between 1996 and 2010, the Murray-Darling Basin (MDB) experienced one of the most severe droughts on record, termed the 'millennium drought' (Murphy and Timbal 2008; Ummenhofer et al. 2009; Figure 1). During this period, mean annual rainfall and run-off were approximately 16% and 39% lower respectively, than the previous long-term average (Murphy and Timbal 2008; Potter et al. 2008) and inflows to the River Murray system were approximately 42% below average. The effects of this drought were pronounced in the heavily regulated lower River Murray between 2007 and 2010. For example, inflows over lock 1 (Blanchetown) were reduced to lower evaporative loss in the barrage weir pool. This resulted in insufficient flows over lock 1 to maintain pool levels resulting in the drying of several previously permanently inundated off-stream habitats. During summer/autumn 2010-11, heavy rainfall throughout much of the southern MDB resulted in widespread flooding and inundation of wetland habitats that had completely dried during the drought period. As the response of wetland fish communities within the lower River Murray to prolonged drying and re-wetting had not been evaluated, the flood event presented a unique opportunity.

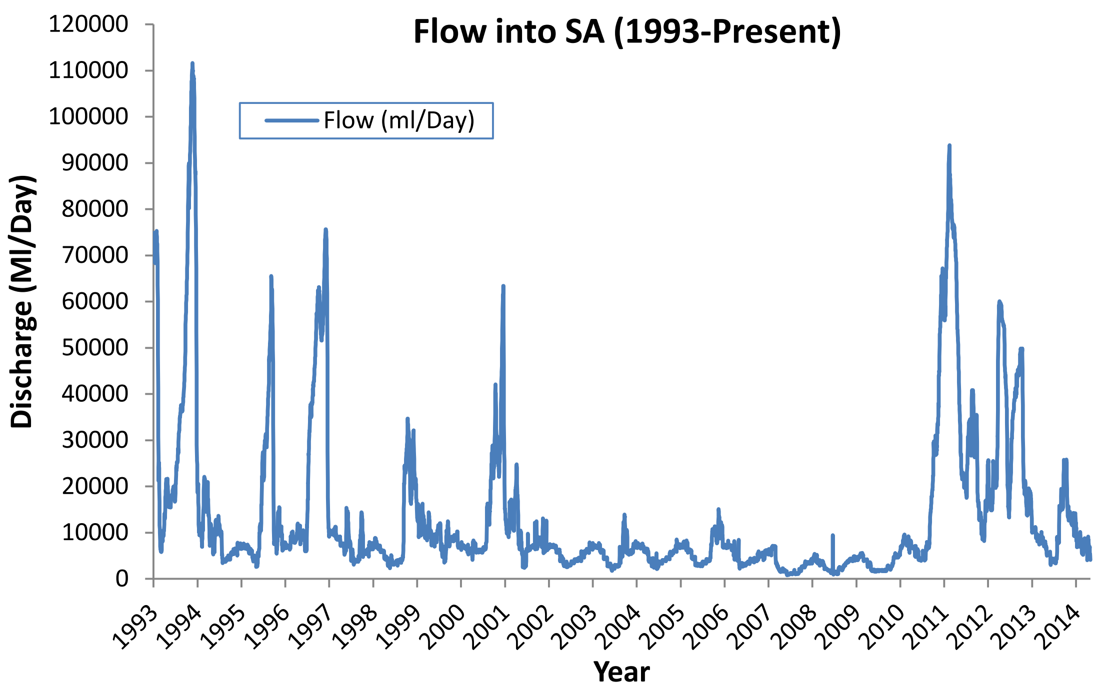


Figure 1. Flow in South Australia (discharge; Ml/day) from 1993 to autumn 2014.

The South Australian River Murray Wetlands Baseline Surveys (RMWBS) were the most comprehensive wetlands surveys undertaken in the MDB (Closs et al. 2005). At each wetland, bi-annual (spring and autumn) baseline data on the site characteristics, fish, and water quality were collected. These data, collected during drought conditions, provide an ideal comparative baseline to determine the flood response of wetland fish communities within the lower River Murray.

Objectives

This project aims to build on previous studies to determine the response patterns of various fish species following drought, focusing on the role that drying and re-wetting (flooding) may have for a range of fish species (i.e. native vs. invasive, large-bodied vs. small-bodied). This project compared the autumn post-flood fish assemblages at 12 selected wetlands (three above, and nine below Lock 1; Blanchetown, SA) with before-flood data from the baseline surveys which occurred in 2005/06.

Specifically the objectives were to determine:

- Short to medium-term spatial and temporal response patterns of key species and wetland fish communities following inundation.

- How invasive species respond in comparison to native species.

METHODS

Study sites

In total, 12 wetlands which had been previously sampled during drought conditions were sampled for fish and water quality data (Figure 2, Table 1, Appendix A). Wetlands were located in one of the following regions: the Floodplain region (Berri to Overland Corner), the Murray Gorge region (Overland Corner to Mannum) and the Lower Swamps/Lower Lakes region (Mannum to Lake Alexandrina). Sampling occurred before flooding (BF) in autumn (March/April 2005/2006) for all 12 wetlands and was again repeated post flooding (PF) during autumn (February to April 2012) (Table 1).

Figure 2. Google Earth image showing the location of 12 wetlands surveyed before-flood (2005-2006) and post-flood (2011-2012). Red place marks indicate specific regions: Floodplain- Berri to Overland Corner, the Murray Gorge region- Overland Corner to Mannum and the Lower Swamps/Lower Lakes region- Mannum to Lake Alexandrina.

Site selection within wetlands

An initial inspection of each wetland was used to identify major habitat types for fish (e.g. emergent littoral-vegetation, submerged and overhanging vegetation, rocks, woody debris including fallen red gums (*Eucalyptus camaldulensis*) and complex fallen branches, open water, inlet/outlet channels, bare bank), and any obvious site variations related to disparities in hydro-geography (Tables 1, 2 and 3). Up to six sampling sites were then chosen in each wetland to encompass the range of available habitat, and one fishing method (with replication) was used at each site. Thus, sites were selected to optimise the diversity of fish sampled; the aim was not to catch as many fish as possible, but to sample as many habitats as possible to ensure we sampled the entire fish community (all species including small and large-bodied fish, and most life stages) and to limit the possibility that rare species might be missed.

Fish sampling - gear and protocols

Complementary sampling gear (fyke nets - 6 m funnel, 80 cm diameter entrance, 6 m x 80 cm deep leader, 6 chambers, single wing and fine 8 mm stretched mesh, gill nets - 15 m long x 1 m deep, 3 x 5 m panels of 3, 4 and 5” monofilament mesh and bait traps - 40 cm x 24 cm wide x 24 cm deep, 7 cm diameter entrance holes, 8 mm green mesh and unbaited) was used across wetland habitats (Tables 1, 2 and 3). Methods used at each sampling site and the number of sites sampled per wetland (n = 3-6) depended on the available habitat. At each sampling location a combination of either 3-6 replicate fyke nets, 3-6 replicate gill nets or 5-10 replicate bait traps were used. Nets were set in the mid-late afternoon and left overnight for approximately 17 hours (Tables 1, 2 and 3). Upon retrieval, total length (TL, mm) was measured for the first 30 fish of each species and the remainder were counted and visually inspected for rare/threatened species. All native fish were released.

Fyke nets are very efficient at sampling small and large-bodied wetland fish, generally capturing several hundred fish per net, per night. As a result, sub-sampling was required at some sites for reasons of animal welfare and to ensure the timely completion of sample processing. Catch data were estimated from sub-samples through extrapolation.

Water quality

At each sampling site, four water quality parameters were recorded: dissolved oxygen (DO, mg L^{-1}); conductivity (concentration of soluble ions, µs cm^{-1}), pH and water temperature (°C). All parameters were recorded on a pre-calibrated TPS-90 water quality meter (TPS Pty Ltd, Springwood, Brisbane, Australia).

Table 1. Summary table describing the dates (BF=Before-Floods, PF=Post-Floods), season, gear type (No. of replicates), average hours fished and habitats (Open= Open Water, Edge= Wetland Edge, Inlet= Inlet Channel and Outlet= Outlet Channel), for all individual wetlands within the Floodplain region.

Wetland/Region	Date *(BF,PF)*	Season	Gear Type	Avg. Hrs Fished	Habitat
Floodplain					
Spectacle Lakes	06-Apr-05 (BF)	Autumn	3 x Gill Nets	15.25	3x Inlet
			6 x Fyke Nets	15	6x Inlet
			10 x Bait Traps	14	10x Inlet
	19-Mar-12 (PF)	Autumn	3 x Gill Nets	17.5	3x Inlet
			6 x Fyke Nets	17	6x Edge
			5 x Bait Traps	15.5	5x Inlet
Yatco	07-Apr-05 (BF)	Autumn	6 x Gill Nets	14.6	3x Open/ 3x Edge
			6 x Fyke Nets	14.1	3x Open/ 3x Edge
			10 x Bait Traps	15.25	10x Edge
	18-Mar-12 (PF)	Autumn	3 x Gill Nets	15	3x Open
			6 x Fyke Nets	15	3x Open/ 3x Edge
			5 x Bait Traps	19.5	5x Edge
Overland Corner	N/A* (BF)	Autumn	N/A*	N/A*	N/A*
	28-Feb-12 (PF)	Autumn	0x Gill Nets	N/A*	N/A*
			6x Fyke Nets	20	6x Inlet
			5x Bait Traps	19	5x Inlet

Note- **N/A=** No sampling occurred.

Table 2. Summary table describing the dates (BF=Before-Floods, PF=Post-Floods), season, gear type (No. of replicates), average hours fished and habitats (Open= Open Water, Edge= Wetland Edge, Inlet= Inlet Channel and Outlet= Outlet Channel), for all individual wetlands within the Murray Gorge region.

Wetland/Region	Date *(BF,PF)*	Season	Gear Type	Avg. Hrs Fished	Habitat
Murray Gorge					
Sweeny's Lagoon	30-Mar-05 (BF)	Autumn	0x Gill Nets	N/A*	N/A*
			2x Fyke Nets	13.5	2x Edge
			5x Bait Traps	13.5	5x Edge
	29-Feb-12 (PF)	Autumn	3x Gill Net	16.5	3x Inlet
			6x Fyke Net	17	3x Inlet
			0x Bait Traps	N/A*	N/A*
Noonawirra	10-Apr-06 (BF)	Autumn	6x Gill Nets	16.75	3x Inlet/ 3x Open
			9x Fyke Nets	17	6x Inlet/ 3x Edge
			10x Bait Traps	16.75	5x Inlet/ 5x Open
	13-Mar-12 (PF)	Autumn	3x Gill Net	17	3x Open
			6x Fyke Net	17.25	3x Inlet/ 3x Edge
			5x Bait Traps	16	5x Edge
Devon Downs North	11-Apr-06 (BF)	Autumn	3x Gill Nets	18.5	3x Open
			9x Fyke Nets	18.5	6x Inlet/ 3x Edge
			5x Bait Traps	18.5	5x Open
	27-Mar-12 (PF)	Autumn	3x Gill Net	18	3x Open
			6x Fyke Net	18.75	3x Inlet/ 3x Edge
			5x Bait Traps	18.5	5x Outlet
Saltbush Flat	12-Apr-06 (BF)	Autumn	6x Gill Nets	17.37	3x Open/ 3x Edge
			6x Fyke Nets	17.75	3x Open/ 3x Edge
			5x Bait Traps	18	5x Edge
	13-Mar-12 (PF)	Autumn	6x Gill Net	26	3x Open/ 3x Edge
			6x Fyke Net	27.25	3x Open/ 3x Edge
			5x Bait Traps	24	5x Inlet
Lake Carlet	31-Mar-05 (BF)	Autumn	6x Gill Nets	18	6x Open
			6x Fyke Nets	16	6x Edge
			10x Bait Traps	18.25	5x Inlet/ 5x Open
	26-Mar-12 (PF)	Autumn	6x Gill Net	18.75	3x Inlet/ 3x Edge
			6x Fyke Net	19	6x Edge
			5x Bait Traps	20	5x Edge

Table 3. Summary table describing the dates (BF=Before-Floods, PF=Post-Floods), season, gear type (No. of replicates), average hours fished and habitats (Open= Open Water, Edge= Wetland Edge, Inlet= Inlet Channel and Outlet= Outlet Channel), for all individual wetlands within the Lower Swamps and Lower Lakes region.

Wetland/Region	Date *(BF,PF)*	Season	Gear Type	Avg. Hrs Fished	Habitat
Lower Swamps					
Reedy Creek	17-Mar-05 (BF)	Autumn	6x Gill Nets	16.75	3x Inlet/ 3x Edge
			6x Fyke Nets	16.75	3x Inlet/ 3x Edge
			10x Bait Traps	16.37	5x Inlet/ 5x Edge
	15-Mar-12 (PF)	Autumn	3x Gill Net	23.5	3x Edge
			6x Fyke Net	17.75	3x Outlet/ 3x Edge
			5x Bait Traps	24.5	5x Edge
Rocky Gully	15-Mar-05 (BF)	Autumn	6x Gill Nets	15	3x Inlet/ 3x Edge
			6x Fyke Nets	16.75	6x Inlet
			5x Bait Traps	13.75	5x Edge
	24-Feb-12 (PF)	Autumn	3x Gill Net	22	3x Inlet
			3x Fyke Net	16	3x Inlet
			0x Bait Traps	N/A*	N/A*
Murrundi	22-Mar-05 (BF)	Autumn	6x Gill Nets	15.75	3x Inlet/ 3x Edge
			6x Fyke Nets	16.5	3x Inlet/ 3x Edge
			10x Bait Traps	16	5x Inlet/ 5x Edge
	15-Mar-12 (PF)	Autumn	3x Gill Net	21.5	3x Inlet
			6x Fyke Net	22	3x Inlet/ 3x Edge
			0x Bait Traps	N/A*	N/A*
Lower Lakes					
Pelican Lagoon	23-Mar-05 (BF)	Autumn	6x Gill Nets	19.25	3x Inlet/ 3x Open
			6x Fyke Nets	18.5	3x Inlet/ 3x Open
			10x Bait Traps	18	10x Edge
	02-Apr-12 (PF)	Autumn	3x Gill Net	17	3x Open
			6x Fyke Net	19.25	3x Inlet/ 3x Edge
			5x Bait Traps	20	5x Open

Data analysis

Fish assemblage data collected during the post-flooding events in autumn 2012 was compared to those collected before flooding in autumn 2005/2006 (Smith 2006). All multivariate analyses were performed using the PRIMER v6.12 package (Clake and Gorley 2001). Data collection in 2012 (PF) was conducted between February to April; while data collection in 2005/2006 (BF) was conducted in March and April respectively.

Descriptive statistics

Catch per unit effort (CPUE) for each wetland and sampling event was standardised to the number of fish captured per hour (fish h^{-1}) for each individual gear type (i.e. fyke net, gill net or bait trap) (Equation 1). Combined catch per unit effort (CCPUE, fish h^{-1}) was calculated for each wetland and sampling event by summing the CPUE for each individual gear type used within that wetland (i.e. fyke net CPUE + gill net CPUE +bait trap CPUE).

$$CPUE = \frac{\text{Total catch per gear type}}{(\text{No.of each indivdual gear type per wetland} \times \text{soak time (average hours)})}$$ ………………………………Equation 1

Species richness is presented as the total number of species captured across all gear types per wetland and for all wetlands combined for both before and post flood sampling events. The relative proportion (%) and changes in relative abundance (%) of native and invasive species within the total catch for all wetlands combined and for individual wetlands for both before and post flood surveys was also calculated.

Multivariate analyses

Multivariate analyses were undertaken using the statistical software packages PRIMER v. 6.12 and PERMANOVA+ (Anderson et al. 2008). Permutational analysis of variance (PERMANOVA) (Anderson 2001) was used to test whether the fish assemblage structure differed between years (before and post-flooding) and among wetlands for autumn samples. Prior to analyses, data transformation (log(x+1)) was performed on the relative abundances of fish from each gear type to down-weight the excessive influence of highly abundant species. In the case of significant interaction between year and wetland factors PERMANOVA pair-wise analyses for fish assemblage structure was performed on each individual wetland to detect any differences in fish assemblage before and post-flooding. When differences occurred between fish assemblages between years (before-flood vs. post-flood), similarity percentages (SIMPER) analysis was undertaken to determine the fish species contributing most to the dissimilarities (Clarke and Warwick 2001).

Principal coordinates (PCO) analysis for the ordination of samples in multivariate space was performed with vector overlays to indicate species that are correlated (Spearman rank correlation, $\rho > 0.3$) with the ordination axes. To model the relationship(s) between fish assemblage structure, as described by the Bray-Curtis resemblance matrix, and one or more environmental, physical and management predictor variables, we used the DistLM (distance-based linear models) routine based on the forward selection procedure using R^2 as the selection criterion (Akaike 1973; Burnham and Anderson 2002). Forward selection begins with a null model, containing no predictor variables. The predictor variable with the best value for the selection criterion is chosen first, followed by the variable that, together with the first, improves the selection criterion the most, and so on.

RESULTS

Fish assemblage comparisons - before and post-flooding

A total of 4653 fish from 17 species, including 12 native species (40.1% of total catch, TC) and five invasive species (59.8% TC), were captured during autumn post-flood sampling (2012) (Table 4). Carp gudgeons (*Hypseleotris* spp.) (*n*=816; 17.5% TC) and bony herring (*Nematolosa erebi*) (*n*=695; 14.9% TC) were the most abundant native species, while common carp (*n*=1501; 32.3% TC) and eastern gambusia (*n*=1141; 24.5% TC) were the most abundant invasive species. In comparison with the autumn before-flood baseline survey (2005-2006), there was a decrease in the total number of fish captured (BF, *n*=6571), a decrease in the total number of species recorded (BF, *n*=20) and a shift in the relative proportions of native and invasive species (BF, native=73.4% TC; invasive=26.6% TC). Before-flood, carp gudgeons (*n*=1700; 25.9% TC) and bony herring (*n*=1028; 15.6% TC) were the most abundant native species, while eastern gambusia (*n*=1485; 22.6% TC) and common carp (*n*=196; 3% TC) were the most abundant invasive species. Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 3. While 14 species were captured in both before-flood and post-flood sampling; bluespot goby (*Pseudogobius olorum*), lagoon goby (*Tasmanogobius lasti*), Murray hardyhead (*Craterocephalus fluviatilis*), sandy sprat (*Hyperlophus vittatus*), smallmouthed hardyhead and southern pygmy perch (*Nannoperca australis*) were only recorded before-flood and congolli, silver perch (*Bidyanus bidyanus*) and tench (*Tinca tinca*) were only recorded post-flood (Figure 3 and Table 4). PERMANOVA comparisons between before-flood and post-flood surveys for relative abundance across all gear types are presented in Table 5. Given that there is significant interaction between wetland and year for each gear type further catch comparisons are presented on a site by site basis (see below) for each region (i.e. Floodplain, Murray Gorge, Lower Swamps and Lower Lakes).

Table 4. Catch summary of species and number of fish sampled in all wetlands during autumn (all gear types combined), before-floods (BF-2005/06) and post-floods (PF-2012).

	Species		Counts	
	Common Name	**Scientific Name**	**BF**	**PF**
Native species	Australian smelt	*Retropinna semoni*	262	19
	Bluespot goby	*Pseudogobius olorum*	1	0
	Bony herring	*Nematolosa erebi*	1028	695
	Carp gudgeons	*Hypseleotris* spp.	1700	816
	Common galaxias	*Galaxias maculatus*	58	2
	Congolli	*Pseudaphritis urvilli*	0	10
	Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	42	2
	Flat-headed gudgeon	*Philypnodon grandiceps*	910	172
	Freshwater catfish	*Tandanus tandanus*	3	2
	Golden perch	*Macquaria ambigua*	47	48
	Lagoon goby	*Tasmanogobius lasti*	159	0
	Murray hardyhead	*Craterocephalus fluviatilis*	7	0
	Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	197	3
	Sandy sprat	*Hyperlophus vittatus*	1	0
	Silver perch	*Bidyanus bidyanus*	0	1
	Smallmouthed hardyhead	*Atherinosoma microstoma*	5	0
	Southern pygmy perch	*Nannoperca australis*	2	0
	Un-specked hardyhead	*Craterocephalus stercusmuscarum fulvus*	401	98
Invasive Species	Common carp	*Cyprinus carpio*	196	1501
	Eastern gambusia	*Gambusia holbrooki*	1485	1141
	Goldfish	*Carassius auratus*	51	97
	Redfin perch	*Perca fluviatilis*	16	45
	Tench	*Tinca tinca*	0	1
	Total number of fish		**6571**	**4653**
	Count of Species		**20**	**17**
	Overall Fish		**11224**	
	Overall Species		**23**	

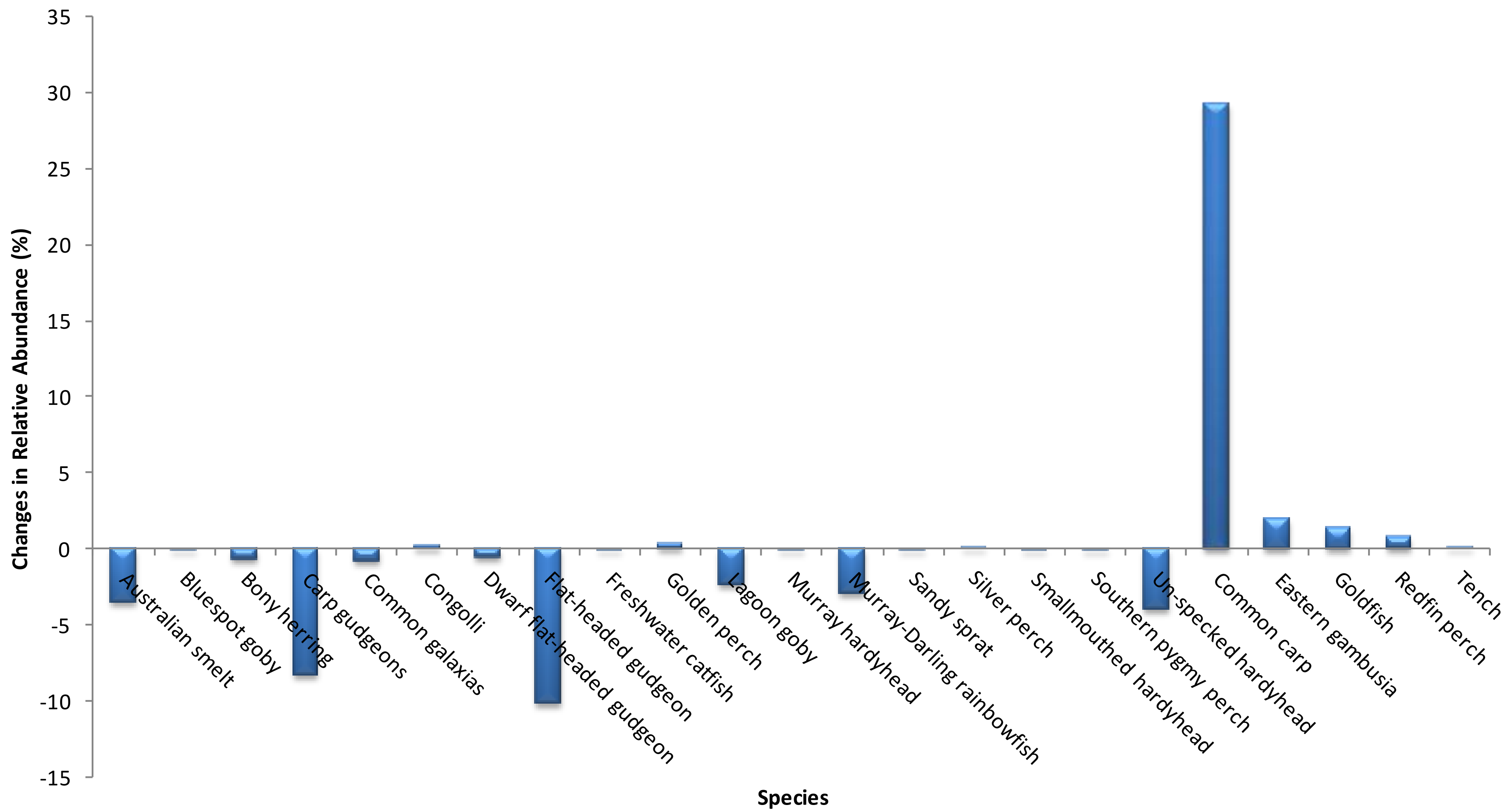


Figure 3. Changes in relative abundance (%) between sampling rounds across all wetlands (Post-flood % TC – Before-flood % TC).

Table 5. PERMANOVA results for fish assemblage comparison (log transformed relative abundance data) between years (before and post-flooding) and wetlands for each gear type based on autumn catches. Bold p-values are significant.

Gear Type	Source of Variation	Relative Abundance (CPUE)		
		df	MS	P(perm)
Gill Net	Wetland	9	685.6	0.065
	Year	1	1309.1	**0.001**
	Wetland x Year	9	280.34	**0.001**
	Residuals	70	83.099	
Fyke Net	Wetland	10	4890.5	0.159
	Year	1	2904.2	**0.001**
	Wetland x Year	10	2477.1	**0.001**
	Residuals	109	1178.5	
Bait Trap	Wetland	7	982.23	0.086
	Year	1	395.85	**0.009**
	Wetland x Year	7	486.77	**0.001**
	Residuals	94	64.458	

Individual Wetland Comparisons - Floodplain

Spectacle Lakes

A total of 687 fish (Combined CPUE, CCPUE=6.98 fish h^{-1}) from seven species, including four native species (21.8% of total catch, TC) and three invasive species (78.2% TC), were captured during autumn post-flood sampling (March 2012) (Table 6 and Table 7). Bony herring (*n*=93; 13.5% TC) and carp gudgeons (*n*=53; 7.7% TC) were the most abundant native species, while eastern gambusia (*n*=333; 48.5% TC) and common carp (*n*=189; 27.5% TC) were the most abundant invasive species. In comparison with the autumn before-flood baseline survey (April 2005), there was an increase in the total number of fish captured (BF, *n*=464), an increase in CCPUE (BF, 5.13 fish h^{-1}) an increase in the total number of species recorded (BF, *n*=5) and a shift in the relative proportions of native and invasive species (BF, native=44.4% TC; invasive=55.6% TC). Before-flood, bony herring (*n*=118; 25.4% TC) and carp gudgeons (*n*=86; 18.5% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=257; 55.4% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 4. All five species captured before-flood were captured post-flood with the addition of golden perch (*Macquaria ambigua*) and common carp (Figure 4 and Table 6). There were significant differences in fish assemblage structure (species composition and relative abundance) between before-flood and post-flood catches for bait traps ($p<0.05$) (Table 8). The observed difference in bait trap catches was primarily due to an increase in the relative abundance of carp gudgeons and to a lesser extent eastern gambusia (Table 9). Water quality parameters for before-flood and post-flood surveys are presented in Table 11. In comparison to the before-flood survey there was an increase in pH, temperature and DO and a decrease in salinity.

Yatco

A total of 393 fish (CCPUE=4.68 fish h^{-1}) from nine species, including six native species (24.4% TC) and three invasive species (75.6% TC), were captured during autumn post-flood sampling (March 2012) (Table 6 and Table 7). Bony herring were the most abundant native species (*n*=70; 17.8% TC), while common carp were the most abundant invasive species and dominated the total catch (*n*=252; 64.1% TC). In comparison with the autumn before-flood baseline survey (April 2005), there was an increase in the total number of fish captured (BF, *n*=301), an increase in CCPUE (BF, 3.51 fish h^{-1}), a decrease in the total number of species recorded (BF, *n*=12) and a shift in the relative proportions of native and invasive species (BF, native=93.7% TC; invasive=6.3% TC). Before-flood, bony herring (*n*=95; 31.6% TC) and Australian smelt (*Retropinna semoni*) (*n*=89; 29.6% TC) were the most abundant native species, while common carp were the most abundant invasive species (*n*=7; 2.3% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 4. While nine species were captured in both before-flood and post-flood sampling, dwarf flat-headed gudgeon (*Philypnodon macrostomus*), flat-headed gudgeon (*Philypnodon grandiceps*) and redfin perch were only recorded during before-flood sampling (Figure 4 and Table 6). There were significant differences in fish assemblage structure between before-flood and post-flood catches for both gill nets ($p<0.05$) and fykes nets ($p<0.05$) (Table 8). The observed difference in gill net catches was primarily due to a decrease in the relative abundance of bony herring and redfin perch and an increase in the relative abundance of common carp while the difference in fyke net catches was primarily due to an increase in the relative abundance of common carp, bony herring and goldfish and a decrease in the relative abundance of Australian smelt, un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*) and Murray-Darling rainbow fish (*Melanotaenia fluviatilis*) (Table 10). Water quality parameters for before and post flood surveys are presented in Table 11. In comparison to the before-flood survey there was an increase in temperature, a decrease in salinity and comparably little difference in pH and DO.

Overland Corner

A total of 486 fish (CCPUE=4.34 fish h^{-1}) from seven species, including four native species (32.5% TC) and three invasive species (67.5% TC), were captured during autumn post-flood sampling (February 2012) (Table 6 and Table 7). Carp gudgeons were the most abundant native species (*n*=142; 29.2% TC), while eastern gambusia (*n*=268; 55.1% TC) and to a lesser extent common carp (*n*=53; 10.9% TC) were the most abundant invasive species. Overland Corner represents the only wetland of the 12 surveyed post-flood where dwarf flat-headed gudgeon where recorded. There is no scope for comparison with the wetlands before-flood fish assemblage as autumn sampling did not occur during 2005/06.

Table 6. Catch summary of individual wetlands sampled in autumn (all gear types combined), before-floods (BF-2005/06) and post-floods (PF-2012) in the Floodplain section of the Murray River, South Australia.

Species	**Spectacle Lakes (counts)**		**Yatco (counts)**		**Overland Corner* (counts)**	
	BF	**PF**	**BF**	**PF**	**BF**	**PF**
Native species						
Australian smelt	-	-	89	3	N/A	-
Bluespot goby	-	-	-	-	N/A	-
Bony herring	118	93	95	70	N/A	8
Carp gudgeons	86	53	5	7	N/A	142
Common galaxias	-	-	-	-	N/A	-
Congolli	-	-	-	-	N/A	-
Dwarf flat-headed gudgeon	-	-	1	-	N/A	2
Flat-headed gudgeon	-	-	9	-	N/A	-
Freshwater catfish	-	-	-	-	N/A	-
Golden perch	-	2	1	6	N/A	-
Lagoon goby	-	-	-	-	N/A	-
Murray hardyhead	-	-	-	-	N/A	-
Murray-Darling rainbowfish	-	-	17	1	N/A	-
Sandy sprat	-	-	-	-	N/A	-
Silver perch	-	-	-	-	N/A	-
Smallmouthed hardyhead	-	-	-	-	N/A	-
Southern pygmy perch	-	-	-	-	N/A	-
Un-specked hardyhead	2	2	65	9	N/A	6
Invasive Species						
Common carp	-	189	7	252	N/A	53
Eastern gambusia	257	333	6	7	N/A	268
Goldfish	1	15	1	38	N/A	7
Redfin perch	-	-	5	-	N/A	-
Tench	-	-	-	-	N/A	-
Total number of fish	**464**	**687**	**301**	**393**	**N/A**	**486**
Count of Species	**5**	**7**	**12**	**9**	**N/A**	**7**
Overall Fish	**1151**		**694**		**486**	
Overall Species	**7**		**12**		**7**	

Note No comparable data available for Overland Corner in autumn, as no sampling occurred at this wetland in 05’/06 (BF, before-flooding)

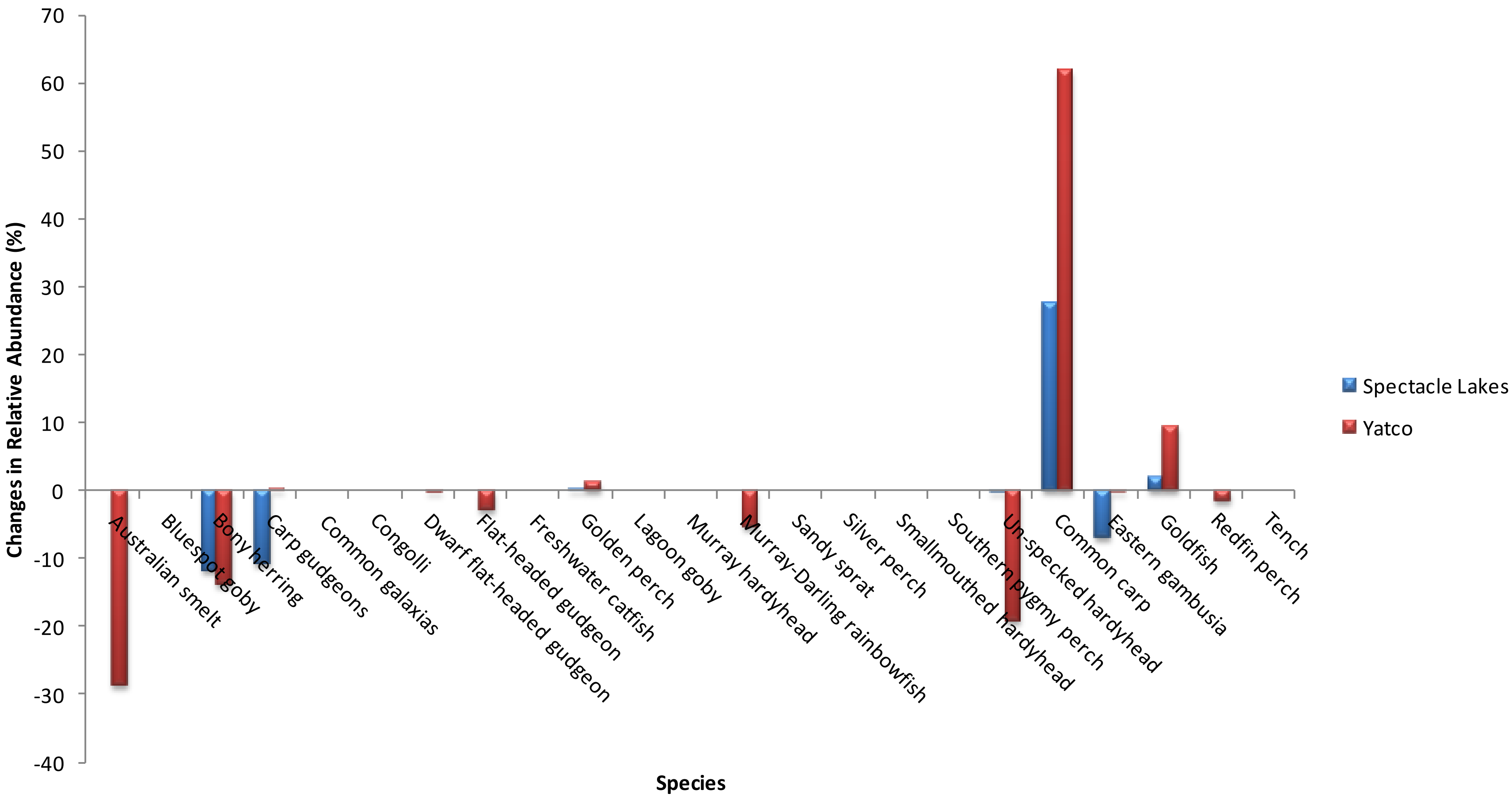


Figure 4. Changes in relative abundance (%) between sampling rounds for the Floodplain region wetlands (Post-flood % TC – Before-flood % TC).

Table 7. Summary table describing the dates (BF=Before-Floods, PF=Post-Floods), season, gear type (No. of replicates), average hours fished, total hours fished per gear type, total number of fish captured for each gear type and the CPUE standardized to one hour soak time of a single net/trap, for all individual wetlands sampled during autumn within the Floodplain region.

Region-Wetland	Date *(BF,PF)*	Season	Gear Type	Avg. Hrs Fished	Total hrs	No. Fish	CPUE
Floodplain							
Spectacle Lakes	06-Apr-05 (BF)	Autumn	3 x Gill Nets	15.25	45.75	0	0.00
			6 x Fyke Nets	15	90	457	5.08
			10 x Bait Traps	14	140	7	0.05
					Combined CPUE		**5.13**
	19-Mar-12 (PF)	Autumn	3 x Gill Nets	17.5	52.5	19	0.36
			6 x Fyke Nets	17	102	645	6.32
			5 x Bait Traps	15.5	77.5	23	0.30
					Combined CPUE		**6.98**
Yatco	07-Apr-05 (BF)	Autumn	6 x Gill Nets	14.6	87.6	89	1.02
			6 x Fyke Nets	14.1	84.6	209	2.47
			10 x Bait Traps	15.25	152.5	3	0.02
					Combined CPUE		**3.51**
	18-Mar-12 (PF)	Autumn	3 x Gill Nets	15	45	29	0.64
			6 x Fyke Nets	15	90	364	4.04
			5 x Bait Traps	19.5	97.5	0	0.00
					Combined CPUE		**4.68**
Overland Corner	N/A* (BF)	Autumn	-	-		-	-
	28-Feb-12 (PF)	Autumn	0x Gill Nets	-		-	-
			6x Fyke Nets	20	120	357	2.98
			5x Bait Traps	19	95	129	1.36
					Combined CPUE		**4.34**

Note- **N/A=** No sampling occurred.

Table 8. PERMANOVA pair-wise test of relative abundance (CPUE) for each gear type and wetland (Log transformed data) sampled before and post-flooding in the Murray River, South Australia. Bold p-values are significant.

	Abundance (CPUE) before and post-floods					
	Gill Net		Fyke Net		Bait Traps	
Wetlands	**t**	**P**	**t**	**P**	**t**	**P**
Floodplain						
Spectacle Lakes	2.4186	0.105	1.5967	0.091	2.1622	**0.017**
Yatco	2.0607	**0.036**	2.6975	**0.004**	Negative*	Negative*
Murray Gorge						
Sweeny's Lagoon	N/A*	N/A*	2.7292	**0.045**	N/A*	N/A*
Noonawirra	2.4582	**0.035**	2.8261	**0.001**	0.4516	0.8
DDN	2.391	0.089	2.2946	**0.003**	1.5673	0.205
Saltbush Flats	3.7272	**0.005**	1.6741	0.062	2.6869	**0.027**
Lake Carlet	2.4927	**0.008**	4.0941	**0.003**	1.151	0.264
Lower Swamps						
Reedy Creek	2.2131	**0.025**	0.93583	0.449	0.81379	0.766
Rocky Gully	2.0487	**0.044**	2.766	**0.017**	N/A*	N/A*
Murrundi	1.2023	0.288	1.3793	**0.015**	N/A*	N/A*
Lower Lakes						
Pelican Lagoon	0.7617	0.655	1.3557	0.15	1.3836	0.18

***Note*- N/A=** No sampling occurred for that gear type, **Negative=** No fish caught in that gear type in post flood years, **Dem is 0=** Same number and diversity of species found in both before flood and post flood years.

Table 9. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events for Spectacle Lakes sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Floodplain						
Spectacle Lakes						
Bait Trap						***(95.02)***
	Hypseleotris spp.	0.05	0.19	2.28	72.28	72.28
	Gambusia holbrooki	0	0.1	0.94	27.72	100

Table 10. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events for Yatco Lagoon sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Floodplain						
Yatco						
Gill Net						***(47.74)***
	Nematolosa erebi	0.92	0.36	1.54	58.21	58.21
	Cyprinus carpio	0.05	0.27	2.17	31.43	89.63
	Perca fluviatilis	0.06	0	0.82	6.73	96.37
Fyke Net						***(86.23)***
	Cyprinus carpio	0.04	2.58	1.75	44.7	44.7
	Retropinna semoni	1.07	0.03	1.02	14.14	58.85
	Craterocephalus stercusmuscarum fulvus	0.78	0.11	1.01	10.39	69.24
	Nematolosa erebi	0.19	0.59	1.38	10.37	79.61
	Carassius auratus	0.01	0.43	0.95	8.23	87.84
	Melanotaenia fluviatilis	0.21	0.01	0.53	3.94	91.78

Table 11. Water quality ranges for before (BF) and post (PF) flooding of individual wetlands sampled in autumn from within the Floodplain region of the River Murray.

Wetland	Variable	BF Range (Min-Max)	PF Range (Min-Max)
Spectacle Lakes	pH	7.2 - 7.5	8.7 - 8.9
(BF *n*=5; PF *n*=4)	Salinity (EC)	776 - 817	467 - 480
	Temperature (C°)	17.3 - 18.4	26.1 - 27.7
	DO (ppm)	1.92 - 5.69	7.6 - 9.8
Yatco	pH	8.4 - 8.9	8.5 - 8.8
(BF *n*=6; PF *n*=5)	Salinity (EC)	976 - 1578	435 - 497
	Temperature (C°)	18.3 - 21	22 - 24.6
	DO (ppm)	7.96 - 10.17	8 - 9.3

Individual Wetland Comparisons - Murray Gorge

Sweeny's Lagoon

A total of 333 fish (CCPUE=3.49 fish h^{-1}) from 10 species, including six native species (27.9% TC) and four invasive species (72.1% TC), were captured during autumn post-flood sampling (February 2012) (Table 12 and Table 13). Bony herring were the most abundant native species (*n*=67; 20.1% TC), while common carp were the most abundant invasive species and dominated the total catch (*n*=185; 55.6% TC). In comparison with the autumn before-flood baseline survey (April 2006), there was a decrease in the total number of fish captured (BF, *n*=341), a decrease in CCPUE (BF, 9.12 fish h^{-1}), an increase in the total number of species recorded (BF, *n*=8) and a shift in the relative proportions of native and invasive species (BF, native=57.2% TC; invasive=42.8% TC). Before-flood, carp gudgeons (*n*=178; 52.2% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=108; 31.7% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 5. All eight species captured before-flood were captured post-flood with the addition of Australian smelt and un-specked hardyhead (Figure 5 and Table 12). While no comparative data was collected for gill nets and bait traps post-flood there was a significant difference in fish assemblage structure between before-flood and post-flood catches for fyke nets ($p<0.05$) (Table 8). The observed difference in fyke net catches was primarily due to a decrease in the relative abundance of carp gudgeons, goldfish and flat-headed gudgeon and an increase in the relative abundance of common carp and bony herring (Table 14). Water quality parameters for before and post flood surveys are presented in Table 19. In comparison to the before-flood survey there was a decrease in salinity, temperature and DO and comparably little difference in pH.

Noonawirra

A total of 355 fish (CCPUE=3.59 fish h^{-1}) from nine species, including five native species (45.6% TC) and four invasive species (54.4% TC), were captured during autumn post-flood sampling (March 2012) (Table 12 and Table 13). Bony herring were the most abundant native species (*n*=138; 38.9% TC), while common carp were the most abundant invasive species (*n*=175; 49.3% TC). In comparison with the autumn before-flood baseline survey (April 2006), there was a decrease in the total number of fish captured (BF, *n*=506), an increase in CCPUE (BF, 3.33 fish h^{-1}), a decrease in the total number of species recorded (BF, *n*=10) and a shift in the relative proportions of native and invasive species (BF, native= 86% TC; invasive= 14% TC). Before-flood, carp gudgeons (*n*=188; 37.1% TC) and un-specked hardyhead (*n*=124; 24.5% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=65; 12.9% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 5. While eight species were captured in both before-flood and post-flood sampling, Australian smelt and Murray-Darling rainbowfish were only recorded before-flood and redfin perch were only recorded post-flood (Figure 5 and Table 12). There were significant differences in fish assemblage structure between before-flood and post-flood catches for both gill nets ($p<0.05$) and fyke nets ($p<0.05$) (Table 8). The observed difference in gill net catches was primarily due to an increase in the relative abundance of bony herring, common carp and golden perch while the difference in fyke net catches was primarily due to an increase in the relative abundance of common carp and bony herring and a decrease in the relative abundance of carp gudgeons, un-specked hardyhead and eastern gambusia (Table 15). Water quality parameters for before and post flood surveys are presented inTable 19. In comparison to the before-flood survey there was a decrease in DO, and increase in temperature and comparably little difference in pH and salinity.

Devon Downs North

A total of 131 fish (CCPUE=1.38 fish h^{-1}) from 10 species, including seven native species (60.3% TC) and three invasive species (39.7% TC), were captured during autumn post-flood sampling (March 2012) (Table 12 and Table 13). Carp gudgeon (*n*=29; 22.1% TC) and bony herring (*n*=22; 16.8% TC) were the most abundant native species, while common carp were the most abundant invasive species (*n*=49; 37.4% TC). In comparison with the autumn before-flood baseline survey (April 2006), there was a decrease in the total number of fish captured (BF, *n*=776), a decrease in CCPUE (BF, 4.76 fish h^{-1}), the same number of species (BF, *n*=10) and a shift in the relative proportions of native and invasive species (BF, native=72.2% TC; invasive=27.8% TC). Before-flood, bony herring (*n*=194; 25% TC) and carp gudgeons (*n*=142; 18.3% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=203; 26.2% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 5. While seven species were captured in both before-flood and post-flood sampling, dwarf flat-headed gudgeon, Murray-Darling rainbowfish and eastern gambusia were only recorded before-flood and goldfish, redfin perch and silver perch (*Bidyanus bidyanus*) were only recorded post-flood (Figure 5 and Table 12). This silver perch represents the only individual captured across all 12 wetlands during both before-flood and post-flood surveys. There was a significant difference in fish assemblage structure between before-flood and post-flood catches for fyke nets ($p<0.05$) (Table 8). The observed difference in fyke net catches was primarily due to a decrease in the relative abundance of carp gudgeons, goldfish and flat-headed gudgeon and an increase in the relative abundance of common carp and bony herring (Table 16). Water quality parameters for before and post flood surveys are presented in Table 19. In comparison to the before-flood survey there was comparably little difference across all parameters.

Saltbush Flat

A total of 856 fish (CCPUE=5.79 fish h^{-1}) from nine species, including six native species (77.7% TC) and three invasive species (22.3% TC), were captured during autumn post-flood sampling (March 2012) (Table 12 and Table 13). Carp gudgeon were the most abundant native species and dominated the overall catch (*n*=502; 58.6% TC), while common carp were the most abundant invasive species (*n*=151; 17.6% TC). In comparison with the autumn before-flood baseline survey (April 2006), there was an increase in the total number of fish captured (BF, *n*=552), an increase in CCPUE (BF, 5.28 fish h^{-1}), an increase in the total number of species recorded (BF, *n*=8) and a marginal shift in the relative proportions of native and invasive species (BF, native=78.3% TC; invasive=21.7% TC). Before-flood, carp gudgeons (*n*=284; 51.5% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=109; 19.8% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 5. While seven species were captured in both before-flood and post-flood sampling, golden perch were only recorded before-flood and Australian smelt and redfin perch were only recorded post-flood (Figure 5 and Table 12). There were significant differences in fish assemblage structure between before-flood and post-flood catches for gill nets ($p<0.05$) and bait traps ($p<0.05$) (Table 8). The observed difference in gill net catches was primarily due to a decrease in the relative abundance of bony herring and an increase in the relative abundance of common carp while the difference in bait trap catches was primarily due to an increase in the relative abundance of carp gudgeon and a decrease in the relative abundance of eastern gambusia (Table 17). Water quality parameters for before and post flood surveys are presented in Table 19. In comparison to the before-flood survey there was a decrease in salinity, and increase in temperature and comparably little difference in pH and DO.

Lake Carlet

A total of 238 fish (CCPUE=2.09 fish h^{-1}) from six species, including three native species (21.4% TC) and three invasive species (78.6% TC), were captured during autumn post-flood sampling (March 2012) (Table 12 and Table 13). Bony herring were the most abundant native species (*n*=43; 18.1% TC), while common carp were the most abundant invasive species and dominated the overall catch (*n*=167; 70.2% TC). In comparison with the autumn before-flood baseline survey (March 2005), there was a decrease in the total number of fish captured (BF, *n*=1690), a decrease in CCPUE (BF, 17.47 fish h^{-1}), a decrease in the total number of species recorded (BF, *n*=13) and a shift in the relative proportions of native and invasive species (BF, native=76.2% TC; invasive=23.8% TC). Before-flood, carp gudgeons (*n*=696; 41.2% TC) and flat-headed gudgeon (*n*=257; 15.2% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=387; 22.9% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 5. While all six species captured post-flood were also captured in before-flood, Australian smelt, common galaxias, dwarf flat-headed gudgeon, flat-headed gudgeon, Murray-Darling rainbowfish, un-specked hardyhead and goldfish were not recorded post-flood (Figure 5 and Table 12). There were significant differences in fish assemblage structure between before-flood and post-flood catches for gill nets ($p<0.05$) and fyke nets ($p<0.05$) (Table 8). The observed difference in gill net catches was primarily due to a decrease in the relative abundance of bony herring and common carp while the difference in fyke net catches was primarily due to a decrease in the relative abundance of carp gudgeon, eastern gambusia, dwarf flat-headed gudgeon and Murray-Darling rainbowfish and an increase in the relative abundance of common carp (Table 18). Water quality parameters for before and post flood surveys are presented in Table 19. In comparison to the before-flood survey there was a decrease in salinity, and increase in temperature and comparably little difference in pH and DO.

Table 12. Catch summary of individual wetlands sampled in autumn (all gear types combined), before-floods (BF-2005/06) and post-floods (PF-2012) in the Murray Gorge section of the Murray River, South Australia.

Species	Sweeny's Lagoon (counts)		Noonawirra (counts)		Devon Downs (counts)		Saltbush Flat (counts)		Lake Carlet (counts)	
	BF	**PF**	**BF**	**PF**	**BF**	**PF**	**BF**	**PF**	**BF**	**PF**
Native species										
Australian smelt	-	3	14	-	8	8	-	1	2	-
Bluespot goby	-	-	-	-	-	-	-	-	-	-
Bony herring	3	67	91	138	194	22	44	95	91	43
Carp gudgeons	178	15	188	6	142	29	284	502	696	2
Common galaxias	-	-	-	-	-	-	-	-	1	-
Congolli	-	-	-	-	-	-	-	-	-	-
Dwarf flat-headed gudgeon	1	-	-	-	8	-	-	-	23	-
Flat-headed gudgeon	13	2	8	1	90	11	97	46	257	-
Freshwater catfish	-	-	-	-	-	-	-	-	-	-
Golden perch	-	3	2	14	14	7	1	-	4	6
Lagoon goby	-	-	-	-	-	-	-	-	-	-
Murray hardyhead	-	-	-	-	-	-	-	-	-	-
Murray-Darling rainbowfish	-	-	8	-	43	-	2	1	107	-
Sandy sprat	-	-	-	-	-	-	-	-	-	-
Silver perch	-	-	-	-	-	1	-	-	-	-
Smallmouthed hardyhead	-	-	-	-	-	-	-	-	-	-
Southern pygmy perch	-	-	-	-	-	-	-	-	-	-
Un-specked hardyhead	-	3	124	3	61	1	4	20	106	-
Invasive Species										
Common carp	6	185	5	175	13	49	11	151	13	167
Eastern gambusia	108	20	65	14	203	-	109	36	387	19
Goldfish	29	31	1	3	-	2	-	-	2	-
Redfin perch	3	4	-	1	-	1	-	4	1	1
Tench	-	-	-	-	-	-	-	-	-	-
Total number of fish	**341**	**333**	**506**	**355**	**776**	**131**	**552**	**856**	**1690**	**238**
Count of Species	**8**	**10**	**10**	**9**	**10**	**10**	**8**	**9**	**13**	**6**
Overall Fish	**674**		**861**		**907**		**1408**		**1928**	
Overall Species	**11**		**11**		**13**		**10**		**13**	

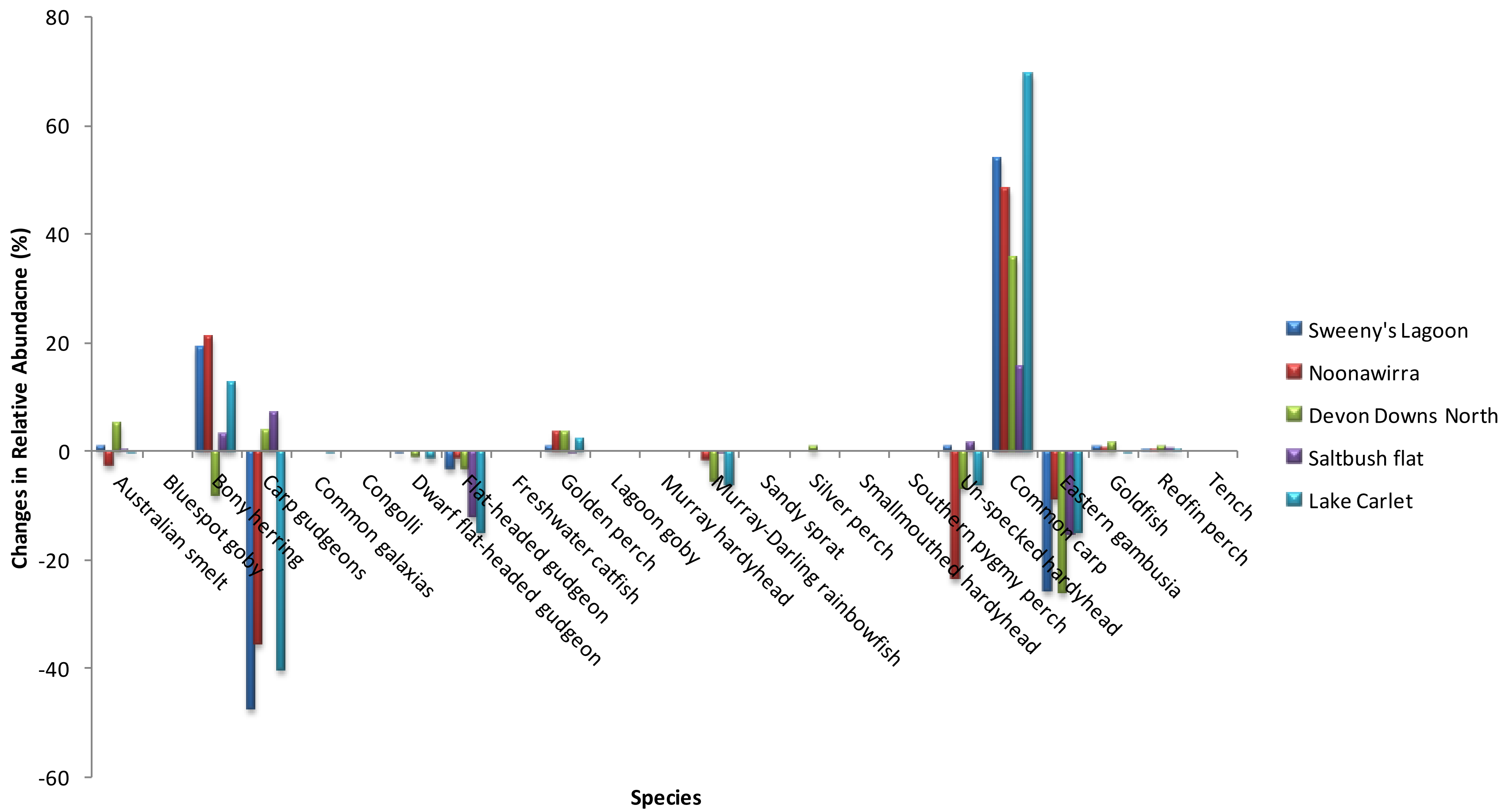


Figure 5. Changes in relative abundance (%) between sampling rounds for the Murray Gorge wetlands (Post-flood % TC – Before-flood % TC).

Table 13. Summary table describing the dates (BF=Before-Floods, PF=Post-Floods), season, gear type (No. of replicates), average hours fished, total hours fished per gear type, total number of fish captured for each gear type and the CPUE standardized to one hour soak time of a single net/trap, for all individual wetlands sampled during autumn within the Murray Gorge region.

Region-Wetland	Date *(BF,PF)*	Season	Gear Type	Avg. Hrs Fished	Total Hrs.	No. Fish	CPUE (fish h^{-1})
Murray Gorge							
Sweeny's Lagoon	30-Mar-05 (BF)	Autumn	0x Gill Nets	-	-	-	-
			2x Fyke Nets	13.5	27	183	6.78
			5x Bait Traps	13.5	67.5	158	2.34
					Combined CPUE		**9.12**
	29-Feb-12 (PF)	Autumn	3x Gill Net	16.5	49.5	23	0.46
			6x Fyke Net	17	102	309	3.03
			0x Bait Traps	-		-	-
					Combined CPUE		**3.49**
Noonawirra	10-Apr-06 (BF)	Autumn	6x Gill Nets	16.75	100.5	9	0.09
			9x Fyke Nets	17	153	485	3.17
			10x Bait Traps	16.75	167.5	12	0.07
					Combined CPUE		**3.33**
	13-Mar-12 (PF)	Autumn	3x Gill Net	17	51	15	0.29
			6x Fyke Net	17.25	103.5	335	3.24
			5x Bait Traps	16	80	5	0.06
					Combined CPUE		**3.59**
Devon Downs North	11-Apr-06 (BF)	Autumn	3x Gill Nets	18.5	55.5	5	0.09
			9x Fyke Nets	18.5	166.5	762	4.58
			5x Bait Traps	18.5	92.5	9	0.10
					Combined CPUE		**4.76**
	27-Mar-12 (PF)	Autumn	3x Gill Net	18	54	22	0.41
			6x Fyke Net	18.75	112.5	106	0.94
			5x Bait Traps	18.5	92.5	3	0.03
					Combined CPUE		**1.38**
Saltbush Flat	12-Apr-06 (BF)	Autumn	6x Gill Nets	17.37	104.22	54	0.52
			6x Fyke Nets	17.75	106.5	449	4.22
			5x Bait Traps	18	90	49	0.54
					Combined CPUE		**5.28**
	13-Mar-12 (PF)	Autumn	6x Gill Net	26	156	64	0.41
			6x Fyke Net	27.25	163.5	549	3.36
			5x Bait Traps	24	120	243	2.03
					Combined CPUE		**5.79**
Lake Carlet	31-Mar-05 (BF)	Autumn	6x Gill Nets	18	108	79	0.73
			6x Fyke Nets	16	96	1602	16.69
			10x Bait Traps	18.25	182.5	9	0.05
					Combined CPUE		**17.47**
	26-Mar-12 (PF)	Autumn	6x Gill Net	18.75	112.5	33	0.29
			6x Fyke Net	19	114	204	1.79
			5x Bait Traps	20	100	1	0.01
					Combined CPUE		**2.09**

Table 14. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events for Sweeny's Lagoon sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Murray Gorge						
Sweeny's Lagoon						
Fyke Net						***(83.40)***
	Hypseleotris spp.	4.63	0.14	5.03	56.33	56.33
	Cyprinus carpio	0.22	1.78	1.23	16.4	72.73
	Carassius auratus	1.04	0.3	1.23	10.22	82.95
	Philypnodon grandiceps	0.48	0.02	1.5	6	88.95
	Nematolosa erebi	0.11	0.49	0.98	3.96	92.91

Table 15. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events for Noonawirra sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Murray Gorge						
Noonawirra						
Gill Net						***(62.89)***
	Nematolosa erebi	0.08	0.2	1.13	67.04	67.04
	Cyprinus carpio	0.01	0.06	1.25	21.45	88.49
	Macquaria ambigua	0	0.04	0.67	11.51	100
Fyke Net						***(80.88)***
	Cyprinus carpio	0.02	1.64	1.42	28.14	28.14
	Hypseleotris spp.	1.16	0.02	2.04	24.5	52.64
	Nematolosa erebi	0.55	1.21	1.47	17.77	70.41
	Craterocephalus stercusmuscarum fulvus	0.8	0.03	0.83	11.93	82.34
	Gambusia holbrooki	0.39	0.14	0.92	9.49	91.84

Table 16. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events for Devon Downs North (DDN) sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Murray Gorge						
DDN						
Fyke Net						***(82.62)***
	Nematolosa erebi	1.16	0.07	1	27.49	27.49
	Gambusia holbrooki	1.23	0	0.76	15.97	43.46
	Hypseleotris spp.	0.84	0.26	1.26	14.87	58.33
	Cyprinus carpio	0.07	0.38	1.09	10.3	68.63
	Philypnodon grandiceps	0.54	0.09	1.39	9.48	78.11
	Craterocephalus stercusmuscarum fulvus	0.37	0.01	1.04	8.97	87.08
	Melanotaenia fluviatilis	0.26	0	0.75	5.44	92.52

Table 17. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events Saltbush Flat sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Murray Gorge						
Saltbush Flats						
Bait Trap						***(82.50)***
	Hypseleotris spp.	0.2	1.77	2.21	70.94	70.94
	Gambusia holbrooki	0.33	0.18	0.99	21.89	92.84

Table 18. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events for Lake Carlet sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Murray Gorge						
Lake Carlet						
Gill Net						***(53.1)***
	Nematolosa erebi	0.58	0.2	1.83	71.4	71.4
	Cyprinus carpio	0.09	0.07	1.27	18.75	90.15
Fyke Net						
						(95.86)
	Hypseleotris spp.	6.99	0.01	2.72	40.18	40.18
	Gambusia holbrooki	3.95	0.15	1.06	22.42	62.59
	Philypnodon grandiceps	2.56	0	1.62	12.81	75.4
	Cyprinus carpio	0.03	1.44	0.89	8.89	84.29
	Melanotaenia fluviatilis	1.11	0	2.21	7.42	91.71

Table 19. Water quality ranges for before (BF) and post (PF) flooding of individual wetlands sampled in autumn from within the Murray Gorge region of the River Murray.

Wetland	**Variable**	**BF** **Range (Min-Max)**	**PF** **Range (Min-Max)**
Sweeny's Lagoon	pH	7.5 - 7.5	7.6 - 7.8
(BF *n*=2; PF *n*=3)	Salinity (EC)	426 - 426	290 - 360
	Temperature (C°)	21.6 - 21.6	19.4 - 20.8
	DO (ppm)	7.91 - 7.91	6 - 6.7
Noonawirra	pH	8 - 8.5	8.1 - 8.5
(BF *n*=7; PF *n*=5)	Salinity (EC)	330 - 357	332 - 316
	Temperature (C°)	17.6 - 17.8	25.8 - 26.6
	DO (ppm)	9.02 - 10.44	7.3 - 8.5
DDN	pH	8.3 - 8.5	8.4 - 8.7
(BF *n*=5; PF *n*=5)	Salinity (EC)	318 - 324	268 - 333
	Temperature (C°)	21.1 - 21.9	21.2 - 22.7
	DO (ppm)	8.88 - 9.37	7 - 9.4
Saltbush Flat	pH	8.7 - 8.9	8.1 - 8.9
(BF *n*=5; PF *n*=5)	Salinity (EC)	2460 - 2710	667 - 895
	Temperature (C°)	20.7 - 21.9	23 - 25
	DO (ppm)	9.05 - 9.86	6.4 - 10.5
Lake Carlet	pH	8.3 - 9.2	8.2 - 8.8
(BF *n*=6; PF *n*=6)	Salinity (EC)	423 - 522	283 - 378
	Temperature (C°)	20.7 - 21.9	22.7 - 25.8
	DO (ppm)	8.48 - 10.6	6.7 - 9.7

Individual Wetland Comparisons - Lower Swamps and Lower Lakes

Reedy Creek

A total of 336 fish (CCPUE=3.25 fish h^{-1}) from 11 species, including eight native species (59.8% TC) and three invasive species (40.2% TC), were captured during autumn post-flood sampling (March 2012) (Table 20 and Table 21). Flat-headed gudgeon were the most abundant native species (*n*=75; 22.3% TC), while common carp were the most abundant invasive species (*n*=125; 37.2% TC). In comparison with the autumn before-flood baseline survey (March 2005), there was a decrease in the total number of fish captured (BF, *n*=808), a decrease in CCPUE (BF, 7.99 fish h^{-1}), a decrease in the total number of species recorded (BF, *n*=12) and a shift in the relative proportions of native and invasive species (BF, native=53.5% TC; invasive=46.5% TC). Before-flood, flat-headed gudgeon (*n*=147; 18.2% TC) and bony herring (*n*=144; 17.8% TC) were the most abundant native species, while eastern gambusia were the most abundant invasive species (*n*=312; 38.6% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 6. While nine species were captured in both before-flood and post-flood sampling, common galaxias, dwarf flat-headed gudgeon and goldfish were only recorded before-flood and congolli and redfin perch were only recorded post-flood (Figure 6 and Table 20). There were significant differences in fish assemblage structure between before-flood and post-flood catches for gill nets ($p<0.05$) and fyke nets ($p<0.05$) (Table 8). The observed difference in gill net catches was primarily due to a decrease in the relative abundance of bony herring and common carp while the difference in fyke net catches was primarily due to a decrease in the relative abundance of carp gudgeon, eastern gambusia, dwarf flat-headed gudgeon and Murray-Darling rainbowfish and an increase in the relative abundance of common carp (Table 22). Water quality parameters for before and post flood surveys are presented inTable 25. In comparison to the before-flood survey there was comparably little difference across all parameters.

Rocky Gully

A total of 137 fish (CCPUE=2.77 fish h^{-1}) from five species, including three native species (24.1% TC) and two invasive species (75.9% TC), were captured during autumn post-flood sampling (February 2012) (Table 20 and Table 21). Bony herring were the most abundant native species (*n*=27; 19.7% TC), while common carp were the most abundant invasive species and dominated the overall catch (*n*=92; 67.2% TC). In comparison with the autumn before-flood baseline survey (March 2005), there was a decrease in the total number of fish captured (BF, *n*=479), a decrease in CCPUE (BF, 4.86 fish h^{-1}), a decrease in the total number of species recorded (BF, *n*=15) and a shift in the relative proportions of native and invasive species (BF, native=90.4% TC; invasive=9.6% TC). Before-flood, bony herring (*n*=162; 33.8% TC) and flat-headed gudgeon (*n*=135; 28.2% TC) were the most abundant native species, while common carp (*n*=28; 5.9% TC) and eastern gambusia (*n*=16; 3.3% TC) were the most abundant invasive species. Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 6. While four species were captured in both before-flood and post-flood sampling, Australian smelt, bluespot goby, carp gudgeon, common galaxias, flat-headed gudgeon, golden perch, Murray hardyhead, Murray-Darling rainbowfish, sandy sprat, small-mouthed hardyhead, eastern gambusia and goldfish were only recorded before-flood and redfin perch were only recorded post-flood (Figure 6 and Table 20). There were significant differences in fish assemblage structure between before-flood and post-flood catches for gill nets ($p<0.05$) and fyke nets ($p<0.05$) (Table 8). The observed difference in gill net catches was primarily due to a decrease in the relative abundance of bony herring, common carp and golden perch while the difference in fyke net catches was primarily due to an increase in the relative abundance of common carp and redfin perch and a decrease in the relative abundance of flat-headed gudgeon, bony herring, carp gudgeon, Australian smelt and common galaxias (Table 23). Water quality parameters for before and post flood surveys are presented in Table 25. In comparison to the before-flood survey there was an increase in temperature and comparably little difference in pH, salinity and DO.

Murrundi

A total of 495 fish (CCPUE=3.81 fish h^{-1}) from seven species, including five native species (7.3% TC) and two invasive species (92.7% TC), were captured during autumn post-flood sampling (March 2012) (Table 20 and Table 21). Un-specked hardyhead were the most abundant native species (*n*=27; 5.5% TC), while eastern gambusia were the most abundant invasive species and dominated the overall catch (*n*=441; 89.1% TC). In comparison with the autumn before-flood baseline survey (March 2005), there was an increase in the total number of fish captured (BF, *n*=93), an increase in CCPUE (BF, 0.94 fish h^{-1}), a decrease in the total number of species recorded (BF, *n*=11) and a shift in the relative proportions of native and invasive species (BF, native=77.4% TC; invasive=22.6% TC). Before-flood, flat-headed gudgeon (*n*=31; 33.3% TC) and bony herring (*n*=21; 22.6% TC) were the most abundant native species, while common carp were the most abundant invasive species (*n*=12; 12.9% TC). Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 6. While seven species were captured in both before-flood and post-flood sampling, dwarf flat-headed gudgeon, Murray-Darling rainbowfish, small-mouthed hardyhead, and redfin perch were only recorded before-flood (Figure 6 and Table 20). There was a significant difference in fish assemblage structure between before-flood and post-flood catches for fyke nets ($p<0.05$) (Table 8). The observed difference in fyke net catches was primarily due to a decrease in the relative abundance of flat-headed gudgeon and bony herring and an increase in the relative abundance of eastern gambusia, carp gudgeon and common carp (Table 24). Water quality parameters for before and post flood surveys are presented in Table 25. In comparison to the before-flood survey there was a decrease in DO and comparably little difference in pH, salinity and temperature.

Pelican Lagoon

A total of 206 fish (CCPUE=1.86 fish h^{-1}) from 13 species, including eight native species (69.9% TC) and five invasive species (30.1% TC), were captured during autumn post-flood sampling (April 2012) (Table 20 and Table 21). Bony herring were the most abundant native species (*n*=78; 37.9% TC), while common carp were the most abundant invasive species (*n*=45; 21.8% TC). In comparison with the autumn before-flood baseline survey (March 2005), there was a decrease in the total numbers of fish captured (BF, *n*=561), a decrease in CCPUE (BF, 4.96 fish h^{-1}), the same total number of species recorded (BF, *n*=13) and a shift in the relative proportions of native and invasive species (BF, native=87.2% TC; invasive=12.8% TC). Before-flood, lagoon goby (*n*=159; 28.3% TC) and flat-headed gudgeon (*n*=123; 21.9% TC) were the most abundant native species, while common carp (*n*=47; 8.4% TC) and eastern gambusia (*n*=19; 3.4% TC) were the most abundant invasive species. Changes in relative abundance (%) between post-flood and before-flood sampling rounds are presented in Figure 6. While 10 species were captured in both before-flood and post-flood sampling, lagoon goby, Murray-Darling rainbowfish and southern pygmy perch were only recorded before-flood and carp gudgeons, congolli and tench were only recorded post-flood (Figure 6 and Table 20). There was no significant difference in fish assemblage structure between before-flood and post-flood catches for all gear types (Table 8). Water quality parameters for before and post flood surveys are presented in Table 25. In comparison to the before-flood survey there was a decrease in salinity and comparably little difference in pH, DO and temperature.

Table 20. Catch summary of individual wetlands sampled in autumn (all gear types combined), before-floods (BF-2005/06) and post-floods (PF-2012) in the Lower Swamps and Lower Lakes of the Murray River, South Australia.

Species	**Reedy creek (counts)**		**Rocky Gully (counts)**		**Murrundi (counts)**		**Pelican Lagoon (counts)**	
	BF	**PF**	**BF**	**PF**	**BF**	**PF**	**BF**	**PF**
Native species								
Australian smelt	25	1	38	-	-	-	86	3
Bluespot goby	-	-	1	-	-	-	-	-
Bony herring	144	51	162	27	21	3	65	78
Carp gudgeons	85	58	36	-	-	-	-	2
Common galaxias	3	-	17	-	-	-	37	2
Congolli	-	9	-	-	-	-	-	1
Dwarf flat-headed gudgeon	8	-	-	-	1	-	-	-
Flat-headed gudgeon	147	75	135	2	31	1	123	34
Freshwater catfish	-	-	-	-	3	2	-	-
Golden perch	2	3	12	-	7	3	4	4
Lagoon goby	-	-	-	-	-	-	159	-
Murray hardyhead	-	-	7	-	-	-	-	-
Murray-Darling rainbowfish	9	1	6	-	3	-	2	-
Sandy sprat	-	-	1	-	-	-	-	-
Silver perch	-	-	-	-	-	-	-	-
Small-mouthed hardyhead	-	-	1	-	4	-	-	-
Southern pygmy perch	-	-	-	-	-	-	2	-
Un-specked hardyhead	9	3	17	4	2	27	11	20
Invasive Species								
Common carp	54	125	28	92	12	18	47	45
Eastern gambusia	312	2	16	-	3	441	19	1
Goldfish	10	-	2	-	-	-	5	1
Redfin perch	-	8	-	12	6	-	1	14
Tench	-	-	-	-	-	-	-	1
Total number of fish	**808**	**336**	**479**	**137**	**93**	**495**	**561**	**206**
Count of Species	**12**	**11**	**15**	**5**	**11**	**7**	**13**	**13**
Overall Fish	**1104**		**616**		**588**		**749**	
Overall Species	**14**		**16**		**11**		**16**	

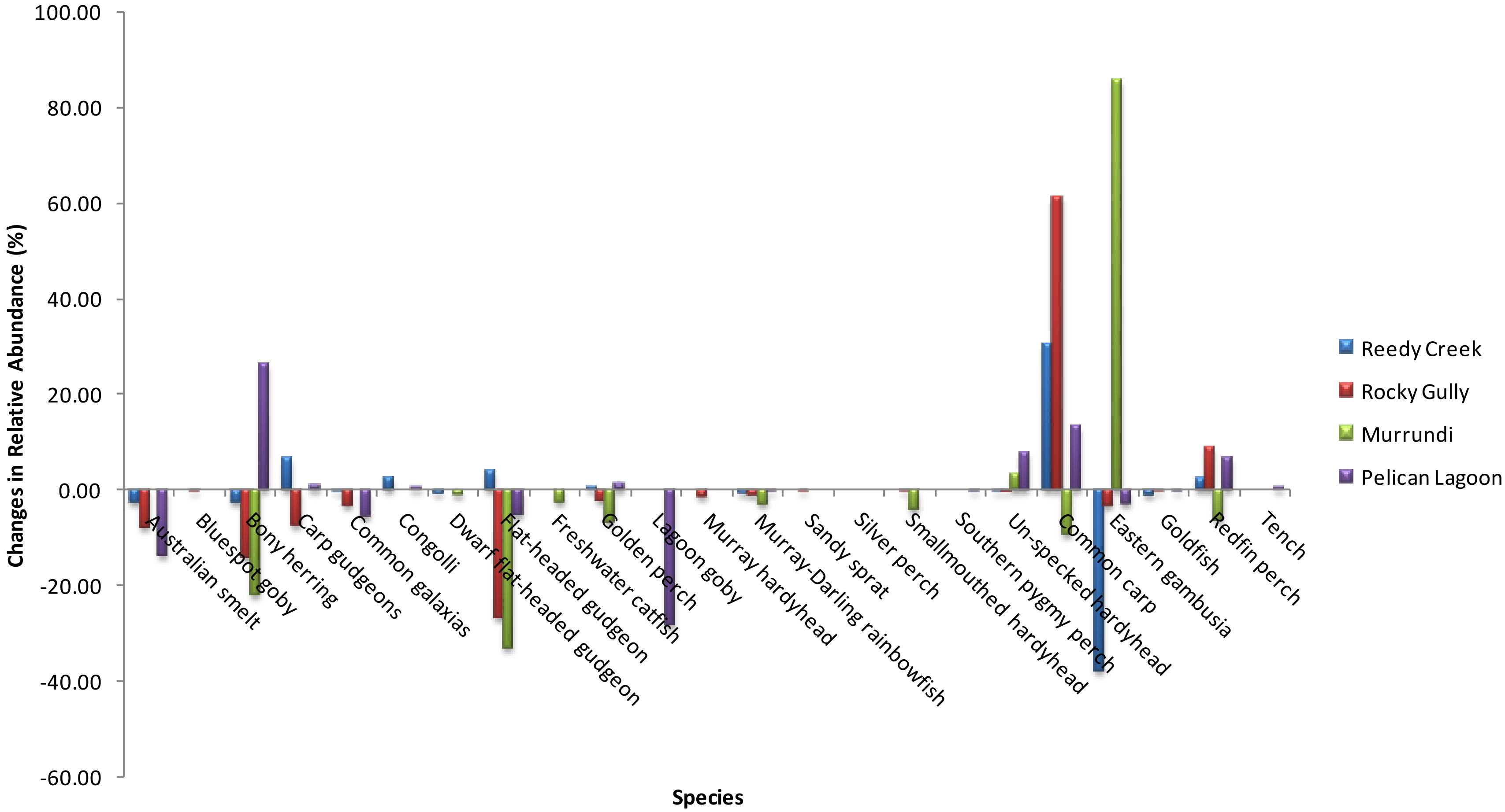


Figure 6. Changes in relative abundance (%) between sampling rounds for the Lower Swamps and Lower Lakes wetlands (Post-flood % TC – Before-flood % TC).

Table 21. Summary table describing the dates (BF=Before-Floods, PF=Post-Floods), season, gear type (No. of replicates), average hours fished, total hours fished per gear type, total number of fish captured for each gear type and the CPUE standardized to one hour soak time of a single net/trap, for all individual wetlands sampled during autumn within the Lower Swamps and Lower Lakes region.

Region-Wetland	Date *(BF,PF)*	Season	Gear Type	Avg. Hrs Fished	Total Hrs.	No. Fish	CPUE (fish h^{-1})
Lower Swamps							
Reedy Creek	17-Mar-05 (BF)	Autumn	6x Gill Nets	16.75	100.5	20	0.20
			6x Fyke Nets	16.75	100.5	774	7.70
			10x Bait Traps	16.37	163.7	14	0.09
					Combined CPUE		**7.99**
	15-Mar-12 (PF)	Autumn	3x Gill Net	23.5	70.5	19	0.27
			6x Fyke Net	17.75	106.5	317	2.98
			5x Bait Traps	24.5	122.5	0	0.00
					Combined CPUE		**3.25**
Rocky Gully	15-Mar-05 (BF)	Autumn	6x Gill Nets	15	90	77	0.86
			6x Fyke Nets	16.75	100.5	400	3.98
			5x Bait Traps	13.75	68.75	2	0.03
					Combined CPUE		**4.86**
	24-Feb-12 (PF)	Autumn	3x Gill Net	22	66	15	0.23
			3x Fyke Net	16	48	122	2.54
			0x Bait Traps	-	-	-	-
					Combined CPUE		**2.77**
Murrundi	22-Mar-05 (BF)	Autumn	6x Gill Nets	15.75	94.5	23	0.24
			6x Fyke Nets	16.5	99	66	0.67
			10x Bait Traps	16	160	4	0.03
					Combined CPUE		**0.94**
	15-Mar-12 (PF)	Autumn	3x Gill Net	21.5	64.5	8	0.12
			6x Fyke Net	22	132	487	3.69
			0x Bait Traps	-	-	-	-
					Combined CPUE		**3.81**
Lower Lakes							
Pelican Lagoon	23-Mar-05 (BF)	Autumn	6x Gill Nets	19.25	115.5	23	0.20
			6x Fyke Nets	18.5	111	512	4.61
			10x Bait Traps	18	180	26	0.14
					Combined CPUE		**4.96**
	02-Apr-12 (PF)	Autumn	3x Gill Net	17	51	7	0.14
			6x Fyke Net	19.25	115.5	199	1.72
			5x Bait Traps	20	100	0	0.00
					Combined CPUE		**1.86**

Table 22. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events Reedy Creek sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Lower Swamps						
Reedy Creek						
Gill Net						***(84.05)***
	Cyprinus carpio	0.02	0.24	2	68.19	68.19
	Nematolosa erebi	0.15	0.03	1.06	30.56	98.75

Table 23. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events Rocky Gully sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Lower Swamps						
Rocky Gully						
Gill Net						***(68.11)***
	Nematolosa erebi	0.53	0.05	1.75	60.77	60.77
	Cyprinus carpio	0.21	0.18	0.96	25.17	85.95
	Macquaria ambigua	0.06	0	1.19	7.78	93.73
Fyke Net						***(81.11)***
	Cyprinus carpio	0.09	1.67	1.74	29.88	29.88
	Philypnodon grandiceps	1.34	0.04	2.73	26.25	56.13
	Nematolosa erebi	1.11	0.5	1.36	14.46	70.58
	Hypseleotris spp.	0.35	0	0.79	6.9	77.49
	Retropinna semoni	0.37	0	0.69	5.39	82.87
	Perca fluviatilis	0	0.25	1.51	4.71	87.58
	Galaxias maculatus	0.17	0	0.64	2.94	90.52

Table 24. SIMPER analysis for relative abundance (CPUE) comparison for all gear types between before-flooding (BF) and post-flooding (PF) events Murrundi sampled in autumn. Results are based on square root transformed data. Mean abundance is the number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Wetland		**Mean Abundance**			**Contribution (%)**	**Cumulative Contribution (%)**
Gear Types	Species	BF	PF	CR		***(Mean Dissimilarity %)***
Lower Swamps						
Murrundi						
Fyke Net						***(94.02)***
	Philypnodon grandiceps	0.29	0.01	1.36	25.82	25.82
	Gambusia holbrooki	0.03	3.27	0.49	18.1	43.91
	Hypseleotris spp.	0	0.2	0.52	11.41	55.32
	Cyprinus carpio	0.03	0.09	0.78	11.31	66.63
	Nematolosa erebi	0.11	0.02	0.89	8.57	75.2
	Macquaria ambigua	0.07	0.02	0.67	7.32	82.52
	Atherinosoma microstoma	0.04	0	0.38	4.24	86.76

Table 25. Water quality ranges for before (BF) and post (PF) flooding of individual wetlands sampled in autumn from within the Lower Swamps and Lower Lakes region of the River Murray .

Wetland	**Variable**	**BF Range (Min-Max)**	**PF Range (Min-Max)**
Reedy Creek	pH	7.7 - 8.6	6.22 - 8.7
(BF *n*=6; PF *n*=5)	Salinity (EC)	516 - 12050	798 - 9560
	Temperature (C°)	19.5 - 21	20.3 - 22.3
	DO (ppm)	7.72 - 15	4.1 - 10.5
Rocky Gully	pH	9.1 - 9.6	9.26 - 9.7
(BF *n*=5; PF *n*=4)	Salinity (EC)	1659 - 4240	2880 - 3840
	Temperature (C°)	20.8 - 21.9	22.4 - 23.8
	DO (ppm)	10.22 - 13.49	8.57 - 11
Murrundi	pH	7.7 - 8.7	7.2 - 7.7
(BF *n*=6; PF *n*=3)	Salinity (EC)	472 - 737	321 - 714
	Temperature (C°)	22 - 22.4	23.3 - 23.8
	DO (ppm)	7.36 - 8.3	2.9 - 6.23
Pelican Lagoon	pH	7.9 - 9	8.1 - 8.2
(BF *n*=6; PF *n*=5)	Salinity (EC)	656 - 5190	511 - 605
	Temperature (C°)	20.1 - 22	21.9 - 24
	DO (ppm)	8.43 - 11.7	7.9 - 9.1

Key species driving the change in post-flood relative abundances

The Principal Components Ordination (PCO) of fish assemblage data accounted for 49% of the total variation in the first two axes (Figure 7). There is clear separation of samples collected from before-flood and post-flood. Differences were driven by greater relative abundance of native carp gudgeon, flat-headed gudgeon and invasive eastern gambusia before-flood and increases in the relative abundance of common carp post-flood. While the native bony herring contributed to the overall change, this contribution was highly variable.

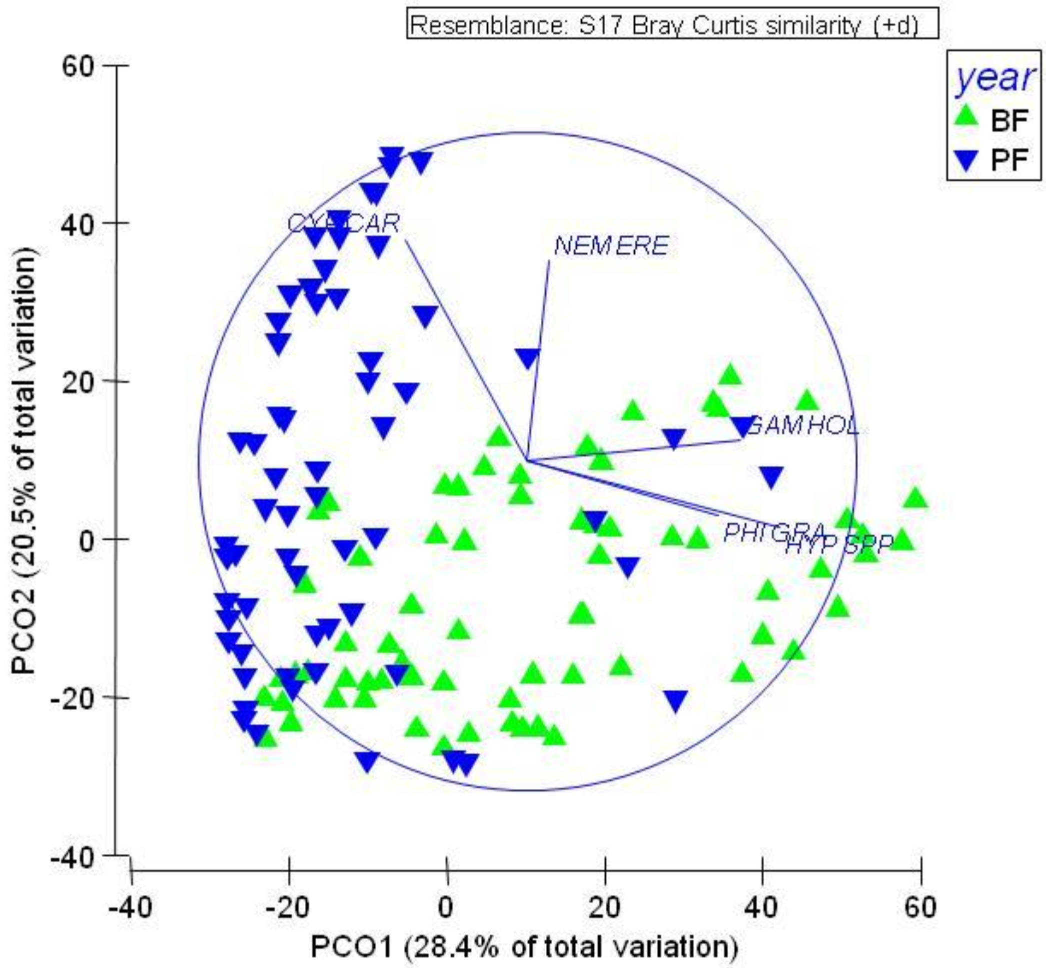


Figure 7. PCO ordination of samples on the basis of the Bray-Curtis measure of log transformed abundances of fish species collected by fyke net during both before (BF) and post-flood (PF) sampling of twelve wetlands in the Lower River Murray. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.3, and with respect to the unit circle). CYP CAR: common carp; NEM ERE: bony herring; GAM HOL: eastern gambusia; PHI GRA: flat-headed gudgeon; HYP SPP: carp gudgeon.

DISCUSSION

Following drought breaking floods throughout the MDB there were variable changes in the autumn wetland fish assemblage structure. Of the 12 wetlands sampled, six shifted from a native dominated fish assemblage to an invasive dominated fish assemblage post-flood. The overall post-flood change in the autumn fish assemblage was driven by changes in the relative abundance of native carp gudgeon, flathead gudgeon and bony herring and invasive eastern gambusia and common carp. The shift in the relative proportions of these small-, medium- and large-bodied species may be associated with differing life history strategies and changes to the available aquatic habitat and hydraulic regime (i.e. flow, drying, rewetting) resulting from both the prolonged drought and subsequent flooding.

Small bodied native species

Significant decreases in the relative abundance of small-bodied native flat-headed gudgeon were recorded within Devon Downs North (Murray Gorge, MG), Lake Carlet (MG), Rocky Gully (MG) and Murrundi (Lower Swamps, LS). Flat-headed gudgeon is a small-bodied foraging generalist (typically 80 mm and less than 115 mm) that displays a life history strategy that is intermediate between opportunistic and equilibrium (Winemiller and Rose 1992; Humphries et al. 1998; Baumgartner et al. 2013). It prefers slow-flowing areas and is often found in weedy or muddy areas with abundant cover in the form of rocks or logs (Lintermans 2007). The species does not routinely utilise the floodplain for larval development (Lintermans 2007) and increases in abundance have been associated with periods of low-flow (Baumgartner et al. 2013).

While carp gudgeon displayed a predominately negative response to flooding with significant decreases in relative abundance within Sweenys Lagoon (MG), Noonawirra (MG), Devon Downs North (MG), Lake Carlet (MG), and Rocky Gully (MG) there was a significant increase in relative abundance within Murrundi (LS). Carp gudgeons are a common small-bodied foraging generalist (typically 40 mm TL and less than 70 mm) species complex that contains at least four taxa and several hybrids (Lintermans 2007; Baumgartner et al. 2013). They display a life history strategy that is intermediate between opportunistic and equilibrium (Bice et al. 2013). Spawning occurs in spring or summer when water temperatures exceed 22.5^{o}C with females laying up to 2000 eggs which are guarded by the male. Recruitment success has been linked to periods of low-flow (Baumgartner et al. 2013). The species complex prefers slow-flowing or still water and is commonly associated with macrophyte beds and other aquatic vegetation (Lintermans 2007, Bice et al. 2013).

Bice et al. (2013) also reported a reduction in the abundance of small-bodied native species (i.e. flat-headed gudgeon, carp gudgeon) within the main river channel and suggest this is due, in part, to a loss of submerged macrophytes resulting from increase flow, turbidity and depth. The authors also suggest that increased inundation of off-channel habitats (i.e. wetland, floodplains) may have resulted in lateral movement of small-bodied fish into these newly inundated habitats, however, this was not witnessed during the current autumn wetland surveys. Although vegetation surveys were not conducted during the present study, Nicol et al. (2013) evaluated the post-flood aquatic and terrestrial vegetation of several wetlands which had been surveyed during the drought within the lower River Murray. The authors recorded a loss of submerged vegetation during the drought period and further losses (over 1-2 months) as a result of high velocities, turbulence and decreased euphotic depth associated with flooding. They also report an increase in inundated terrestrial and amphibious vegetation. Although the inundated terrestrial and amphibious vegetation may have provided some alternative habitat, it is possible that the decreased abundance of small-bodied species within wetlands was partially associated with a decrease in preferred habitat. Further, Ye et al. (2013) sampled the larval abundance of flat-headed gudgeon and carp gudgeon within the main river channel below lock 1 during the flood period (2010-11) and subsequent high flow period (2011-12). For 2010-11 sampling, they reported a significant decline in larval abundance to between 3-20% of previous drought years (2005-2009). Abundances increased during the high flow period however they were still significantly lower than those recorded during the drought. The authors suggested that these lower abundances were a result of reduced reproductive performance associated with flooding and high flow. The low abundances recorded in the present study may also be partially attributed to the reduced spawning success reported by Ye et al. (2013).

Medium bodied native species

While the native medium-bodied bony herring contributed to the overall change in the post-flood fish assemblage, this contribution was highly variable with the species relative abundance increasing significantly in Yatco Lagoon (Floodplain, FP), Sweenys Lagoon (MG) and Noonawirra (MG) and decreasing significantly in Devon Downs North (MG), Rocky Gully (MG) and Murrundi (Lower Swamps, LS). Bony herring, a common native species, displays an opportunistic life history strategy (Winemiller and Rose 1992; Ferguson et al. 2013). The species are algal detritivores, highly fecund (up to 880,000 eggs), tolerant to high temperatures (up to 38^{o}C), high turbidity and salinity (up to ≈51,000 EC) and low dissolved oxygen (Lintermans 2007). They are known to spawn in shallow sandy bays or backwaters during floods (Humphries et al. 1999; Lintermans 2007); however recruitment is not dependent on river flow (Puckridge and Walker 1990). Recently, Bice et al. (2013) found that bony herring were not positively associated with microhabitats within the main channel of the River Murray indicating flexible habitat use and high mobility. The variable response recorded in the present study is likely an artifact of the species mobility and lack of association with any microhabitats.

Invasive species

The relative abundance of invasive small-bodied eastern gambusia decreased significantly within Noonawirra (MG), Devon Downs North (MG) and Lake Carlet (MG) and increased significantly within Murrundi (LS- increase). Eastern gambusia are a live-bearing small-bodied (typically 10-30 mm TL and less than 80 mm TL) invasive species that displays an opportunistic life history strategy (Winemiller and Rose 1992). Eastern gambusia reproduce over a protracted period (up to nine batches per year). Fertilised eggs develop inside the female and young are born at a few millimeters in length. Eastern gambusia prefer shallow (5-15 cm in depth) low flow or still water habitats commonly found in wetlands, lakes and slow-flowing streams (Pyke 2005; Lintermans 2007; Rowe et al. 2008). Although they are able to withstand a wide range of temperatures, oxygen levels, salinities and turbidities (Lintermans 2007), it is possible that the decreased abundance of eastern gambusia within wetlands is associated with variable hydrology, adverse changes in physio-chemical parameters (i.e. lethal concentrations of leachates, diurnal fluctuations in dissolved oxygen), variable prey availability and a decrease in preferred habitat resulting from flood waters (Humphries et al. 1999; Bice et al. 2013).

Common carp displayed the greatest positive response to the flood with significant increases in relative abundance within Yatco Lagoon (FP), Sweenys Lagoon (MG), Noonawirra (MG), Devon Downs North (MG), Lake Carlet (MG), Rocky Gully (MG) and Murrundi (LS). Common carp display a life history strategy which is intermediate between opportunistic and periodic (Winemiller and Rose 1992; Bice et al. 2013). Carp have high fecundity (100,000 eggs.kg^{-1}; up to 1 million eggs.y^{-1}), a high level of recruitment, longevity (28+ years), an ability to occupy a broad range of habitats and tolerance to extreme environmental conditions (Smith 2005). Common carp are highly mobile and make annual migrations from the main river channel to off-stream habitats (i.e. wetlands, floodplains) during spring/summer for spawning and recruitment (Smith and Walker 2004; Stuart and Jones 2006; Penne and Pierce 2008). The increase in available spawning habitat (i.e. inundated submerged, terrestrial and amphibious vegetation; Nicol et al. 2013) associated with extended floodplain inundation during the latter half of the know carp spawning period (summer/autumn 2010-11) provided ideal conditions for carp to proliferate. In sampling of the main channel of the River Murray conducted post-flood (2012), Bice et al. (2013) also reported an increased abundance of this species and that carp was one of the large-bodied fish that dominated the fish assemblage of the main channel of the River Murray.

Given that common carp displayed the greatest response within the first year post-flooding, a similar response may be expected during future floodplain/wetland inundation. This will require careful management in order to disadvantage carp, while minimising impact and maximising benefits for native species (e.g. carp screens vs. native fish passage). Controlling and managing carp has been a primary focus of invasive species research over the last decade. Current management options include commercial fishing, carp exclusion screens in wetland flow control structures to restrict access to spawning sites (French et al. 1999; Hillyard et al. 2010), tracking Judas carp to locate and harvest aggregations (Inland Fisheries Service 2008), innovative jumping traps (William's carp separation cages; Stuart et al. 2006) and pushing traps (Thwaites et al. 2010), water level manipulations to reduce access to littoral spawning sites and expose eggs to desiccation (Shields 1957; Yamamoto et al. 2006), electrical barriers to restrict movements (Verrill and Berry 1995) and chemical piscicides (Clearwater et al. 2008). Genetic ('daughterless' carp; Thresher 2008), biological (Kio herpes virus; McColl et al. 2007) and chemical (pheromones; Sorensen and Stacey 2004) control technologies are in development, but are largely untested and still many years from deployment. As many of these control/management strategies carry the potential to impact native species, their application will require site specific information (i.e. fish assemblage structure, species life history strategies, timing and duration of wetland utilisation) to develop a management strategy that will minimise or mitigate any potential negative effects. It is also important to consider that the majority of carp control strategies are likely to become redundant during flooding and high overbank flows.

Future considerations

While increased carp abundance is a by-product of flooding, the overall importance to native fish communities cannot be overlooked. Indeed, flooding of wetlands/floodplains is essential for stimulating primary and secondary production (Junk et al. 1989; Balcombe et al. 2005). This is key to the maintenance of species/biotic diversity and recruitment in native fish communities (Junk et al. 1989; Ribeiro et al. 2004; Balcombe and Arthington 2009). As such, further monitoring is required to evaluate the long-term response of native and invasive species to both natural and human induced inundation of individual floodplains/wetlands (i.e. timing and duration of off-channel fish movements). This monitoring should aim to determine the long-term persistence of both native and invasive species associated with the recent flooding event (i.e. aging, frequency distributions, etc).

REFERENCES

Akaike, H. (1973). Information theory as an extension of the maximum likelihood principle. In Proceedings, 2nd International Symposium on Information Theory (Petrov, B. N. & Caski, F., eds), 267-281. Akademiai Kiado, Budapest.

Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology* **26**, 32-46.

Anderson, M. J., Gorley, R. N. and Clarke, K. R. (2008). PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth, UK.

Balcombe, S. R., and Arthington, A. H. (2009). Temporal changes in fish abundance in response to hydrological variability in a dryland floodplain river. *Australian Journal of Marine and Freshwater Research* **60**,146-159.

Baumgartner, L. J., Conallin, J., Wooden, I., Campbell B., Gee, R., Robinson, W. A. and Mallen-Cooper, M. (2013). Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems. *Fish and Fisheries*. DOI: 10.1111/faf.12023

Bice, C. M., Gehrig, S. L., Zampatti, B. P., Nicol, J. M., Wilson, P., Leigh, S. L. and Marsland, K. (2013). Flow induced alterations to fish assemblages, habitat and fish-habitat associations in a regulated lowland river. Inland Waters and Catchment Ecology Program, South Australian Research Development Institute (SARDI), Aquatic Sciences, South Australia.

Burnham, K. P. and Anderson, D. R. (2002). Model Selection and Multi-model Inference: a Practical Theoretic-Information Approach, 2nd Edition. Springer, New York.

Clarke, K. R. and Gorley, R. N. (2001). Primer Version 5. Primer-E, Plymouth, UK.

Clarke, K. R. and Warwick, R. M. (2001). Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. PRIMER-E Ltd: Plymouth, UK.

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

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

Ferguson, G. J., Ward, T. M., Ye, Q., Geddes, M. C. and Gillanders, B. M. (2013). Impacts of drought, flow regime, and fishing on the fish assemblage in southern Australia's largest temperate estuary. *Coastal and Estuarine Research Federation.*

French, J. R. P.,Wilcox, D. A. and Nicols, S. J. (1999). Passing of northern pike and common carp through experimental barriers designed for use in wetland restoration. *Wetlands* **19,** 883–888.

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

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

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

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

Junk, W. J., Bayley, P. B. and Sparks, R. E. (1989). The flood pulse concept in river–floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences* **106,** 110–127.

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

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

MDBC (2005). Native fish and wetlands in the Murray-Darling Basin: Action plan, knowledge gaps and supporting papers. Proceedings from a workshop held in Canberra 7-8 June 2005.

Murphy, B. F., and Timbal, B. (2008) A review of recent climate variability and climate change in southeastern Australia. *International Journal of Climatology* **28**(7), 859-879.

Nicol, J. M., Gehrig, S. L., Frahn, K. A. and Strawbridge, A. D. (2013). Resilience and resistance of aquatic plant communities downstream of Lock 1 in the Murray River. Goyder Institute for Water Research, Technical Report Series No. 13/5, Adelaide, South Australia.

Nichols, S., and Gilligan, D. (2004). *What About the Fish? Improving Fish Passage through Wetland Flow Control Structures in the Lower River Murray*. Australian Landscape Trust, Melbourne, Vic, Australia, 131 pp.

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

Potter, N. J., Chiew, F. H. S., Frost, A. J., Srikanthan, R., McMahon, T. A., Peel, M. C. and Austin, J. M. (2008). Characterisation of recent rainfall and runoff in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia.

Puckridge, J. T. and Walker, K. F. (1990). Reproductive biology and larval development of a gizzard shad, *Nematalosa erebi* (Günther) (Dorosomatinae: Teleostei), in the River Murray, South Australia. *Australian Journal of Marine and Freshwater Research* **41,** 695–712.

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

Ribeiro, F., Crain, P. K. and Moyle, P. B. (2004). Variation in condition factor and growth in young-of-year fishes in floodplain and riverine habitats of the Consumnes River, California. *Hydrobiologia* **527,** 77–84.

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

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

Smith, B. B. and Hammer, M. (2006). Mapping the current distribution of native and exotic fishes within the South Australian Murray-Darling Basin. Primary Industries and Resources South Australia, SARDI Aquatic Sciences, Adelaide. Research Report Series No. 119

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

Smith, B. B. and Fleer, D. (2007). Final report on the 'Fish' and 'Water Quality' components of the 2006 River Murray Wetlands Baseline Survey. Final Report to the Mid-Murray Local Action Planning Committee. Prepared by Primary Industries and Resources South Australia, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Aquatic Sciences Publication Number RD 04/0245-3. 44 pp.

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

Smith, B. B., Conallin, A., Fleer, D., Hillyard, K. and Ellis, E. (2007b). River Murray wetlands baseline surveys of fish, water quality and acidification risk to inform drought planning. SARDI Aquatic Sciences Publication Number RD 04/0245-5. SARDI Research Report Series No. 197. Primary Industries and Resources SA, SARDI Aquatic Sciences.

Smith, B. B. (2006) Final report on the 'fish' component of the 2005 River Murray Wetlands Baseline Survey. Primary Industries and Resources SA, SARDI Aquatic Sciences, Adelaide.

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

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

Stuart, I., Williams, A., Mckenzie, J. and Holt, T. (2006a). Managing a migratory pest species: a selective trap for common carp. *North American Journal of Fisheries Management* **26**, 888-93.

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

Thwaites, L. A., Fleer, D. and Smith, B. B. (2010). Estimating the biomass of adult common carp in Lake Albert, South Australia: A progress report for Biosecurity SA. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000681-1. SARDI Research Report Series No. 490. 18pp.

Ummenhofer, C. C., England, M. H., McIntosh, P. C., Meyers, G. A., Pook, M. J., Risbey, J. S., Sen Gupta, A., and Taschetto, A. S. (2009). What causes Southeast Australia's worst drought?. *Geophysical Research Letters* **36**.

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

Wilson, G. G. (2005). Impact of invasive exotic fishes on wetland ecosystems in the Murray-Darling Basin. In *Native fish and wetlands in the Murray-Darling Basin: Action plan, knowledge gaps and supporting papers. Proceedings from a workshop held in Canberra 7-8 June 2005.* pp. 45-60.

Winemiller, K. O., and Rose, K. A. (1992). Patterns of life-history diversification in North-American fishes-Implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* **49**, 2196-2218.

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

Ye, Q., Livore, J. P., Bucater, L. B., Cheshire, K. J. M., and Fleer, D. (2013). Changes in larval fish assemblages related to Commonwealth environmental watering in the lower River Murray in 2011/2012 with emphasis on golden perch. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000293-1. SARDI Research Report Series No. 753. 43pp.

APPENDIX A

Spectacle Lakes

Spectacle Lakes is an ephemeral managed wetland situated within the Floodplain region of the River Murray, South Australia (462 river kilometres from the Murray mouth; 445481 m E, 6199490 m S; Figure 8). The wetland is categorised as shallow (< 1 m) and comprises two main water bodies with a combined surface area of ≈105 hectares at pool level (Smith et al. 2007). It is a regulated wetland with flow control structures and carp screens at its inlet.

Figure 8. Google Earth Image of Spectacle Lakes wetland within the Riverland region of the River Murray, South Australia.

Yatco Lagoon

Yatco Lagoon is large permanent managed wetland situated within the Floodplain region of the River Murray, South Australia (452 river kilometres from the Murray mouth; 441987 m E, 621074 m S; Figure 9). The wetland is categorised as deep (> 1 m) and comprises two main water bodies with a combined surface area of ≈345 hectares (Smith et al. 2007).

Figure 9. Google Earth Image of Yatco Lagoon wetland within the Riverland region of the River Murray, South Australia.

Overland Corner

Overland Corner is an ephemeral managed wetland situated within the Floodplain region of the River Murray, South Australia (425 river kilometres from the Murray mouth; 440141 m E, 6220092 m S; Figure 10). The wetland is categorised as shallow (< 1 m) and comprises several wetlands with a combined surface area of ≈17 hectares (Smith et al. 2007). It is a partially regulated wetland with no provision for regulation at its inlet but flow control structures and carp screens at its outlet.

Figure 10. Google Earth Image of Overland Corner wetland within the Riverland region of the River Murray, South Australia.

Sweeny's Lagoon

Sweeny's Lagoon is an ephemeral managed wetland situated within the Murray Gorge region of the River Murray, South Australia (271 river kilometres from the Murray mouth; 373450 m E, 6195626 m S; Figure 11). It is categorised as shallow (< 1m) and has a surface area of ≈14.7 hectares (Smith et al. 2007). Flow control structure and carp screens are fitted at the southern inlet and several regulating structures have been installed on creeks to the north of the wetland that connect during high flows.

Figure 11. Google Earth Image of Sweeny's Lagoon wetland within the Murray Gorge region of the River Murray, South Australia.

Noonawirra

Noonawirra is a permanent unmanaged wetland situated within the Murray Gorge region of the River Murray, South Australia (255 river kilometres from the Murray mouth; 369087 m E, 6181883 m S; Figure 12). It is categorised as shallow (< 1 m) and has a surface area of ≈11.1 hectares (Smith et al. 2007). Flow control structures are fitted at its inlet but there is was no provision for carp control at the time of sampling.

Figure 12. Google Earth Image of Noonawirra wetland within the Murray Gorge region of the River Murray, South Australia.

Devon Downs North

Devon Downs North is an unmanaged wetland situated within the Murray Gorge region of the River Murray, South Australia (222 river kilometres from the Murray mouth; 374815 m E, 6160761 m S; Figure 13). It is categorised as shallow (< 1 m) and has a surface area of ≈262 hectares (Smith et al. 2007). The wetland is unregulated with no provision for flow or carp control.

Figure 13. Google Earth Image of Devon Downs North wetland within the Murray Gorge region of the River Murray, South Australia.

Saltbush Flat

Saltbush Flat is a permanent unmanaged wetland situated within the Murray Gorge region of the River Murray, South Australia (186 river kilometres from the Murray mouth; 375964 m E, 6140758 m S; Figure 14). It is categorised as shallow (≈ 1 m) and has a surface area of ≈93 hectares. The wetland is unregulated with no provision for flow or carp control.

Figure 14. Google Earth Image of Saltbush Flat wetland within the Murray Gorge region of the River Murray, South Australia.

Lake Carlet

Lake Carlet is a permanent unmanaged wetland situated within the Murray Gorge region of the River Murray, South Australia (170 river kilometres from the Murray mouth; 360478 m E, 6140959 m S; Figure 15). It is categorised as deep (> 1 m) and has a surface area of ≈343 hectares (Smith et al. 2007). The wetland is unregulated with no provision for flow or carp control.

Figure 15. Google Earth Image of Lake Carlet wetland within the Murray Gorge region of the River Murray, South Australia.

Reedy Creek

Reedy Creek is a partially managed wetland situated within the Lower Swamps region of the River Murray, South Australia (144 river kilometres from the Murray mouth; 340811 m E, 6131063 m S; Figure 16). It is categorised as shallow (< 1 m) and has a surface area of ≈101 hectares (Smith et al. 2007). During the 2005 baseline surveys the wetland was unregulated with no provision for flow or carp control however flow control structures and carp screens were installed prior to the 2012 autumn post-flood sampling.

Figure 16. Google Earth Image of Reedy Creek wetland within the Lower Swamps region of the River Murray, South Australia.

Rocky Gully

Rocky Gully is a permanent managed wetland situated within the Lower Swamps region of the River Murray, South Australia (114 river kilometres from the Murray mouth; 341994 m E, 6112999 m S; Figure 17). It is categorised as deep (> 1 m) and has a surface area of ≈6.2 hectares (Smith et al. 2007). The wetland has carp screens at its inlet which were shut during post-flood sampling.

Figure 17. Google Earth Image of Rocky Gully wetland within the Lower Swamps region of the River Murray, South Australia.

Murrundi

Murrundi is a permanent unmanaged wetland situated within the Lower Swamps region of the River Murray, South Australia (78 river kilometres from the Murray mouth; 352550 m E, 6090886 m; Figure 18). It is categorised as deep (> 1 m) and has a surface area of ≈9.2 hectares (Smith et al. 2007). The wetland is unregulated with no provision for flow or carp control.

Figure 18. Google Earth Image of Murrundi wetland within the Lower Swamps region of the River Murray, South Australia.

Pelican Lagoon

Pelican Lagoon is a permanent unmanaged wetland situated within the Lower Lakes region of the River Murray, South Australia (46 river kilometres from the Murray mouth; 349241 m E, 6083957 m S; Figure 19). It is categorised as shallow (< 1 m) and has a surface area of ≈185 hectares (Smith et al. 2007). The wetland is unregulated with no provision for flow or carp control.

Figure 19. Google Earth Image of Pelican Lagoon wetland within the Lower Lakes region of the River Murray, South Australia.

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.