Barmah-Millewa Fish Condition Monitoring: 2012/2013 Annual Report

Raymond, S. Robinson, W. Duncan, M. and Tonkin, Z.

August 2013

Arthur Rylah Institute for Environmental Research
Unpublished Client Report for the Murray Darling Basin Authority

Arthur Rylah Institute for environmental research

Department of Environment and Primary Industries

State Government Victoria

Barmah-Millewa Fish Condition Monitoring: 2012/13 Annual Report

Scott Raymond[1], Wayne Robinson[2], Meaghan Duncan[2] and Zeb Tonkin[1]

[1]Arthur Rylah Institute for Environmental Research

Department of Environment and Primary Industries

PO Box 137

Heidelberg, Victoria 3084.

Phone (03) 9450 8600

[2] Department of Trade and Investment NSW,

Narrandera Fisheries Centre,

PO Box 182

Narrandera, NSW 2700.

Phone (02) 6958 8200

August 2013

In partnership with:

Arthur Rylah Institute for Environmental Research
Department of Environment and Primary Industries
Heidelberg, Victoria

Report produced by: Arthur Rylah Institute for Environmental Research
Department of Environment and Primary Industries
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.depi.vic.gov.au/ari

Citation: Raymond, S., Robinson, W., Duncan, M. and Tonkin, Z. (2013). Barmah-Millewa Fish Condition Monitoring: 2012/13 Annual Report. Arthur Rylah Institute for Environmental Research Unpublished Client Report for the Murray Darling Basin Authority. Department of Environment and Primary Industries, Heidelberg, Victoria. This project was funded by The Living Murray initiative of the Murray-Darling Basin Authority.

Accessibility:
If you would like to receive this publication in an accessible format, such as large print or audio, please telephone 136 186, or through the National Relay Service (NRS) using a modem or textphone/teletypewriter (TTY) by dialling 1800 555 677, or email customer.service@depi.vic.gov.au

This document is also available in PDF format on the internet at www.depi.vic.gov.au

Front cover photo: Barmah and inhabitants 2013, Scott Raymond.

Contents

Acknowledgements v

Summary 1

1 Introduction 4

2 Methods 7

2.1 Fish monitoring 7

2.2 River sampling 7

2.3 Creek, wetland and lake sampling 11

2.4 Data analysis: Fish surveys 12

2.4.1 Univariate 12

2.4.1.1 Nativeness index 12

2.4.1.2 Expectedness and Recruitment indexes 13

2.4.2 Multivariate 16

2.4.2.1 Size distributions 16

2.5 Riverine larval drift sampling 16

3 Results 18

3.1 Hydrology 18

3.2 Fish surveys 20

3.2.1 Total catch and community composition 20

3.2.2 Rivers 20

3.2.3 Creeks 25

3.2.4 Lakes 25

3.2.5 Wetlands 26

3.2.6 Statistical analysis 27

3.3 Riverine larval drift 34

4 Discussion 41

4.1 Rivers 42

4.2 Creeks, lakes and wetlands 45

4.3 Riverine spawning assessment 46

5 Conclusion 48

6 References 49

Appendix 1. 53

Appendix 2. 54

Acknowledgements

We would like to thank the Barmah-Millewa Coordinating Committee, Barmah-Millewa Technical Advisory Committee and the Living Murray section of the Murray-Darling Basin Authority for their financial and technical support. The following staff are thanked for their contribution to field and laboratory work for the 2012/13 season: Graeme Hackett, Justin O'Mahony, Joanne Kearns, Renae Ayres, John Mahoney, and Dean Hartwell (Arthur Rylah Institute); Jonathon Doyle, Jamie Hutchison and John Stuart (Department of Trade and Investment NSW). Dan Stoessel (ARI) provided comments on the draft report. Sampling in NSW waters was conducted under Industry and Investment NSW Fish Collection Permit P01/0059 (A). Sampling within Victorian waters was covered under Fisheries Victoria Permit RP 827 and National Parks Victoria (Flora and Fauna Guarantee Act 1988) Permit 10002155. Animal Care and Ethics Approval is granted under Department of Trade and Investment NSW general biodiversity project Number ACEC98/14.

Summary

The Barmah-Millewa Forest (B-MF) is a wetland complex on the mid-Murray River that provides important habitat for both terrestrial and aquatic fauna. The fish community supported by the Forest is particularly important, and is the focus of a condition monitoring program. This program has been underway since 2006/07 as part of The Living Murray (TLM) assessment program. The condition monitoring has been designed to assess the health and status of the fish community across 21 sampling sites distributed across creeks, wetlands and river habitats. It provides reasoning for observed changes in fish assemblage and population structure. This report gives a summary of the results of the 2012/13 sampling season and relates these to the previous six years of sampling.

After ten years of drought conditions, the B-MF experienced major flooding and a significant hypoxic blackwater event in late 2010/early 2011. Following this, the forest was characterised by spring flooding and above average flows. Changes in the fish assemblage over the duration of the study and in particular the medium term impact of the flood/blackwater event on the native and alien fish community are discussed.

A total of 2,029 fish from nine native (719) and four alien (1310) species were recorded in 2012/13 (caught and observed) within four habitat types (rivers, creeks, wetlands and lakes). This represents the smallest fish total since the monitoring program began with changes in abundance over the last year primarily driven by small-bodied alien species. Fish community composition was significantly different between habitats and across years, with differences between habitats dependant on the year. Replicate sites within rivers and creeks were 60 to 70% similar across years while replicate sites within wetlands and lakes were much more variable.

Reporting on large-bodied native and exotic Common Carp are a key objective of the condition monitoring program and as such are a focus of this report. All of the large-bodied native fish species previously recorded in B-MF (Murray Cod, Trout Cod, Golden Perch and Silver Perch) were collected this year; however, Young-Of-Year (YOY) fish were absent indicating recruitment of all species was low in the region. No YOY Murray Cod, Trout Cod, Golden Perch or Silver Perch were collected in 2012/13. Whilst YOY Golden and Silver Perch have always been rare, reasonable numbers of YOY Murray Cod were caught from 2007 to 2010 with lower numbers sampled in 2010/11. In general, Murray and Trout Cod abundances were higher in 2007 to 2010 than 2011 to 2013, abundances of Golden Perch was

stable from 2007 to 2010 and increased from 2010 to 2013, while Silver Perch numbers fluctuated across years.

The number of Murray Crayfish collected increased following a marked decline in 2010/11. The increase in Murray Crayfish abundance was predominantly due to increases in numbers within sites not impacted by blackwater. The capture of Murray Crayfish from the Edwards River show a range extension and is the first record of Murray Crayfish from the Edwards River since the current monitoring program was initiated seven years ago. While the abundance of Murray Crayfish within the B-MF has continued to improve over the last three years, their continued absence from their pre-blackwater stronghold (Murray River at Morning Glory) is cause for concern.

Common Carp continued to dominate the large-bodied fish community of the B-MF. Common Carp was the most abundant species in river, creek and lake habitats with small numbers recorded from wetlands. The lack of YOY Common Carp across habitats in 2012 and 2013 indicates that environmental conditions were less suitable for Common Carp recruitment in the last two years than during the major flooding and consequent floodplain inundation in 2010/11. We propose that Common Carp had a competitive advantage over many small and large-bodied native fish species during the floods and the hypoxic blackwater, and that this advantage was diminished post-flood and a return to normoxic conditions.

The collection of eggs and/or larvae in drift nets set in river sites indicate that Murray and Trout Cod, Silver Perch, Carp Gudgeons and Australian Smelt all spawned during the spring/summer of 2012/13. There was no evidence of Golden Perch spawning this year. The capture of cod larvae from Morning Glory in the past two years, after their absence in 2010/11, indicates that some adult Murray Cod persisted in this reach during the blackwater event or that downstream larval drift is re-colonizing the region. Large numbers of drifting Common Carp larvae were also captured from Morning Glory in 2012/13.

The seventh year of sampling has provided additional insight into the flow related dynamics of native and alien fish species in this icon site. Importantly, it has highlighted that large-scale flooding and/or increased flows do not always deliver short to medium-term benefits to native fish. While we suggest that mortality (or avoidance movement) caused by the flow-related hypoxic blackwater event contributed to the reduced abundance of native fish, we cannot rule out that flow-related variation in electrofishing efficiency and downstream displacement of small-bodied species during flood have contributed to these results. The paucity of information available for these three factors makes it difficult to identify the key mechanism(s) shaping the fish assemblage. This highlights the need for long-term monitoring with a concerted effort to sample under similar hydrological conditions.

1 Introduction

The Living Murray (TLM) initiative (established in 2002) is a partnership of the Australian federal government and the governments of the Australian Capital Territory, New South Wales, South Australia and Victoria, coordinated by the Murray-Darling Basin Authority (MDBA). The Living Murray program aims ‘to improve the environmental health of six icon sites chosen for their significant ecological, cultural, recreational, heritage and economic values’(MDBA 2013). The six icon sites are;

- Barmah-Millewa Forest
- Gunbower-Koondrook-Perricoota Forest
- Hattah Lakes
- Chowilla Floodplain and Lindsay-Wallpolla Islands
- River Murray Channel
- Lower lakes, Coorong and Murray mouth.

Condition monitoring of fish, waterbirds and vegetation is necessary to provide ongoing information used to assess the ‘health’ of the Murray River (MDBA 2012). An outcome/ evaluation framework was established to ensure consistent monitoring and agreed benchmarks across all icon sites. Murray-Darling Basin (MDB) riverine ecosystems are typified by variable hydrological conditions, which have resulted in temporal and spatial variability of its flora and fauna. The development of long-term monitoring programs is essential for reliable interpretation and management of the MDB ecosystems.

The Barmah-Millewa Forest (B-MF) is a 66,000 ha wetland complex on the mid-Murray River, up-stream of Echuca (Figure 1). The B-MF contains a range of aquatic habitats including rivers, permanent and ephemeral creeks, wetlands, swamps and floodplains; historically these habitats contained an abundant and diverse range of native fish (King 2005). Until around the 1930s, the area also supported the largest inland commercial fishery in Australia. Since the regulation of the Murray River by dams and weirs, native fish abundance and diversity have been substantially reduced and alien species have become common (King 2005). Given the importance of the region for a range of flora and fauna, the B-MF is listed as an internationally important wetland under the Ramsar convention, and has received iconic status under the MDBA’s Living Murray Initiative.

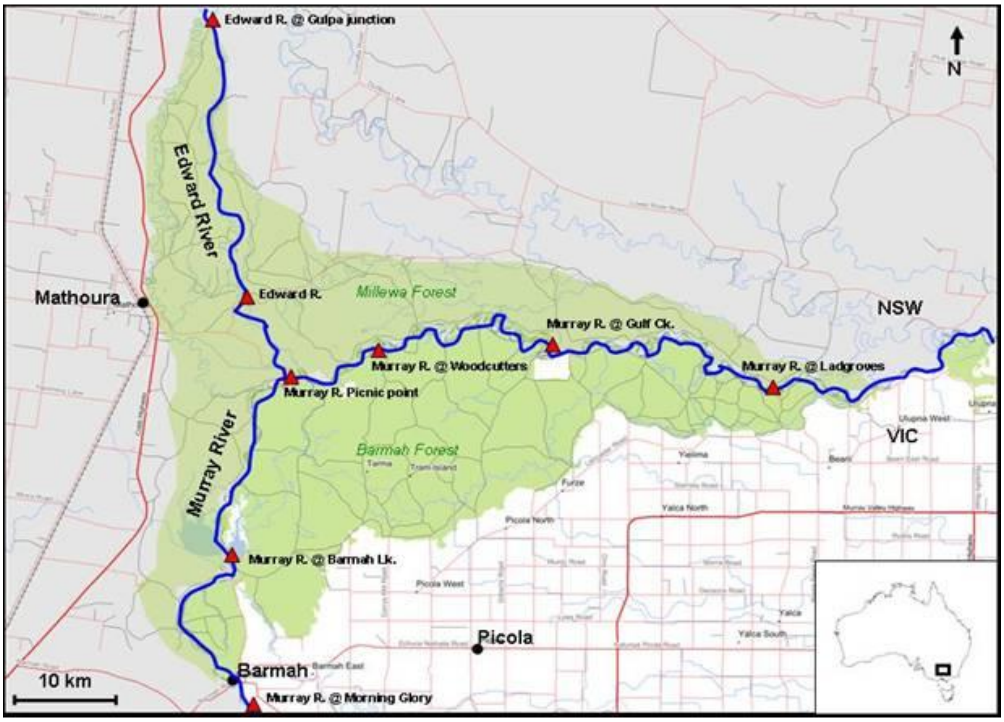


Figure 1. The Barmah-Millewa Forest (shaded green).

In 2006/07, a condition monitoring program commenced in the B-MF region to benchmark the status of fish communities at three major 'ecotypes'; rivers, creeks and wetlands (Tonkin and Baumgartner 2007). The overall objectives of the monitoring program were to:

- Monitor the health and status of the B-MF fish community through annual sampling;
- Assess long-term changes in fish community structure and correlate changes with flow, water temperature and other environmental factors (e.g. blackwater); and
- Report on icon site condition and provide information to guide management plans.

In 2008/09, a spawning component was introduced to the project to enable the detection of potential links between flow and temperature and the abundance of drifting eggs and larvae.

Specifically, the spawning component of the monitoring program aimed to:

- Document the presence of spawning of riverine fish species (Murray Cod *Maccullochella peelii*, Trout Cod *Maccullochella macquariensis*, Silver Perch *Bidyanus bidyanus*, Golden Perch *Macquaria ambigua ambigua*, and introduced Common Carp, *Cyprinus carpio*) that have drifting egg and/or larval stages, within a portion of the B-MF.

- Add to a long-term data set of sampling for riverine fish eggs and larvae in the region, which had been underway since 2003 (King et al. 2009). In combination, the results will add greater confidence in what environmental variables act as triggers for spawning.

This year (2012/13) marks the seventh year of sampling and is the third consecutive year that sampling has occurred following substantial floodplain inundation. In addition, it is the second year post a blackwater event that affected some of the sampling sites and has been implicated in major fish kills (King et al. 2011). This report summarises the results of data collected for the seventh year of fish condition monitoring, which incorporates sampling for Murray Crayfish and spawning success of five primarily riverine large-bodied fish species, and compares this data with previous years.

2 Methods

2.1 Fish monitoring

Fish monitoring of the B-MF was undertaken within two major habitat types; rivers (Murray and Edward Rivers) and non-riverine habitats (creeks, lakes and wetlands). Rivers were sampled in May, after water levels declined to winter base flows to maximise fish detection and to ensure that water temperatures were low enough to sample Murray Crayfish. Creek and wetland sites were sampled in February when water levels were high enough to allow effective sampling. To assess the condition of fish communities within the B-MF, methods were developed to maintain compatibility with current Sustainable Rivers Audit (SRA) protocols (SRA 2004). The program also maintained consistency by sampling the same number of sites in the Barmah Forest and Millewa Forest.

2.2 River sampling

Fish

Previous sampling undertaken within B-MF identified unique fish communities in four broad river regions; lower, mid and upper Murray River main channel and the Edwards River main channel (Figure 2) (King et al. 2007). Subsequently, a balanced design was developed with two sites sampled in each of these four regions (Table 1). All Murray River sites were sampled using a 7.5 KVA, Smithroot boat-mounted electrofishing unit (1000v, 120 pulses/second, 40 hertz), while sites on the Edward River were sampled using a 2.5 KVA, Smithroot boat-mounted electrofishing unit (1000v, 120 pulses/second, 40 hertz). Twelve replicates of 90 second electrofishing shots were conducted at each river site. In addition, 10 unbaited bait-traps were set at each site for 2hrs to sample small fish not sampled during routine electrofishing. At the completion of each operation, all fish were identified to species, counted (maximum of 50 individuals per species per site) and measured for total length (to the nearest mm). Once processed all fish were returned to the site of capture.

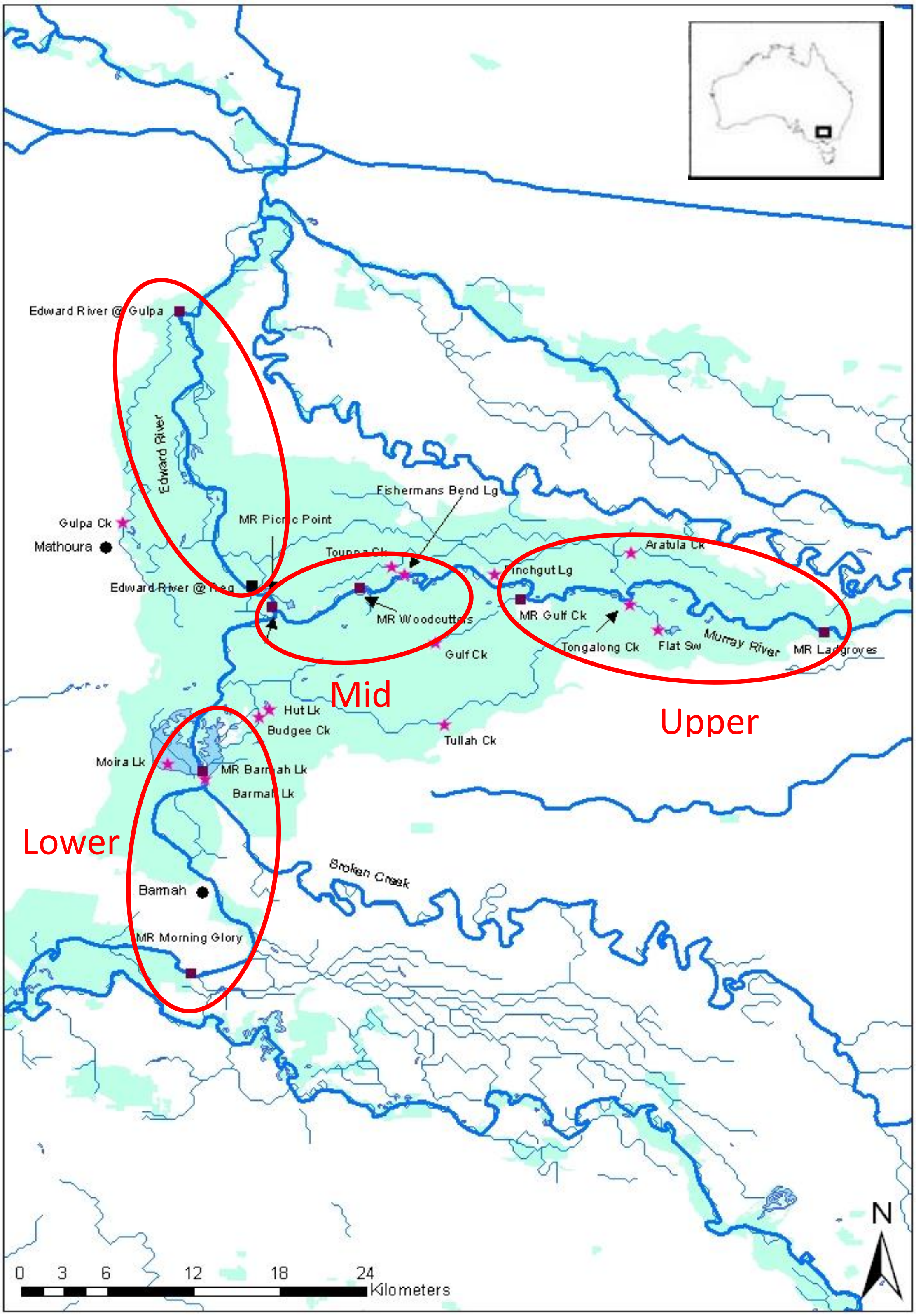


Figure 2. Barmah-Millewa Forest (green shading) illustrating locations of river (squares) and creek and wetland (stars) fish monitoring sites and river regions (red ovals).

Table 1. River sites in the B-MF successfully sampled in each study year.

River region	Site	2007	2008	2009	2010	2011	2012	2013
Murray River								
Downstream Region								
	MR Morning Glory	✓	✓	✓	✓	✓	✓	✓
	MR Barmah Lake area	✓	✓	✓	✓	✓	✓	✓
Mid Forest Region								
	MR Picnic Point	✓	✓	✓	✓	✓	✓	✓
	MR Woodcutters	✓	✓	✓	✓	#	✓	✓
Upstream region								
	MR Ladgroves Beach	✓	✓	✓	✓	✓	✓	✓
	MR Gulf Creek	✓	✓	✓	✓	✓	✓	✓
Edward River								
	Edward River @ regulator	✓	✓	✓	✓	✓	✓	✓
	Edward River @ Gulpa	✓	✓	✓	✓	✓	✓	✓

✓ Site successfully sampled
Site inaccessible

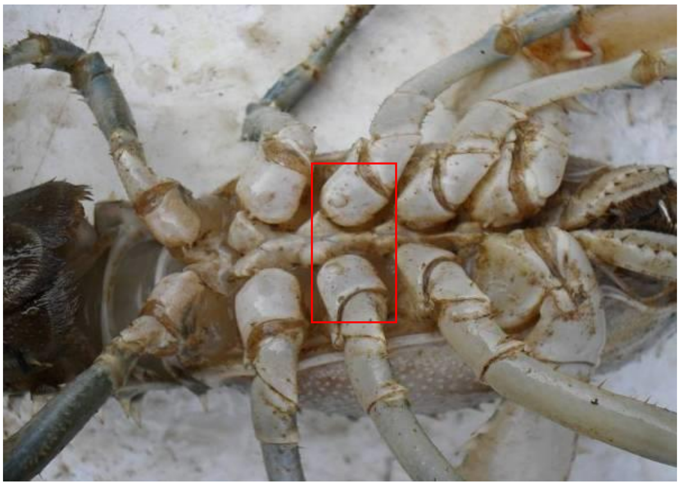
Murray Crayfish

Ten Munyana crab traps, 75 cm in diameter and baited with liver, were set prior to the commencement of electrofishing with a minimum two-hour soak (Figure 3). All Murray Crayfish *Euastacus armatus* captured were measured for occipital carapace length (OCL) and sex determined where possible. Females were assessed for maturation, setae surrounding the gonopores, and for the presence of eggs (berries) (Figure 4).

Figure 3. Munyana crab trap used for sampling Murray Crayfish.

(a)

(b)



(c)

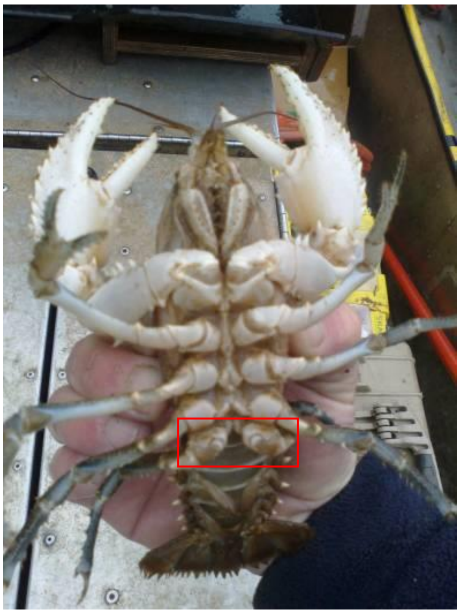


Figure 4. Mature female Murray Crayfish in berry (a) immature female Murray Crayfish as indicated by lack of setae surrounding gonopores (b) and male Murray Crayfish (c). Gonopores of Murray Crayfish outlined within red rectangle.

2.3 Creek, wetland and lake sampling

The B-MF contains a complex matrix of creek systems and wetlands with a wide variety of fish species, some of which only occur in these off-channel habitats (King et al. 2007). Twelve off-channel sites were therefore selected for inclusion in annual sampling (Table 2). Sampling was fixed at six creek and six wetland/lake sites. These sites were spatially stratified to include six within the Barmah Forest and six within the Millewa Forest. An additional creek site on Gulf Creek was included in 2009 after surveys in 2008 revealed it to be an important refuge area for a large number of species (see Tonkin and Rourke 2008).

Table 2. Creek and wetland fish sites in the B-MF indicating sites successfully sampled in each year of the study

Site	Forest	2007	2008	2009	2010	2011	2012	2013
Creek sites								
Tongalong Creek	Barmah	✓	✓	✓✠	✓	✓	✓	✓
Budgee Creek	Barmah	✓	✓	✓	✓	#	✓	✓
Tullah Creek	Barmah	✓	×	×	×	✓	✓	×
Toupna Creek	MVNP	✓	✓	×	✓	✓	✓	✓
Gulpa Creek	MVNP	✓	✓	✓	✓	✓	✓	✓
Aratula Creek	MVNP	✓	✓	✓	✓	✓	✓	✓
Gulf Creek @ 4 mile*	Barmah	*	*	✓	✓	✓	✓	✶
Wetland/Lake sites								
Barmah Lake	Barmah	✓	✓	✓	✓	✓	✓	✓
Hut Lake	Barmah	×	×	×	×	✓	✓	×
Flat Swamp	Barmah	✓	×	×	×	✓	✓	×
Moira Lake	MVNP	✓	×	×	✓	✓	✓	✓
Pinchgut lagoon	MVNP	✓	×	✓	×	✓	✓	✓
Fishermans Bend Billabong	MVNP	✓	×	✓	✓	✓	✓	✓

* commenced sampling in 2009

✓ Site contained water and successfully sampled

✶ Site not sampled

× Site dry and not sampled

Site was inaccessible

✠ An additional search comprising of 1,500 electrofishing seconds was conducted in an attempt to locate southern pygmy perch. None were found.

Sites within the B-MF experience a range of flow or water regimes over any given year, and this can greatly affect accessibility and the area available to be sampled. Therefore, where necessary, sampling effort was reduced from SRA standards, to ensure all sites could be completed in most years. Sampling involved 5-12 replicates of 90 second boat electrofishing shots at each site, with a 5 shot minimum during low water conditions. If the minimum of five boat electrofishing shots could not be completed due to reduced wetland area or depth, eight replicates of 150 seconds were undertaken with a backpack electrofishing unit (Smithroot Model LR20B, 600v, 120 pulses/second, 40 Hertz) at each site. In addition, 10 unbaited bait-traps were set for a minimum two hour soak time to capture fish not effectively targeted using electrofishing techniques. As with river sites, all fish were identified, counted and measured (maximum of 50 individuals per species per site) at the completion of each operation.

The ecological objective of successful recruitment of native fish species (MDBA 2012) was determined by the presence of Young-Of-Year (YOY) fish. YOY fish were classified based on their total length (Murray Cod and Trout Cod <150 mm, Golden Perch <100 mm, Silver Perch <100 mm and Common Carp <150 mm; King et al. 2008).

2.4 Data analysis: Fish surveys

2.4.1 Univariate

Analyses of capture data was based on SRA methodology as this was the basis for the sampling strategies. The indices used in this report are to be treated as interim indices because the SRA methodology is primarily for river channel sampling, and habitat specific indices for B-MF habitats are not yet developed. The SRA uses three indices of condition; Nativeness, Expectedness and Recruitment. Each indice consists of 2 or 3 sub-indicators (Table 3). This paper reports on six of the seven sub-indicators, excluding the OP sub-metric as it was deemed inappropriate for the current B-MF sampling effort.

The observed to expected (OE) score is a measure of α-diversity, the fish species diversity within each site.

2.4.1.1 Nativeness index

The Nativeness sub-indicators and the observed to expected (OE) sub-indicator are scored at the site scale (Table 3) and were averaged to get a score for each habitat type in B-MF. This method gives all sites (e.g. even the largest and the smallest wetlands) equal weight in the analysis. Equal weighting ensures that the nativenesses analysed are habitat averages and not population averages and is important as it allows us to compare changes in Nativeness and E/O within habitat types over time. The three site-scale indicators were assessed statistically for change through time. We used a mixed model, with sites as subjects in a repeated measures analysis, to compare the % Native Biomass, % Native Abundance and Native Observed to expected species between habitats in B-MF through the seven years of this report. The recruitment indices were developed for the SRA tri-annual sampling strategy and not the B-MF annual sampling strategy. Hence indices should be interpreted not as absolute recruitment scores to be compared against the SRA values, but rather a relative measure of recruitment to allow comparisons of recruitment levels between years and habitats in B-MF.

2.4.1.2 Expectedness and Recruitment indexes

The Expectedness and Recruitment sub-indicators require a Reference Condition for Fish (RCF) score to be allocated for each species (Table 3). The score allocates species to one of three categories (common, intermediate, rare) and incorporates expert opinion and catch records into a score that represents catchability and rareness for each taxon in each region. Species that were common and therefore easily collected score 5, species that were rare and difficult to collect score 1, and intermediate species score 3. SRA recruitment indicators do not identify the source of recruitment, just presence of recruits. The RCF scores used are those developed for the Central Murray River and anabranches(given its close proximity to the B-MF), hence wetland results are to be interpreted with caution. Nevertheless, it is feasible that values may differ for some species that are more specific to floodplains rather than rivers. However, the values are likely to be a close approximation and will be open to adjustment in future reports. Whilst the absolute values should be interpreted with caution, the comparisons between years are meaningful.

The Recruitment indicators require knowledge of the biology of each species, including length at maturity and life cycle (Life Guild code). The values used in this report (Table 3) are from the SRA Central Murray River section, which includes Torrumbarry to the Wakool junction. For further information and example calculations for all sub-indices, refer to Robinson (2012) . The Life Guild indicates the life cycle is < 3years (SL), 3-6 years (IL) or > 6 years (LL). We use the SRA definitions for recruitment where all short-lived fish are deemed as recruits, and for all other species, individuals that are < the lengths at maturity are deemed as recruits. The recruitment metrics were not calculated for lake habitats because they were deemed inappropriate for that habitat type.

Management targets have not been finalised relative to the SRA indicators in this ecosystem. Achieving 75% nativeness would place B-MF fish community approximately 20% above the Central Murray River scores in SRA 1 (2008) and SRA 2 (2012) (Davies et al. 2012) . It is acknowledged that the recruit abundance sub-indicator should have a lower reference than the others because large-bodied fish need adults to recruit and these could take several years to appear. Nevertheless 75% is deemed a reasonable target for B-MF given that most expected taxa are small-bodied and short-lived (Table 3), hence most fish collected should be recruits.

Table 3. Indicators used to assess fish condition in B-MF.

Indicator	Sub-indicator	Description	Scale of calculation
Nativeness	Native biomass	Proportion of fish biomass that is from native fish	Site
	Native abundance	Proportion of fish abundance that is from native fish	
Expectedness	Observed to expected (OE) species	Proportion of expected fish species that occur in a site	
	Observed to predicted (OP) species	Proportion of predicted (the historical list in Table 4) fish species that occur[1]	Icon Site
Recruitment	Recruiting sites	Proportion of sites with RCF species recruiting	
	Recruiting taxa	Proportion of fish species recruiting in the strata	
	Recruit Abundance	Proportion of all RCF fish in the strata that were recruits	

[1]Not calculated for B-MF in 2013.

Sub-indicator descriptions available from Robinson (2012).

Note that only fish in Table 4 (RCF species) contribute to the Expectedness and Recruitment sub-indices.

Table 4. Native fish expected to occur within B-MF. Reference Condition for Fish (RCF) score is from the MDB SRA Central Murray River, Middle Section. Life guilds (life cycles) are short-lived (SL <3 years), intermediate-lived (IL ≥ 3 years to 6 years) and long-lived (LL > 6 years).

Common Name	Scientific name	RCF Score	Life Guild	Length at
Murray Cod	*Macullochella peelii*	5	LL	235
Trout Cod	*Maccullochella macquariensis*	(5)	LL	150
Golden Perch	*Macquaria ambigua*	5	LL	75
Silver Perch	*Bidyanus bidyanus*	5	LL	35
Freshwater Catfish	*Tandanus tandanus*	3	LL	83
Bony Bream	*Nematalosa erebi*	3	IL	67
River Blackfish	*Gadopsis marmoratus*	3	IL	70
Short-headed Lamprey	*Mordacia mordax*	(3)	*	*
Macquarie Perch	*Macquaria australasica*	(3)	LL	75
Murray Darling Rainbowfish	*Melanotenia fluviatilis*	3	SL	30
Murray Hardyhead	*Craterocephalus fluviatilis*	1	SL	40
Unspecked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	3	SL	15
Australian Smelt	*Retropinna semoni*	5	SL	30
Carp Gudgeon	*Hypseleotris spp.*	5	SL	35
Flathead Gudgeon	*Philypnodon grandiceps*	3	IL	40
Southern Pygmy Perch	*Nannoperca australis*	3	SL	30
Purple Spotted Gudgeon	*Mogurnda adspersa*	1	IL	49
Flathead Galaxias	*Galaxias rostratus*	3	IL	80
Mountain Galaxias	*Galaxius olidus*	1	IL	30
Olive Perchlet	*Ambassis agassizii*	3	SL	31
Dwarf flathead Gudgeon	*Philypnodon macrostomus*	1	SL	20

* Short-Headed Lampreys were not included in the recruitment calculations because of insufficient knowledge of their biology.

Riverine only species are shown in parentheses.

Source: Muschal et al. (2010)

2.4.2 Multivariate

Multivariate analyses were used to compare the community composition of fish between the different habitats and across sampling dates. All fish (caught + observed) were included in a three factor permutational analysis of variance (PERMANOVA) (Andersen 2001) with habitat (River, Creek, Wetland and Lake) and year (2007 to 2013) as fixed effects and sites nested within habitat. Interactions of habitat and year were tested, however, standard pairwise comparisons between habitats were unsuitable as wetland and lake sites were not all sampled in all years, resulting in reduced power from lack of permutations. Instead, similarities between the fish communities in the different habitats through time were plotted.

The sampled fish sites were then ordinated using non metric multi-dimensional scaling and fish species that showed a rank correlation of 0.5 or higher, with the space overlayed on the ordination to aid with interpretation. For all multivariate analyses, the data were converted to presence/absence to moderate the potential difference in abundances from different electrofishing on-times for some dates. All analyses were based on the Jaccard similarity coefficient which is directly interpretable as proportion of shared species and were carried out with e-primer v6 (Clarke and Gorley 2006).

2.4.2.1 Size distributions

Length frequency histograms were generated for species that had at least 20 individuals collected in any habitat in 2013. The histograms are calculated to give equal weight to each site within a habitat that had at least five fish collected. That is, the fish are not pooled across the whole Icon Site, rather a histogram of distributions is created for each site and the habitat histogram presented here is the average histogram for the entire habitat. Standard length frequency histograms that were not averaged across habitat were also generated for Murray Cod and Trout Cod to identify fish cohorts and recruitment success. For these histograms, YOY fish were classified based on their total length (Murray Cod and Trout Cod < 150mm, Golden Perch and Silver Perch < 100mm and Common Carp < 150mm; King et al. 2008).

2.5 Riverine larval drift sampling

Larval drift sampling targeted drifting eggs and larvae of four native (Murray Cod, Trout Cod, Silver Perch and Golden Perch) and one alien (Common Carp) large-bodied species. All are known to have drifting egg and/or larval life stages. Sampling was conducted fortnightly, from the 15th October 2012 to 11th December 2012. This period encompassed the dominant spawning period for these species (Humphries 2005; Koehn and Harrington 2006; King et al. 2007). Drifting fish eggs and larvae were collected in nets set at three sites on the Murray River: MR Morning Glory, MR Barmah Lake (Barmah Choke) and MR Ladgroves Beach, which are located downstream, mid and upstream of the B-MF floodplain respectively (see Figure 3 for site locations).

At each site, three 1.5 m long passive drift nets were deployed just below the surface, across the river channel to account for spatial variability in drifting densities. The nets constructed of 500 µm mesh with a 0.5 m diameter opening, tapering to a removable collection jar (Figure 5). Each net was anchored to an emergent tree within the river channel. Within each net, a General Oceanics Inc. (Florida, USA) flow meter was fixed to determine the volume of water filtered, thus enabling raw catch data to be standardised to the number of eggs and/or larvae per 1000 m^{-3} of water filtered. All nets were set at dusk and retrieved before 10:00 hours. Contents of collection jar were preserved in 95% ethanol in the field and returned to the laboratory for processing. Samples were sorted using a dissecting microscope and larvae and eggs identified using Serafini and Humphries (2004), and from a reference collection of successive larval stages.

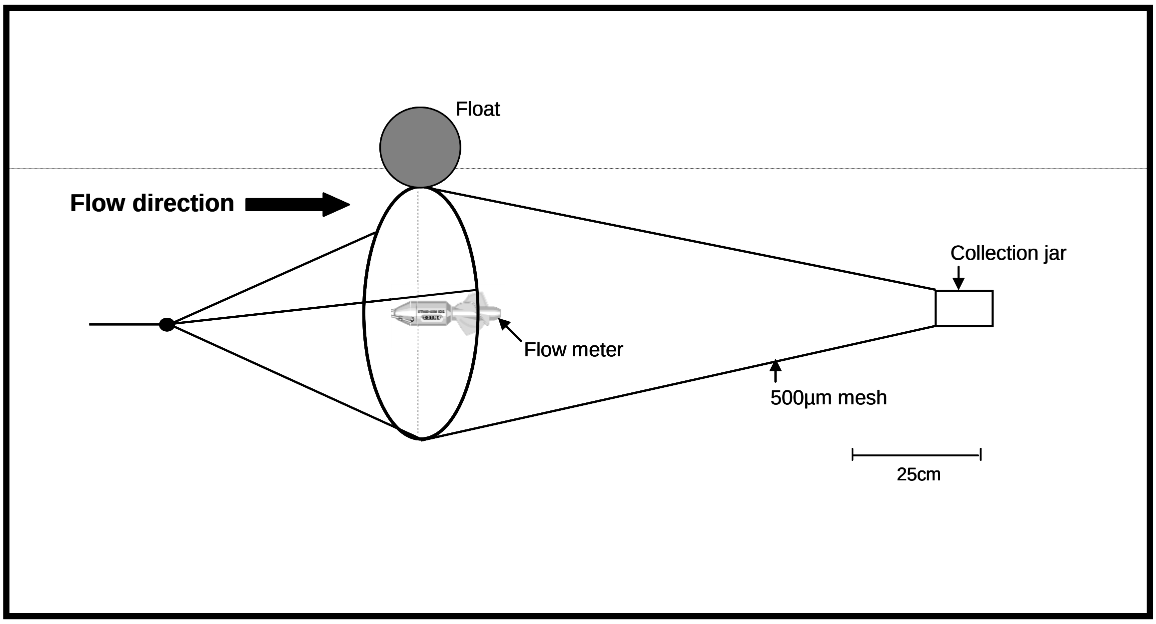


Figure 5. Side view of the standard passive drift net used in the study.

3 Results

Seventeen of the twenty one B-MF survey sites were sampled this year; two creek and two wetland/lake sites were not sampled as they were dry (Tullah Creek, Gulf Creek at 4 mile, Hut Lake and Flat Swamp). All river sites were sampled using a boat mounted electrofisher and Munyana nets.

3.1 Hydrology

Two short-duration floods occurred in July and August/September 2012, sufficient to inundate the B-MF floodplain from July to mid-October 2012, followed by eight months of drying (Figure 6). This drying prevented the sampling of four non-river sites. The flooding of 2011/12 and 2012/13 was more extensive than 2005, but less widespread than 2010/11 which covered approximately 90% of the floodplain (King et al. 2011).

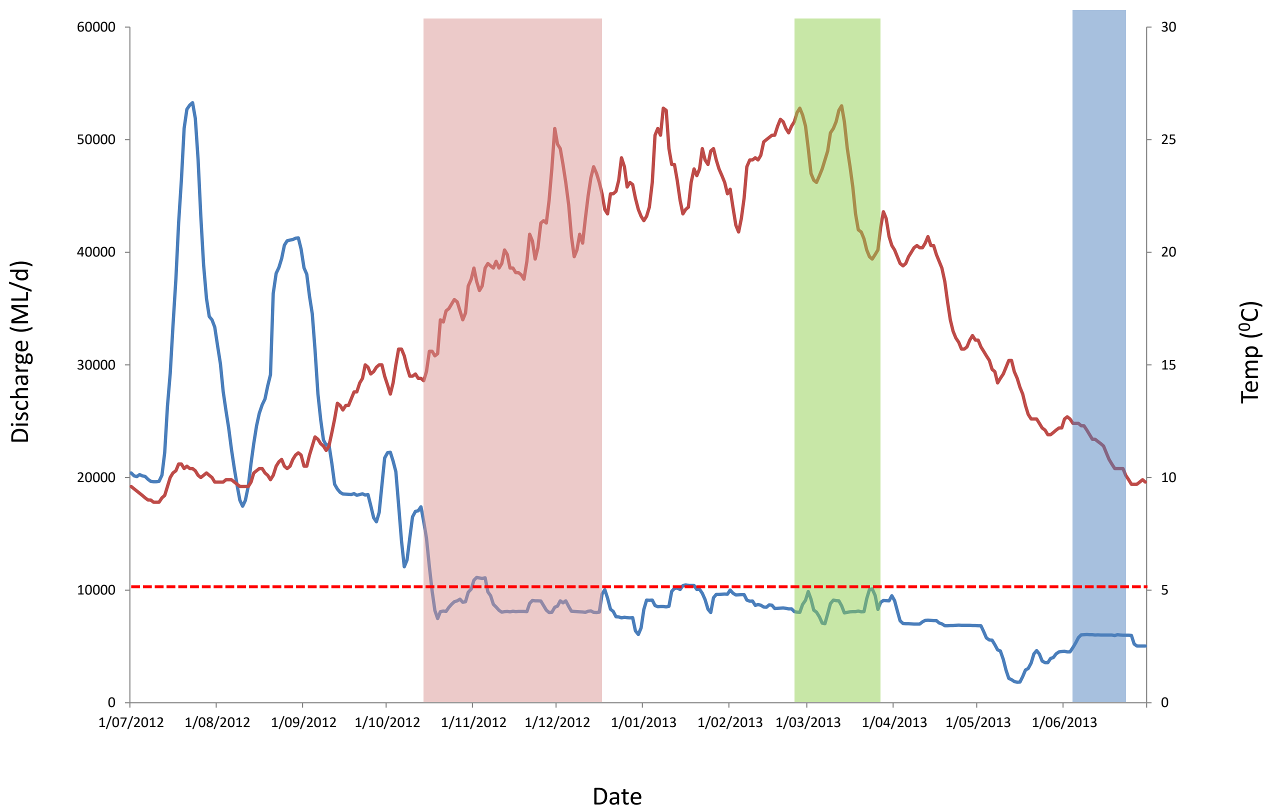


Figure 6. Mean daily discharge of the Murray River downstream of Yarrawonga Weir from June 2012 to July 2013 (blue line). The dashed red line indicates the approximate floodplain inundation height (11,000 ML/d) and the solid red line indicates water temperature. The pink shaded potion of the graph depicts the time of egg and larval sampling, green shading represents creek, wetland and lake sampling and the blue shade indicates time of river sampling (Source: MDBA, Gauge # 409025).

After ten years of drought conditions, multiple flood peaks exceeding 11,000 ML/d (the approximate flow required for commencement of B-MF floodplain inundation) were recorded for the Murray River from July 2010 until October 2012 (Figure 7). The flooding triggered a hypoxic blackwater event, from mid-November 2010 to mid-March 2011, affecting Barmah Lake and the Murray River downstream of Barmah Lake (King et al. 2011). Blackwater events occurred in many rivers and creeks in the southern Murray-Darling Basin, including the Edward-Wakool River system (Lugg 2011), the Lower Murrumbidgee River, Billabong Creek, Broken Creek, Goulburn River, Loddon River, Avoca River, and the Lower Darling River (Whitworth et al. 2012).

During the November 2010 blackwater event Murray Crayfish in the Murray River were observed (pers. obs., S. Raymond) climbing up banks to escape hypoxic conditions, thereby potentially placing themselves at increased risk of poaching and predation. While B-MF floodplain inundation continued from July 2011 to October 2013, peak levels were lower and of less duration compared with November 2010 to February 2011 flows (Figure 7).

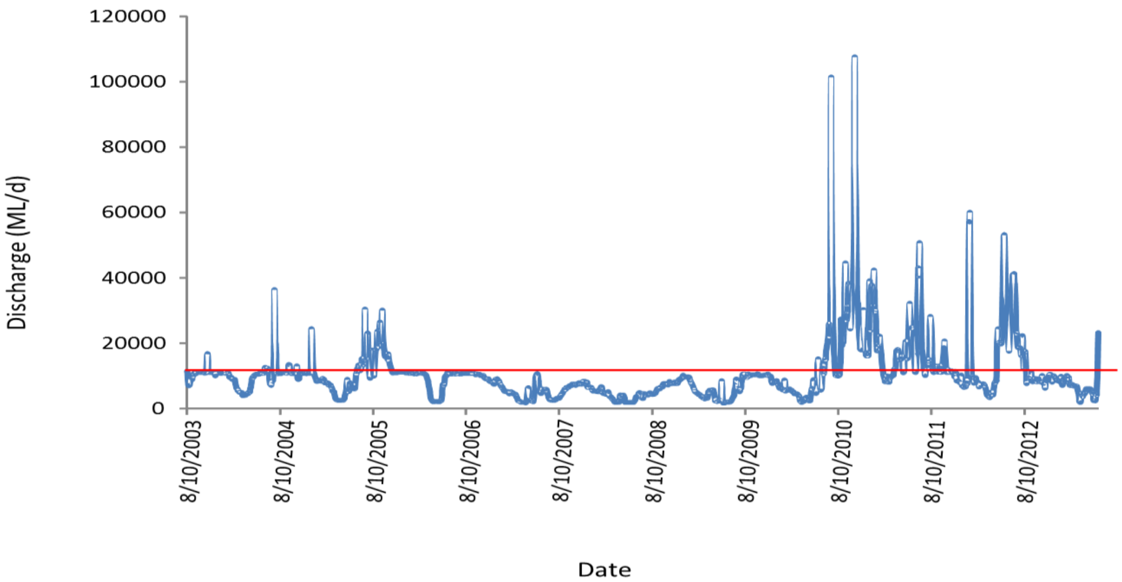


Figure 7. Average daily flows (ML/Day) downstream of Yarrawonga Weir from 2003 to 2013 (Source: MDBA, Gauge # 409025). The red line indicates flow at which B-MF floodplain is inundated.

3.2 Fish surveys

3.2.1 Total catch and community composition

A total of 2,029 fish were either captured (n=1,093) or observed (n= 936) in 2013, representing nine native and four alien species (Table 5). Accordingly, most native and exotic species declined in numbers from 2012, with the notable exceptions being Murray Crayfish and Un-specked Hardyhead *Craterocephalus stercusmuscarum fulvus*. Murray Crayfish numbers doubled and Un-specked Hardyhead abundance increasing 16-fold from 2012 to 2013 (Table 5).

3.2.2 Rivers

A total of 1,300 fish were either captured (n=611) or observed (n=689) from river sites, comprising eight native and three alien species (Table 6). Most common in the catch were Common Carp (71%) and Australian Smelt (12%) with large percentages of Common Carp recorded from the Murray River at Barmah Lake (45%) and Edwards River sites (14%). All of the large-bodied native species previously captured at river sites, such as Murray Cod, Trout Cod, Golden Perch and Silver Perch, were collected.

There was an increase in the total abundance of riverine fish from 2007 to 2010, followed by a decline to 2013. While native fish abundance peaked in 2010 pre-floods, the abundance of alien fish, in particular Common Carp, peaked in 2011 post-flood. Murray and Trout Cod abundances were comparatively higher in 2007 to 2010 than 2011 to 2013. In contrast, abundances of Golden Perch and Common Carp were lower from 2007 to 2010 and higher from 2011 to 2013. Silver Perch abundances fluctuated across years with no clear trends observed .

Of the 15 Murray Cod sampled in 2012/13 (not including those observed), six (40%) were over the recreational size limit of ≥ 600 mm. Murray Cod have maintained a breadth of size classes (cohorts) from 2007 to 2013, but with comparably fewer juvenile fish in 2013 than in previous years (Figure 8).

No YOY Murray Cod, Trout Cod, Silver Perch or Golden Perch were collected this year while a single Common Carp YOY was recorded. This is the first year that YOY Murray Cod and Trout Cod (<150 mm TL) have not been collected from river sites of the B-MF since condition monitoring began in 2007 (Figures 8 & 9). However, a number of cohorts representing juvenile to adult fish were evident for Murray and Trout Cod. In contrast, all Golden and Silver Perch captured across all years were adults with the exception of a single YOY Golden Perch sampled in 2009/10 (Figures 10 and 11).

The abundance of Common Carp at the most downstream site Morning Glory was similar to other river sites from 2006/07 to 2009/10. This changed in 2010/11 when Morning Glory was heavily impacted by flooding and a significant blackwater event prior to sampling. The abundance of Common Carp at Morning Glory increased from nine individuals in 2009/10 to 591 individuals in 2010/11. Since 2010/11, the abundance of Common Carp captured from Morning Glory has declined to 23 individuals in 2012 and 26 individuals in 2013. The 2012/13 total catch and species richness for individual river sites are presented in Appendix 1.

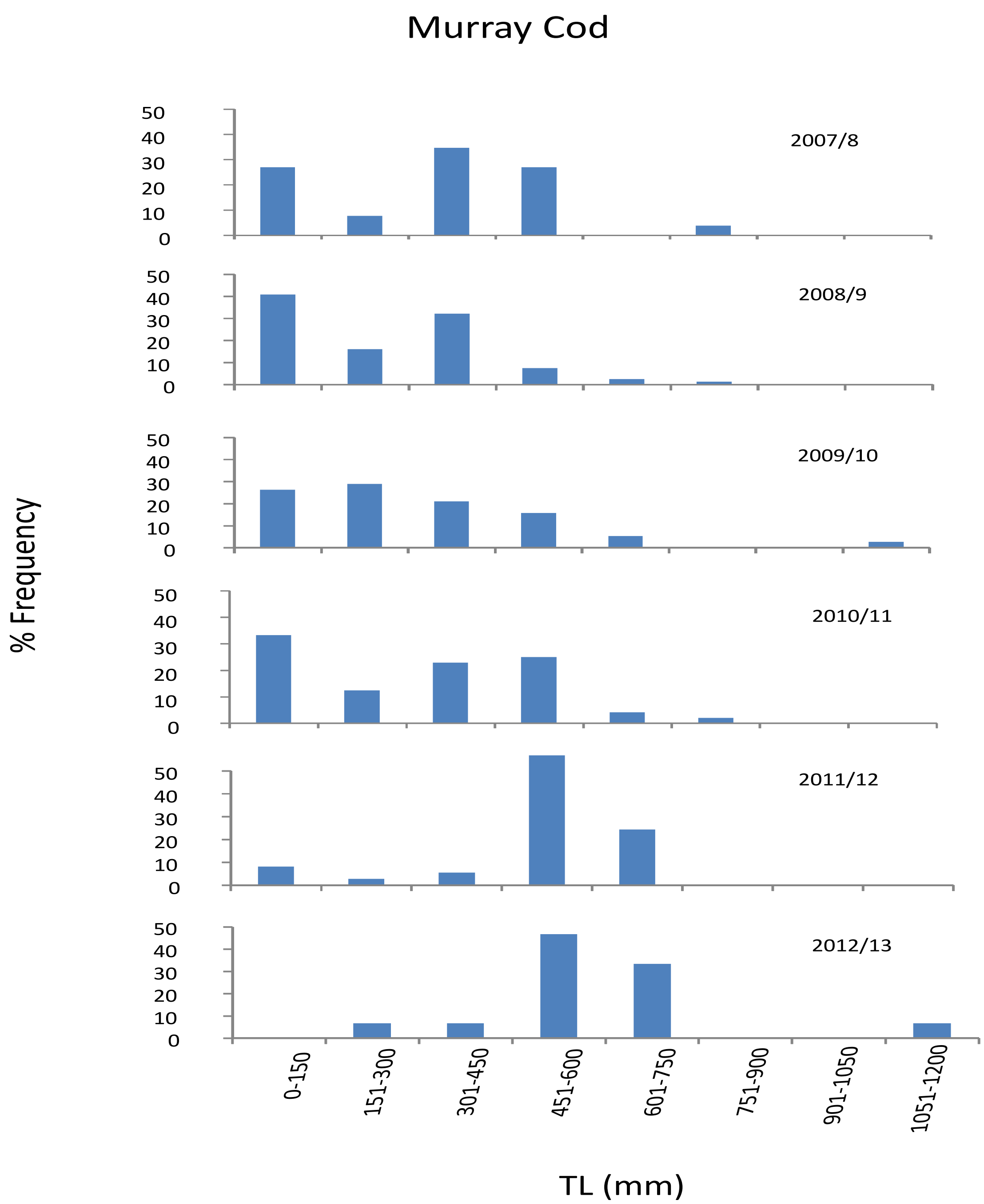


Figure 8. Length frequency (TL) of Murray Cod, 2007 – 2013.

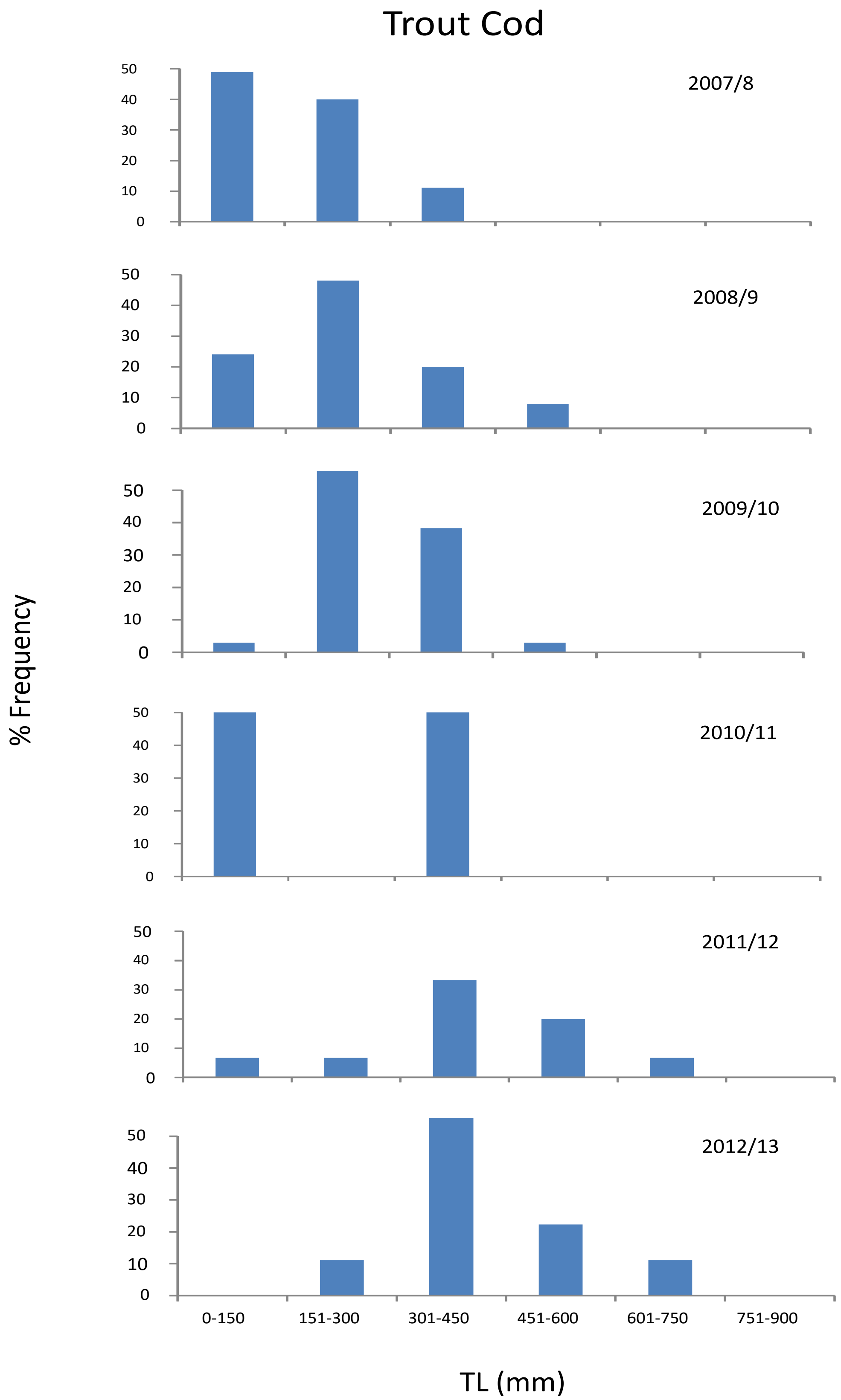


Figure 9. Length frequency (TL) of Trout Cod, 2007 – 2013.

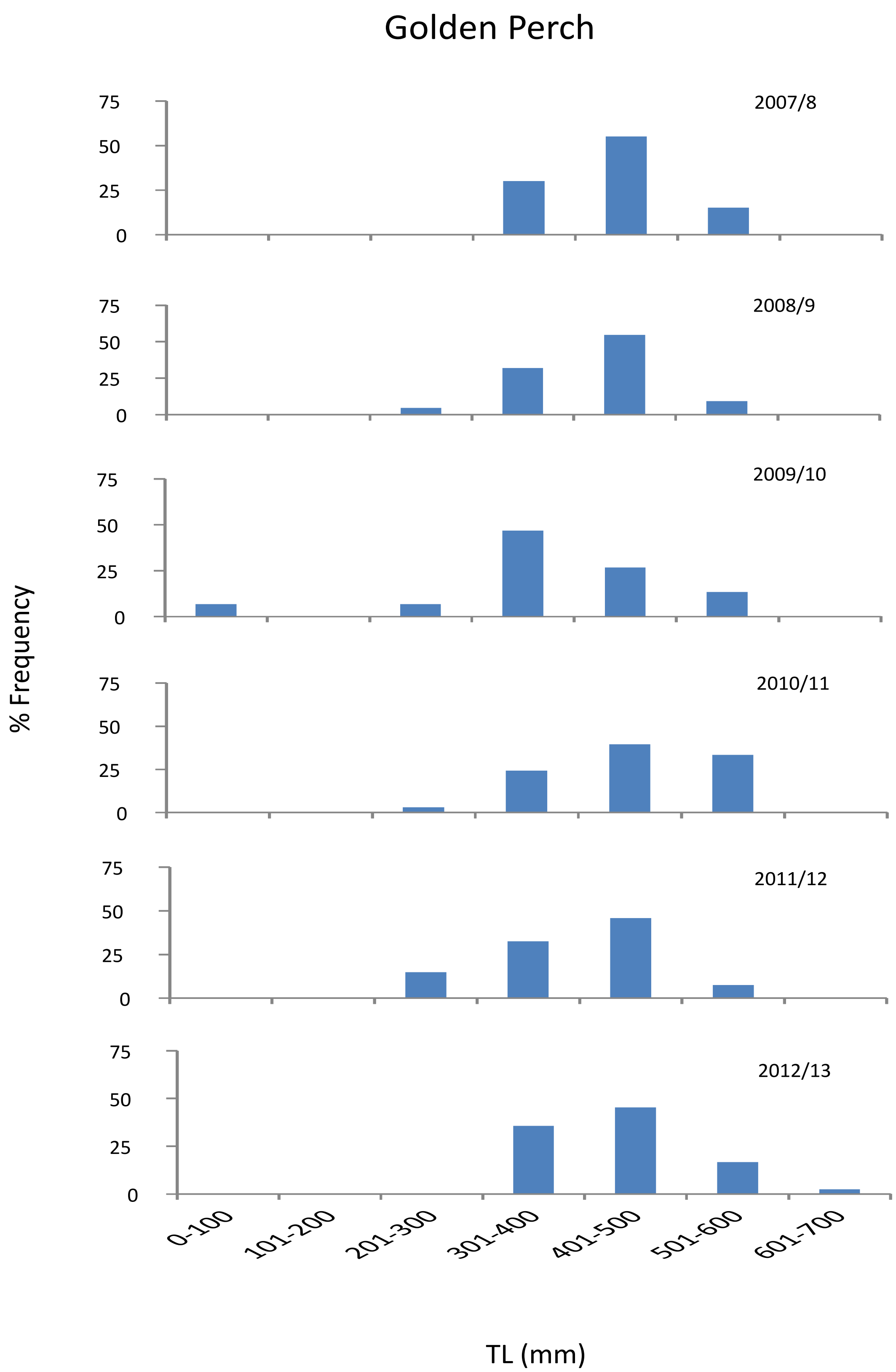


Figure 10. Length frequency (TL) of Golden Perch, 2007 – 2013.

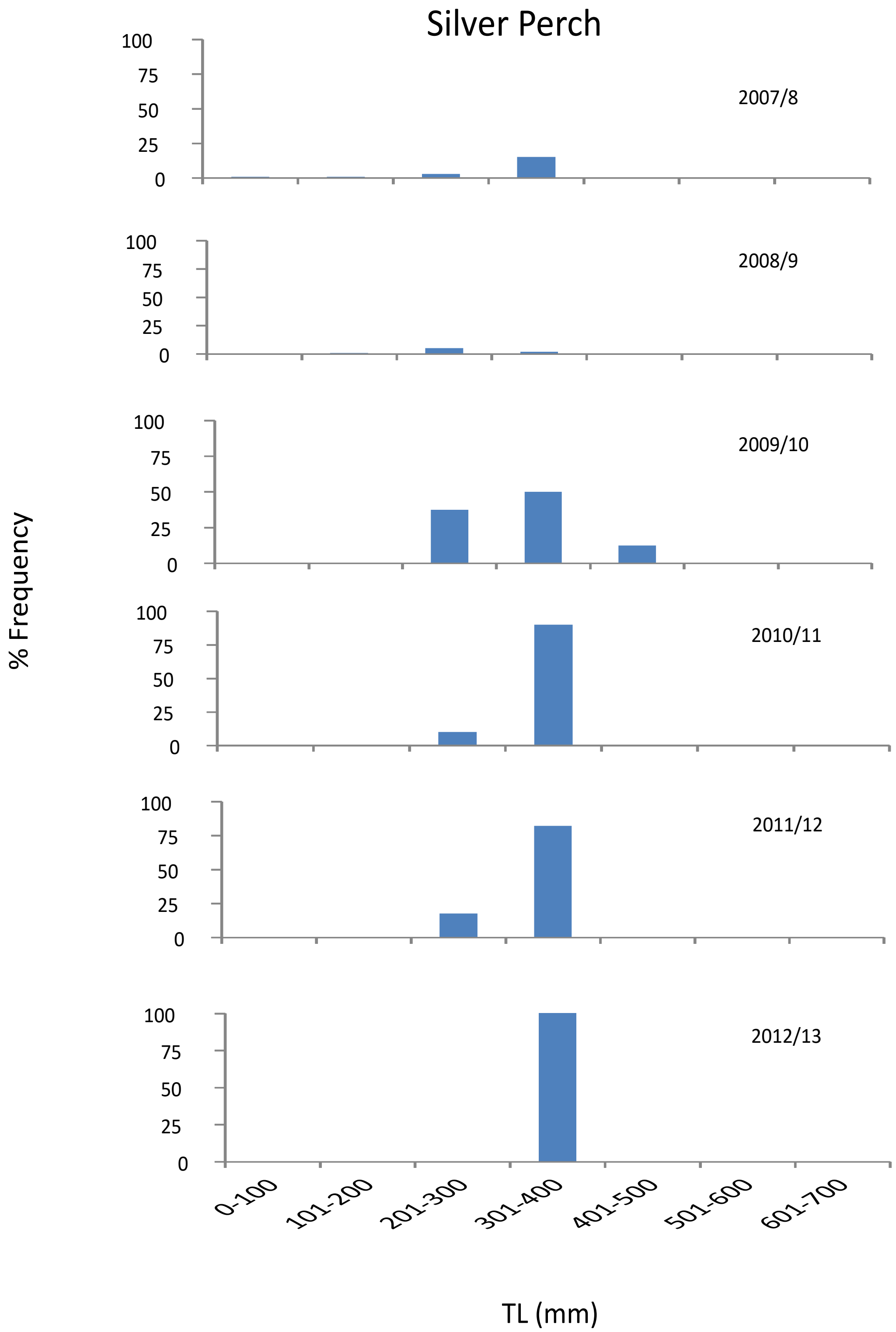


Figure 11. Length frequency (TL) of Silver Perch, 2007 – 2013.

Table 5. Total (caught and observed) fish, 2007-2013.

Common name	Scientific name	2007	2008	2009	2010	2011	2012	**2013**
Native								
Australian Smelt	*Retropinna semoni*	949	1547	1790	4297	2,017	645	**190**
Bony Herring	*Nematalosa erebi*				59			
Dwarf Flat-headed Gudgeon	*Philypnodon macrostoma*	2						
Flat-headed Gudgeon	*Philypnodon grandiceps*	61	18	9	36		39	**1**
Golden Perch	*Macquaria ambigua*	26	22	25	20	36	73	**45**
Murray Cod	*Maccullochella peelii*	29	90	45	85	39	18	**17**
Murray Crayfish	*Euastacus armatus*	9	28	52	24	5	13	**30**
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*	210	89	935	607	149	6	
Silver Perch	*Bidyanus bidyanus*	5	24	12	10	21	21	**9**
Southern Pygmy Perch	*Nannoperca australis*	46						
Trout Cod	*Maccullochella macquariensis*	16	47	25	34	2	8	**9**
Carp Gudgeon	*Hypseleotris spp.*	2854	1570	2142	1951	169	334	**338**
Unidentified cod	*Maccullochella sp.*		2	1				
Un-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	349	1945	1532	3505	65	5	**80**
total natives		**4,556**	**5,382**	**6,568**	**10,628**	**2,503**	**1,162**	**719**
Alien								
Common Carp	*Cyprinus carpio*	377	648	392	632	2,885	1152	**994**
Eastern Gambusia	*Gambusia holbrooki*	467	326	617	1899	3,309	1212	**281**
Goldfish	*Carassius auratus*	167	190	146	409	883	123	**33**
Oriental Weatherloach	*Misgurnus anguillicaudatus*	225	26	61	24	64	58	**2**
Redfin Perch	*Perca fluviatilis*	53			2		1	
total aliens		**1,289**	**1,190**	**1,216**	**2,966**	**7,141**	**2,546**	**1310**
Total Fish Count		**5,845**	**6,572**	**7,784**	**13,594**	**9,644**	**3,708**	**2029**

Table 6. Total (caught and observed) fish (rivers), 2007 - 2013.

Common name*	Species	2007	2008	2009	2010	2011	2012	**2013**
Native								
Australian Smelt	*Retropinna semoni*	615	1,350	1,455	4,254	1015	507	**132**
Bony Herring	*Nematalosa erebi*				59			
Flat-headed Gudgeon	*Philypnodon grandiceps*		9	1				
Golden Perch	*Macquaria ambigua*	24	20	25	19	31	73	**45**
Murray Cod	*Maccullochella peelii*	28	87	41	82	28	18	**12**
Murray Crayfish	*Euastacus armatus*	9	28	52	24	5	13	**30**
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*	208	88	925	577	37		
Silver Perch	*Bidyanus bidyanus*	4	24	11	9	13	18	**9**
Trout Cod	*Maccullochella macquariensis*	16	47	25	34	2	8	**9**
Carp Gudgeon	*Hypseleotris spp.*	392	692	376	96	4	3	**8**
Unidentified *Maccullochella*	*Maccullochella sp.*		2	1				
Un-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	245	1,943	1,450	3,498			**77**
	Cherax longipes							
Alien								
Common Carp	*Cyprinus carpio*	217	453	232	381	902	945	**783**
Common Carp - Goldfish hybrid	*Cyprinus carpio/Carassius auratus*		1					
Eastern Gambusia	*Gambusia holbrooki*	1	7	20	35	53		**1**
Goldfish	*Carassius auratus*	21	45	51	139	275	7	**1**
Oriental Weatherloach	*Misgurnus anguillicaudatus*		1	2			5	
Redfin Perch	*Perca fluviatilis*	1			2			
Total		**1,781**	**4,797**	**4,667**	**9,209**	**2,365**	**1,597**	**1,107**

3.2.3 Creeks

A total of 268 fish, representing four native and four exotic species were sampled from creeks in 2012/13. The species composition of the creeks reflected the absence of Flat-headed Gudgeon *Philypnodon grandiceps* and the addition of Un-specked Hardyhead and Murray Cod over the last year. Australian Smelt (*Retropinna semoni* and Carp Gudgeon *Hypseleotris spp.* made up 22% of the total catch, with Common Carp (32%), Eastern Gambusia *Gambusia holbrooki* (16%) and Goldfish (7%) dominating the alien fish assemblage. Eastern Gambusia numbers (n=42) were significantly lower than 2012 (n=1008) and 2011 (n=1178) and all previous years (Table 7).

From 2007 to 2011, at least three of the following four native species were collected from creek sites; Murray Cod, Golden Perch, Silver Perch and Murray Darling Rainbowfish. The only large-bodied native collected from creek sites in 2013 was Murray Cod. The abundance of all fish species captured in creeks in 2012 was comparably higher than 2013 (Table 7).

Table 7. Total (caught and observed) fish (creeks) 2007 - 2013.

Common name*	Species	2007	2008	2009	2010	2011	2012	**2013**
Australian Smelt	*Retropinna semoni*	196	197	233	40	584	118	**58**
Flat-headed gudgeon	*Philypnodon grandiceps*	29			17		3	
Golden Perch	*Macquaria ambigua*	2	2		1	5		
Murray Cod	*Maccullochella peelii*	1	3	4	3	11		**5**
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*	2	1	8	30	74		
Silver Perch	*Bidyanus bidyanus*			1	1	8		
Southern Pygmy Perch	*Nannoperca australis*	40						
Carp Gudgeon	*Hypseleotris spp*	1,108	532	480	1,399	69	144	**54**
Un-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	13	1	71	5	53		**3**
Common Carp	*Cyprinus carpio*	103	135	116	144	1,616	175	**85**
Eastern Gambusia	*Gambusia holbrooki*	234	305	553	984	1,178	1008	**42**
Goldfish	*Carassius auratus*	93	125	68	111	449	68	**20**
Redfin Perch	*Perca fluviatilis*	1					1	
Oriental Weatherloach	*Misgurnus anguillicaudatus*	67	25	58	24	46	42	**1**
Total		**1,889**	**1,326**	**1,592**	**2,759**	**4,093**	**1,559**	**268**

3.2.4 Lakes

The total fish catch from the B-MF lakes in 2013 was half of last year and similar to 2007 - 2009. Alien fish have dominated the lakes fish assemblage since the beginning of the condition monitoring program, with the exception of 2009 when Australian Smelt accounted for 54% of the catch. No native fish were captured or observed from the B-MF lakes in 2013. The absence of native fish from the lakes is in contrast to previous survey years with the exception of 2008.

Common Carp dominated (87%) the 2013 lake fish assemblage along with Eastern Gambusia (9%) and Goldfish (4%).

Table 8. Total (caught and observed) fish (lakes) 2007 - 2013.

Common name	Species	2007	2008	2009	2010	2011	2012	**2013**
Australian Smelt	*Retropinna semoni*	33		102	3	242	15	
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*			2		6	1	
Silver Perch	*Bidyanus bidyanus*	1					3	
Carp Gudgeon	*Hypseleotris spp*	25			9	5	38	
Un-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*			11		5	5	
Common Carp	*Cyprinus carpio*	36	60	44	105	335	16	**115**
Eastern Gambusia	*Gambusia holbrooki*			2	15	227	190	**12**
Goldfish	*Carassius auratus*	35	20	27	159	146	47	**5**
Oriental Weatherloach	*Misgurnus anguillicaudatus*	2					2	
Total		**132**	**80**	**188**	**291**	**966**	**317**	**132**

3.2.5 Wetlands

The wetland fish community increased from 235 individuals in 2012 to 522 fish in 2013; the change in abundance was largely the result of increases in Carp Gudgeon (n=276) and Eastern Gambusia (n=226). Small numbers of Common Carp (n=11), Goldfish (n=7) and Flat-headed Gudgeon (n=1) were also captured in the 2013 lake survey. Carp Gudgeon and Eastern Gambusia fluctuated in their dominance of the wetland fish community from 2006/7 to 2011/12; native Carp Gudgeons dominated from 2007 to 2009 followed by Eastern Gambusia in 2010 and 2011 and Carp Gudgeons in 2012. In 2013, however, both species were recorded in relatively high numbers. After three years of absence from2007 to 2010, Australian Smelt and Murray-Darling Rainbowfish were observed in the wetlands following the floods of 2011 and 2012, albeit in lower numbers in 2012 and absent from the 2013 catch.

Table 9. Total (caught and observed) fish (wetlands) 2007 – 2013.

Common name	Species	2007	2008	2009	2010	2011	2012	**2013**
Australian Smelt	*Retropinna semoni*	105				176	5	
Dwarf Flat-headed Gudgeon	*Philypnodon macrostomus*	2						
Flat-headed Gudgeon	*Philypnodon grandiceps*	32	9	8	19		36	**1**
Murray-Darling Rainbowfish	*Melanotaenia fluviatilis*					32	5	
Southern Pygmy Perch	*Nannoperca australis*	6						
Carp Gudgeon	*Hypseleotris spp*	1,329	346	1286	447	91	149	**276**
Un-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	91	1		2	7		
Common Carp	*Cyprinus carpio*	21			2	32	16	**11**
Eastern Gambusia	*Gambusia holbrooki*	232	14	42	865	1,851	14	**226**
Goldfish	*Carassius auratus*	17				13	1	**7**
Oriental Weatherloach	*Misgurnus anguillicaudatus*	156		1		18	9	**1**
Redfin Perch	*Perca fluviatilis*	51						
Total		**2,042**	**370**	**1,337**	**1,335**	**2,220**	**235**	**522**

3.2.6 Statistical analysis

Univariate

The difference in the OE score between years was dependant on habitat (Fyear×habitat = 2.8, df = 16, 78, p = 0.001). River sites had higher OE scores than other habitats in all years, averaging 0.6 to 0.7 (2007 – 2010) and 0.4 and 0.5 from 2011 to 2013 (Figure 12). Expected species were not sampled from lake habitats in 2008 and 2013 and, on average, less than 0.3 of expected species were present in sample years. Creek and Wetland sites averaged 0.3 to 0.4 of expected species throughout the study (Figure 12).

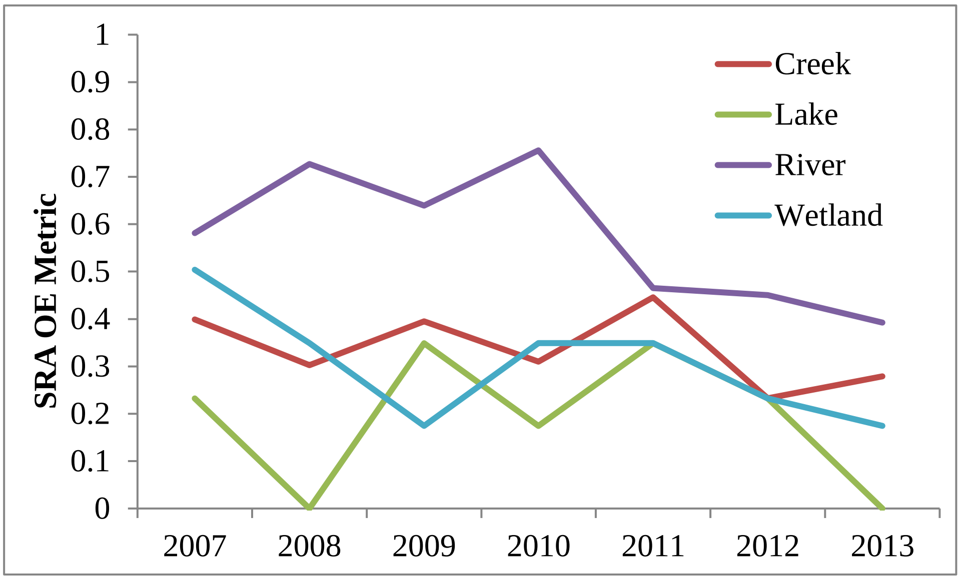


Figure 12. The average proportion of observed to expected species per site, per year in B-MF, 2007 - 2013.

The difference in the proportion of native fish by biomass between years was dependant on habitat (Fyear×habitat = 3.15, df = 18, 78, p = 0.0002). All habitats returned less than 0.4 native fish biomass in all years of the study, except the wetlands in 2008 and 2009 (Figure 12). Generally, the rivers have the highest native fish biomass scores, averaging between 0.2 and 0.3 (Figure 13).

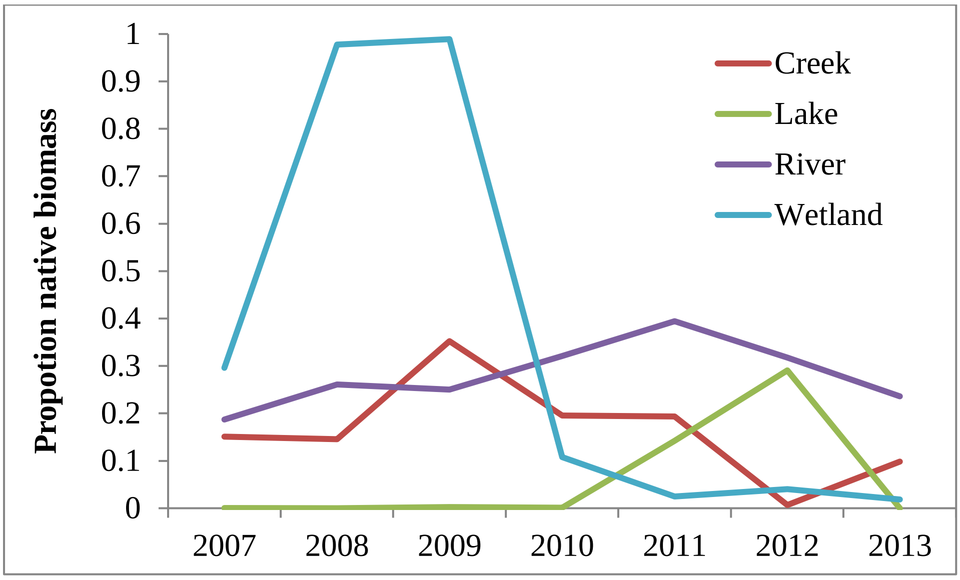


Figure 13. The average proportion of native fish by biomass in B-MF, 2007 - 2013.

The difference in the proportion of native fish abundance between years was dependant on habitat (Fyear×habitat = 2.0, df = 18, 79, p = 0.018). The proportion of native fish was generally lower and more variable in lake habitats, varying between 0 and 0.4 to 0.5 on a year to year basis (Figure 14). Wetland habitats also showed variable proportions of native fish abundance ranging from > 0.95 in 2008 and 2009, to less than 0.3 in 2010 and 2011, improving to > 0.7 native fish in the last two years. Rivers averaged 0.7 to 0.8 native fish 2007 – 2010, however, declined to < 0.5 in the last three years. The proportion of native fish in river habitats was generally greater than in creek habitats. The lowest proportion of native fish sampled were from lake habitats whilst the proportion of native fish in wetland habitats varied throughout the study (Figure 14).

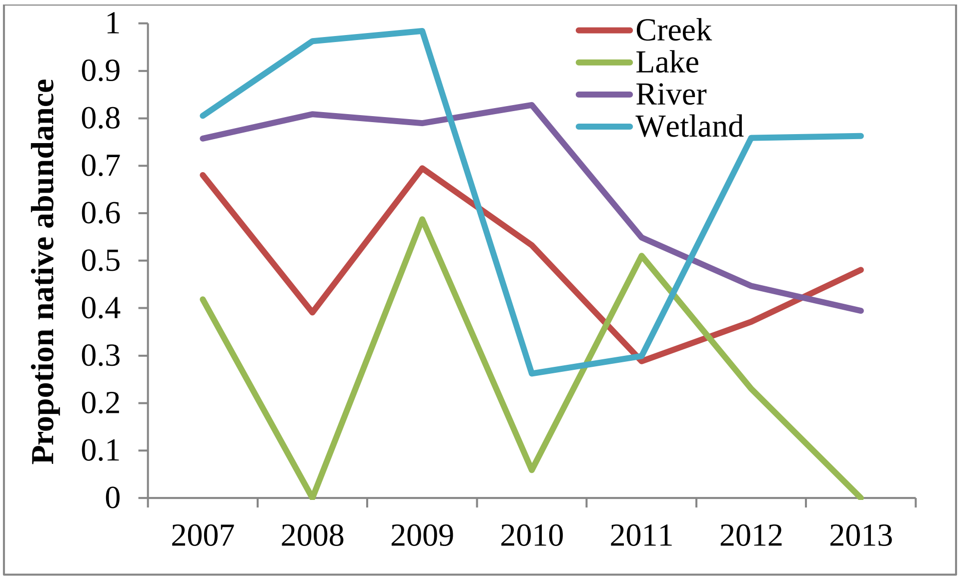


Figure 14. The average proportion of native fish by abundance in B-MF, 2007 - 2013.

All habitats scored more than 0.4 for recruits by abundance in all years, indicating that recruitment occurred in all habitat types throughout the study. However, absolute scores should be treated with caution because of the annual rather than tri-annual sampling used. Temporal trends show that Creek and Wetland recruit abundances were highly variable between years, while river sites were more consistent. River sites showed a clear and consistent downward trend in recruits by abundance from 2008 - 2012, with a slight upturn in 2013 (Figure 15).

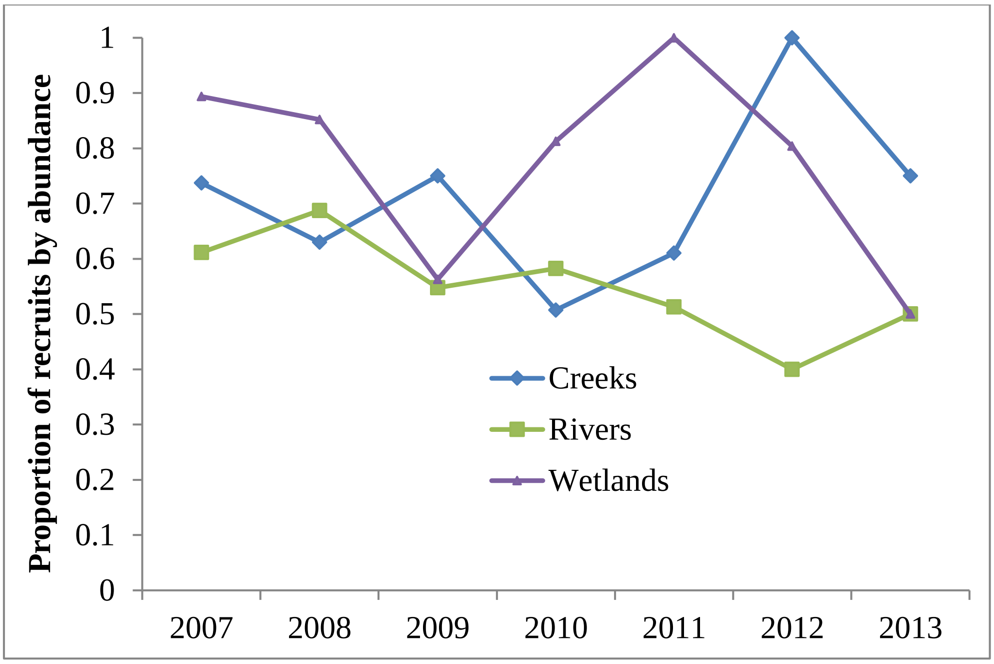


Figure 15. The average proportion of recruits by abundance for fish (including exotic species) in B-MF, 2007 - 2013. Note that this index was not suitable for Lakes.

All wetland sites contained recruited fish between 2007 and 2011, however, only half of wetland sites contained recruits in 2013 (Figure 16). River and Creek sites had 0.5 to 0.7 of sites with recruits; creeks increased to 0.8 in 2012 and declined to 0.6 in 2013. Rivers had 0.3 sites with recruits in 2012 and less than 0.4 of sites with recruits in 2013 (Figure 16).

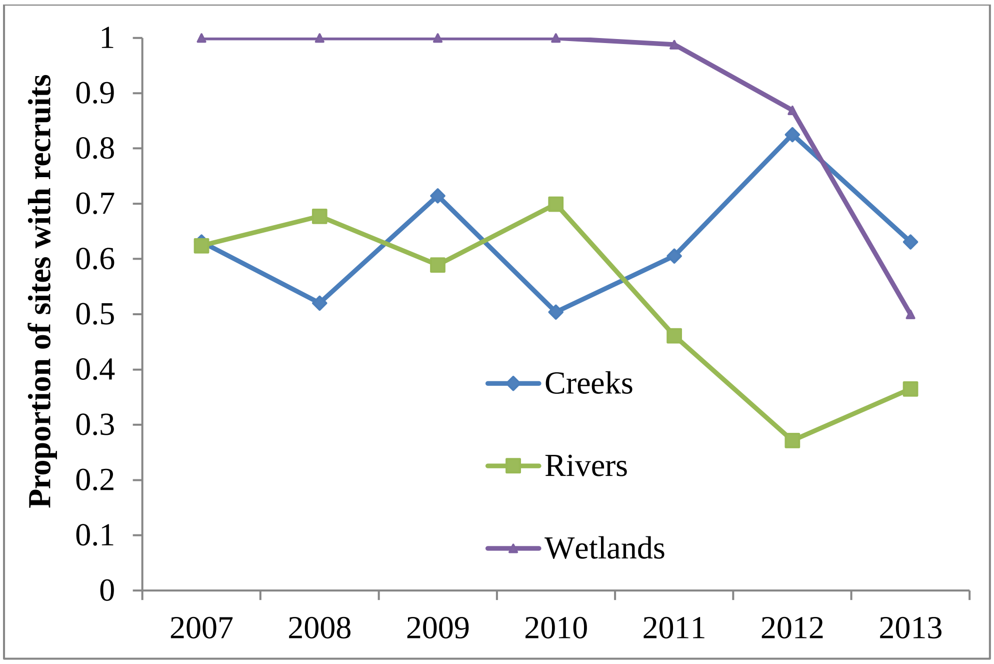


Figure 16. The average proportion of sites with recruits in B-MF, 2007 - 2013. Note that this index was not suitable for Lakes.

Reference Condition for Fish (RCF) recruiting taxa scored 1 in wetlands every year from 2007 - 2012 and declined to less than 0.5 in 2013 (Figure 17). Taxa in rivers and creeks recruited every year from 2007 to 2011 (RCF approximated 0.7); 0.5 of taxa recruited in rivers in the last 2 years, whilst more the 0.75 of taxa recruited in creeks in the last two years (Figure 17).

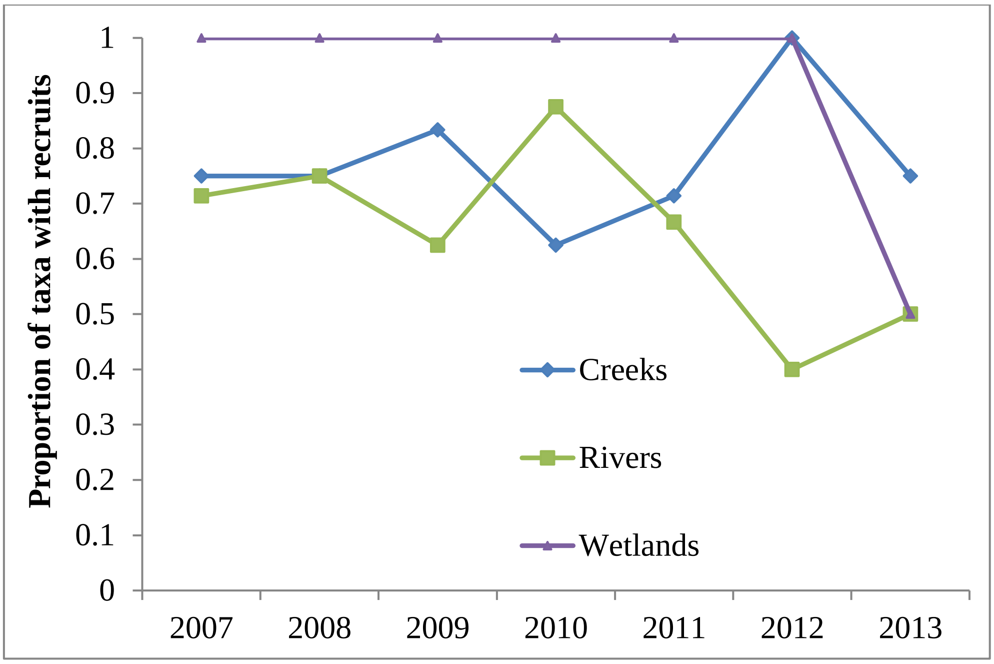


Figure 17. The average proportion of taxa with recruits in B-MF, 2007 - 2013. Note that this indicie was not suitable for Lakes.

Multivariate

There was a significant difference in the fish communities between habitats (pseudo F = 12.3, df = 3, 80, p < 0.0001) and over years (pseudo F = 3.6, df = 6, 80, p < 0.0001). However, the difference between habitats was dependent on the year (pseudo F = 2.4, df =18, 80, p < 0.0001). The similarity plots showed that replicate sites within rivers and creeks maintained consistent similarity through time (Figure 18a). River sites in any year generally had average similarity of 60 - 70%, whilst creek sites had similarities between 40 - 60%. Wetland and lake replicate sites had varying similarities across study years (Figure 18a).

The fish communities in the creek and lake habitats generally shared between 40 - 60% of species throughout the years and about 40% of species with river sites (Figure 18b). The similarity of the wetland fish communities to the other habitats, however, were much more variable, notably with less than 20% of species in common with other habitats in 2009. River sites consistently shared 30 - 40% of species with creeks and wetlands, and 0 - 30% with lakes (Figure 18b).

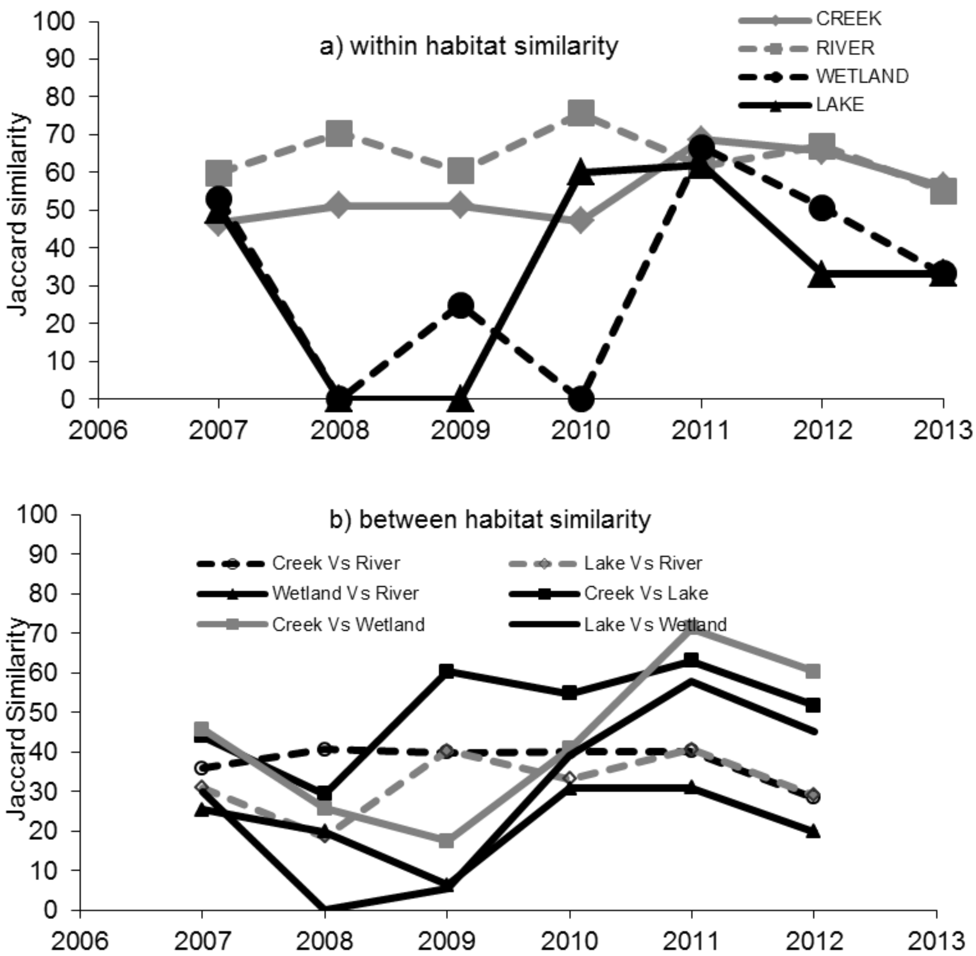


Figure 18. Jaccard Similarity of fish communities a) within and b) between habitat types in B-MF Condition monitoring program, 2007 – 2012/13. The Jaccard similarity can be directly interpreted as the percentage of species in common.

Ordination of fish communities showed a division in fish species between habitats for most years (Figure 18). In particular, a large number of the river sites were associated with large-bodied species, such as Murray and Trout Cod and Golden and Silver Perch, and small bodied Australian Smelt in all years (Figure 19). Many of the creek and wetland sites showed an affinity with Eastern Gambusia, Carp Gudgeon and Flat-headed Gudgeon. Murray-Darling Rainbowfish and Un-specked Hardyhead were also strongly correlated with the ordination space, but not in the direction of any particular habitats. However, most river sites were related to these latter two species in 2007 (Figure 19) .

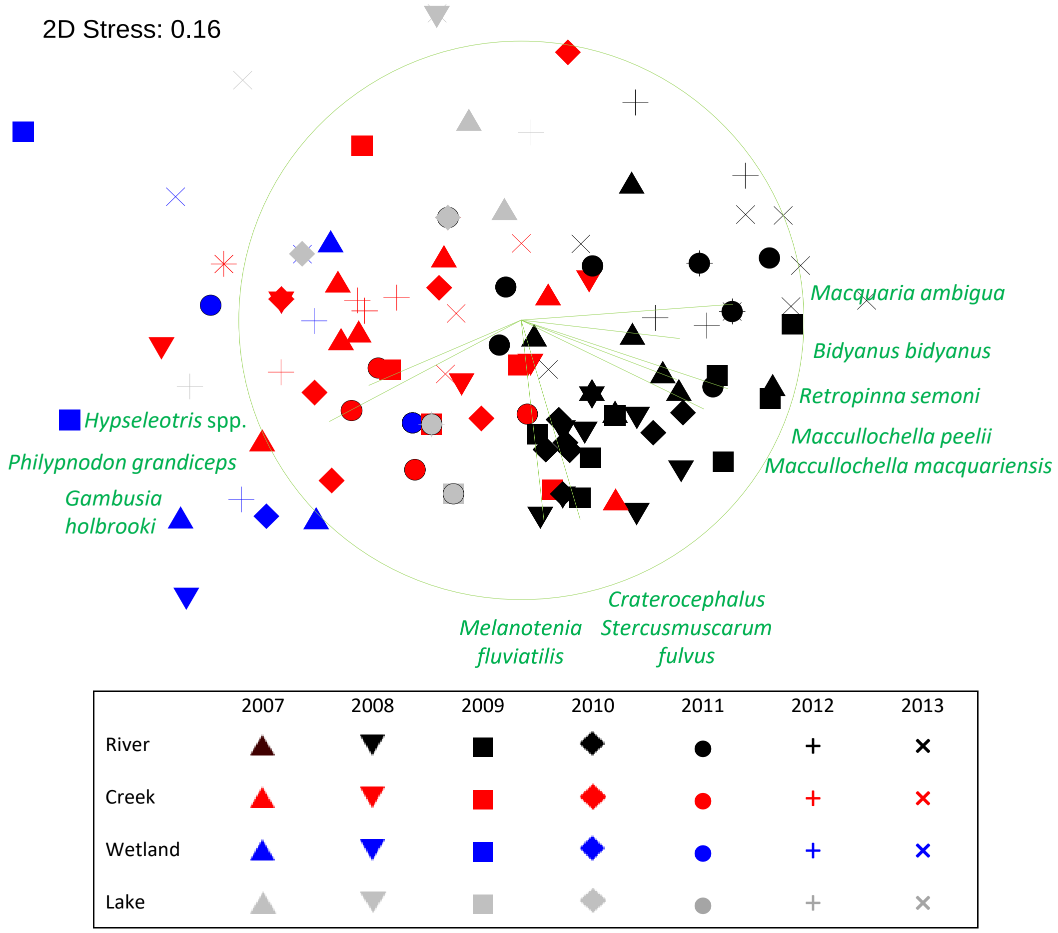


Figure 19. Non-metric multi-dimensional scaling of Barmah fish communities from 2007 to 2013. Fish species showing strong rank correlations (Spearman's rank correlation > 0.5) with the ordination space are included. The circle indicates a correlation of 1.0. Note the position of the taxa in the space should not be interpreted, just the direction of the correlation vector for the taxa.

Murray Crayfish

Thirty Murray Crayfish were sampled in 2012/13, 28 from the five most upstream Murray River sites and two from the most upstream Edwards River site. This brings the total Murray Crayfish collected to 162 over the course of the B-MF condition monitoring program (Table 10). This is the first capture of Murray Crayfish from the Edwards River since the monitoring program began. Murray Crayfish were not detected at the 2010/11 blackwater-affected Morning Glory site for the third consecutive year. A single Murray Crayfish was captured from Barmah Lake, where Murray Crayfish have not been sampled in the previous two years. Thirteen of the Murray Crayfish captured were male, and six of the seventeen females were in berry (with eggs). Four of the five females in berry were captured from the furthest upstream site Ladgroves Beach, with the remaining female in berry captured from the Edwards River. Seven male and ten female Murray Crayfish were over the legal size limit of 100mm. In addition, five juvenile (<2mm occipital carapace length) Murray River Crayfish were captured in larval drift nets set at Morning Glory (n=3) and Barmah Choke (n=2).

Table 10. Number of Murray Crayfish captured from Murray River monitoring sites, 2007 - 2013.

Site name	2007	2008	2009	2010	2011	2012	2013	**Total**
Ladgroves Beach	1	4	0	5	0	3	11	**24**
Murray River @ Gulf Creek	2	1	5	3	0	6	4	**21**
Woodcutters	1	9	7	2	ns	4	3	**26**
Picnic Point	1	0	1	8	5	1	9	**25**
Barmah - Moira Lake area	1	4	0	1	0	0	1	**7**
Morning Glory	3	10	39	5	0	0	0	**57**
Edwards River (5km d/s regulator)	0	0	0	0	0	0	2	**2**
Total	**9**	**28**	**52**	**24**	**5**	**14**	**30**	**162**

ns = not sampled

3.3 Riverine larval drift

Six hundred and seventy four eggs and 401 larvae from seven native and two alien fish species were collected in drift net sampling. Larvae were predominantly identified as being Murray Cod (222), and eggs were predominantly identified as Silver Perch (670). One Trout Cod larvae was sampled over the period, however, no Golden Perch eggs or larva were captured.

Peak and average densities of larvae and eggs varied from 2003 to 2012. These years exhibited different flow regimes (see Figure 7). Larval drift data for each of the Murray River sample locations is presented in Table 11.

The average density of Murray Cod larvae per sampling trip recorded in 2012/13 was 1.8/m^{-3}, which is higher than the 2011/12 average density of larvae, but lower than average densities in 2003 to 2010 of 3.6 - 14 larvae/m^{-3} (Figure 20). The highest density of drifting Murray Cod larvae was recorded at the end of October in five (2004, 05, 06, 08 & 09) of the 10 sample years with no larvae recorded in the first sampling trip (mid-October) in any year. Murray Cod larvae were recorded from end-October to mid-December in 2012, similar to previous years.

The majority (79%) of 2012/13 Murray Cod larval fish (204) were captured from the middle Murray River drift site (Barmah Lake) with smaller numbers captured from Ladgroves Beach (13) and Morning Glory (5) (Table 11). This is in agreement with the 2008 and 2009 data. Since 2010, the majority of drifting Murray Cod larvae captured from the Murray River were sampled from Ladgroves Beach, the furthermost upstream site.

Drifting Trout Cod larvae were only captured in 2009 (4) and 2012 (2), in low numbers with an average density ≤ 1 larvae / m^{-3} per trip. Drifting Trout Cod larvae were captured from Barmah Lake in 2009 and from Morning Glory and Ladgroves Beach in 2012.

Silver Perch eggs were captured in all sample months throughout the larval drift study (Figure 21).The average density of drifting Silver Perch eggs per sample trip in 2012/13 was 28/m^{-3}, lower than previous sample years. The highest density of drifting Silver Perch eggs was 8,275/m^{-3} in December, 2005 with remaining densities less than 2,100/m^{-3} . In the first five years of the study (2003 – 2007) average numbers of drifting Silver Perch eggs per trip ranged from 87 to 1,962/m^{-3} , higher than 2011/12 and 2012/13 averages of 42 and 28, respectively. Silver Perch eggs were most abundant at Ladgroves Beach, followed by Morning Glory, and least abundant at Barmah Lake. Silver Perch eggs were recorded in high abundance (>100) in 2008, 09, 11 & 12 but were not sampled in 2010 (Table 11).

No drifting Golden Perch larvae or eggs were sampled in 2012/13 (Figure 22). This is in contrast with 2003 and 2005 when peak (>500) and average (>100) densities of drifting Golden Perch eggs were recorded in Murray River sites (Morning Glory, Barmah Lake and Ladgroves Beach). Since 2005, peak and average densities of drifting Golden Perch eggs declined to 30 and seven in 2006 and 2010, to less than 1 in other sample years. A single Golden Perch larva was captured from Barmah Lake (2008), three each at Morning Glory and Barmah Lake (2009) and one from Ladgroves Beach (2011) (Table 11).

The majority (92%) of drifting Common Carp larvae were captured from Morning Glory in 2012, consistent with previous years (Table 11). A peak density of 259/m^{-3} drifting Common Carp larvae was recorded in 2007 with densities in subsequent years (2008 – 2012) less than 50/1000 m^{-3} . Drifting Common Carp larvae were generally captured in October throughout the study years (Figure 23). .

Table 11. Raw abundances of drifting larvae and eggs (in parentheses) collected from the Murray River, 2008 - 2012.

		Murray River monitoring sites															
Common name	**Scientific name**	MR Morning Glory					MR Barmah Lake					MR Ladgroves Beach					**Total (2012)**
		2008	2009	2010	2011	**2012**	2008	2009	2010	2011	**2012**	2008	2009	2010	2011	**2012**	
Native																	
Murray Cod	*Maccullochella peelii*	16	10	0	2	**5**	22	26	10	0	**204**	4	0	38	5	**13**	**222**
Trout Cod	*Maccullochella macquariensis*	0	0	0	0	**1**	0	4	0	0	**0**	0	0	0	0	**0**	**1**
Unidentified cod spp.	*Maccullochella spp.*	1	0	0	0	**0**	3	0	0	0	**2**	0	0	0	0	**0**	**2**
Silver Perch	*Bidyanus bidyanus*	0 (15)	(234)	0	(106)	**(39)**	2 (15)	2 (154)	0	(7)	**(72)**	(231)	(426)	0	(139)	**(559)**	**670**
Golden Perch	*Macquaria ambigua*	0	3	(1)	0	**0**	1	3	(7)	0	**0**	0	0	(22)	1	**0**	**0**
Carp Gudgeons	*Hypseleotris spp.*	1	0	1	7	**0**	0	0	0	0	**2**	0	0	7	1	**0**	**2**
Flat-headed Gudgeon	*Philypnodon grandiceps*	5	20	0	9	**0**	31	28	0	0	**0**	22	11	5	2	**0**	**0**
Australian Smelt	*Retropinna semoni*	129	7 (4)	4 (31)	5	**39(2)**	325 (3)	2 (1)	(26)	(7)	**9(2)**	8 (1)	29 (29)	2 (46)	2	**1**	**53**
Murray Crayfish	*Euastacus armatus*	0	0	0	0	**3**	0	0	0	0	**2**	0	0	0	0	**0**	**5**
Alien																	
Goldfish	*Carassius auratus*	2	0	2	0	**0**	0	0	3	0	**1**	1	0	1	0	**0**	**1**
Common Carp	*Cyprinus carpio*	42	14	8	92	**109**	0	6	0	0	**9**	12	2	0	1	**1**	**119**
Eastern Gambusia	*Gambusia holbrooki*	0	0	0	0	**0**	0	0	0	0	**0**	2	0	0	0	**0**	**0**
TOTAL (eggs and larvae)		211	292	47	221	**198**	402	226	46	14	**303**	277	497	121	151	**574**	**1075**

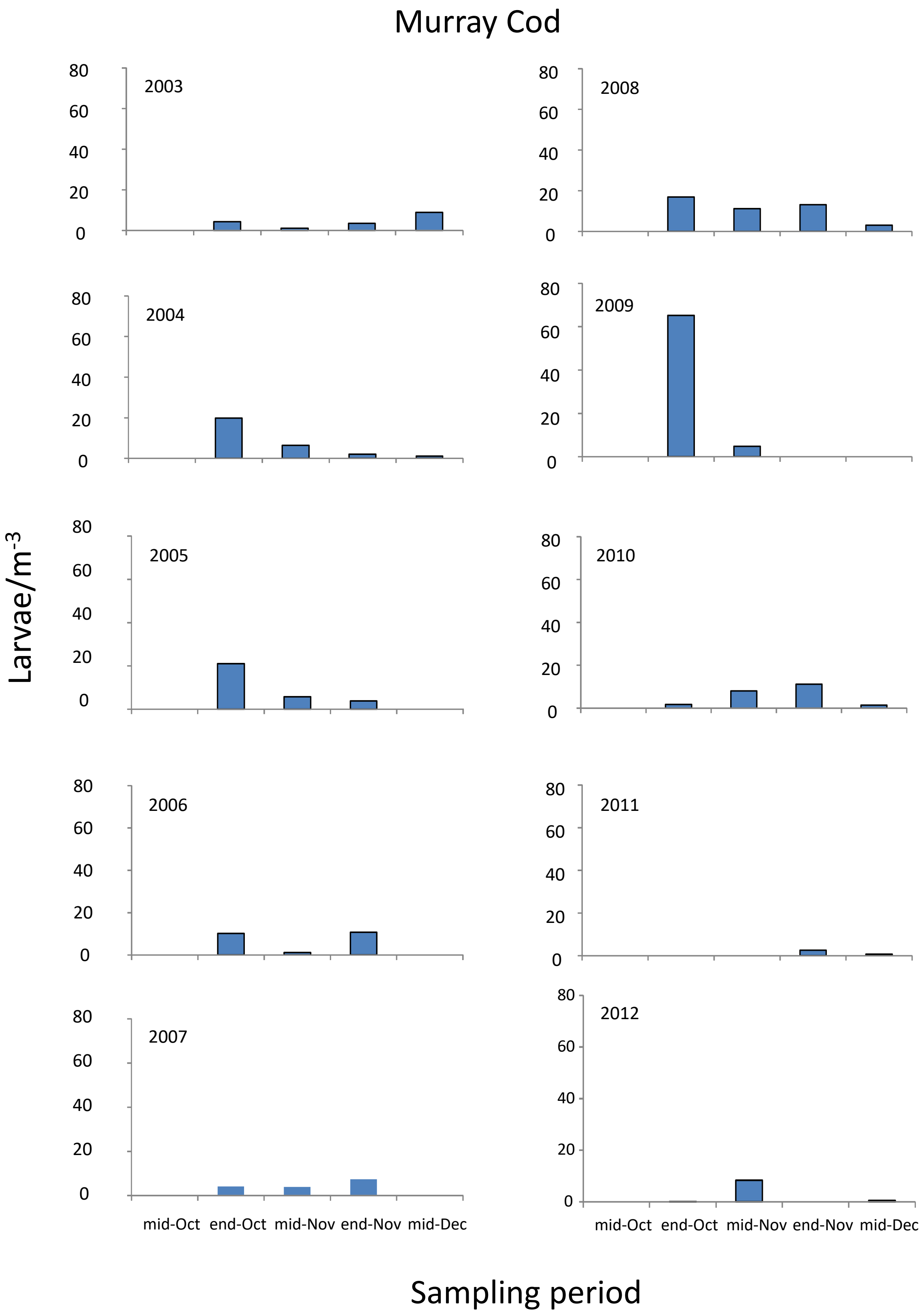


Figure 20. Mean densities (per m^{-3}) of drifting Murray Cod larvae collected from the Murray River, 2003 - 2012.

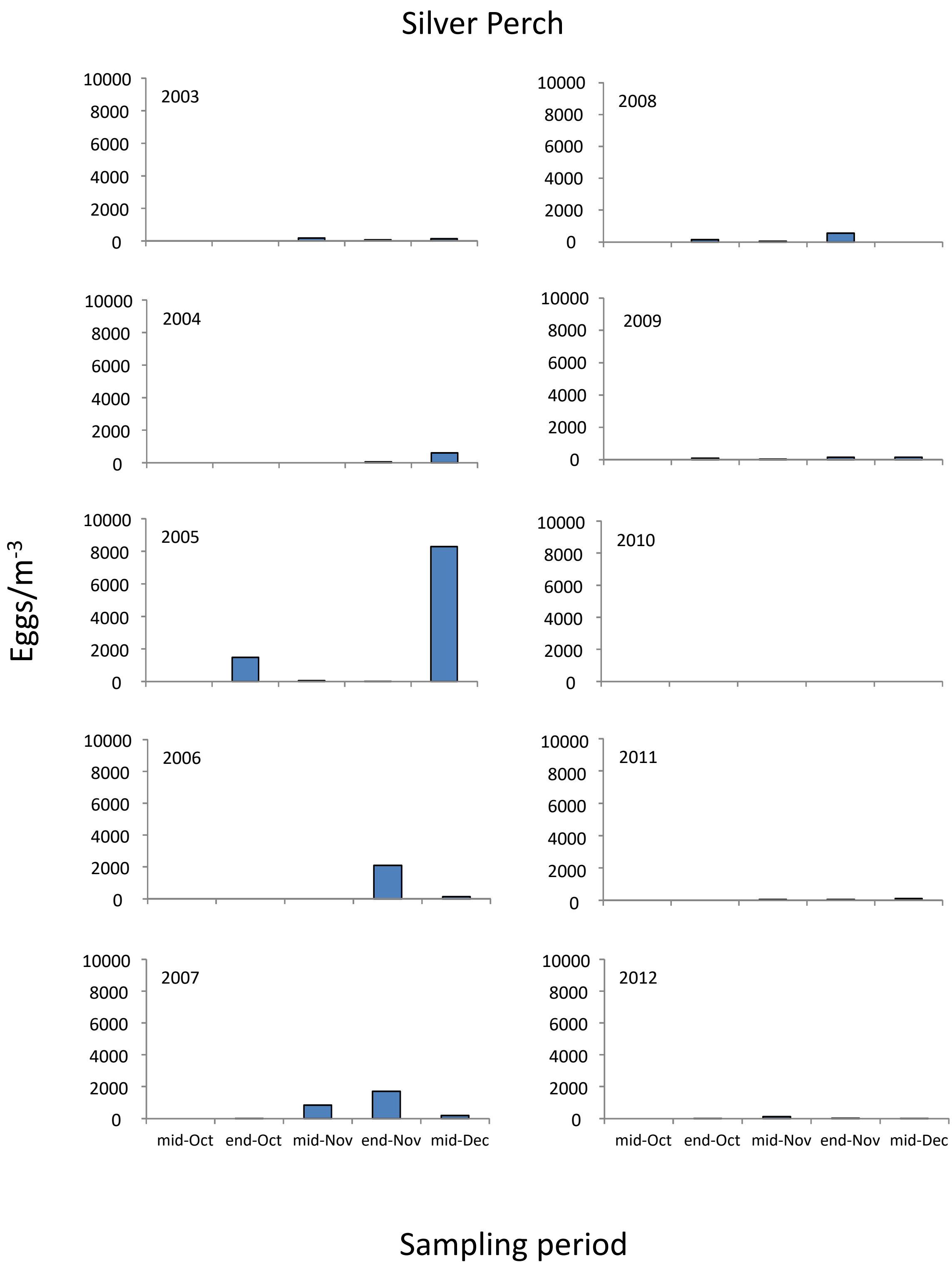


Figure 21. Mean densities (per m^{-3}) of drifting Silver Perch eggs collected from the Murray River, 2003 - 2012.

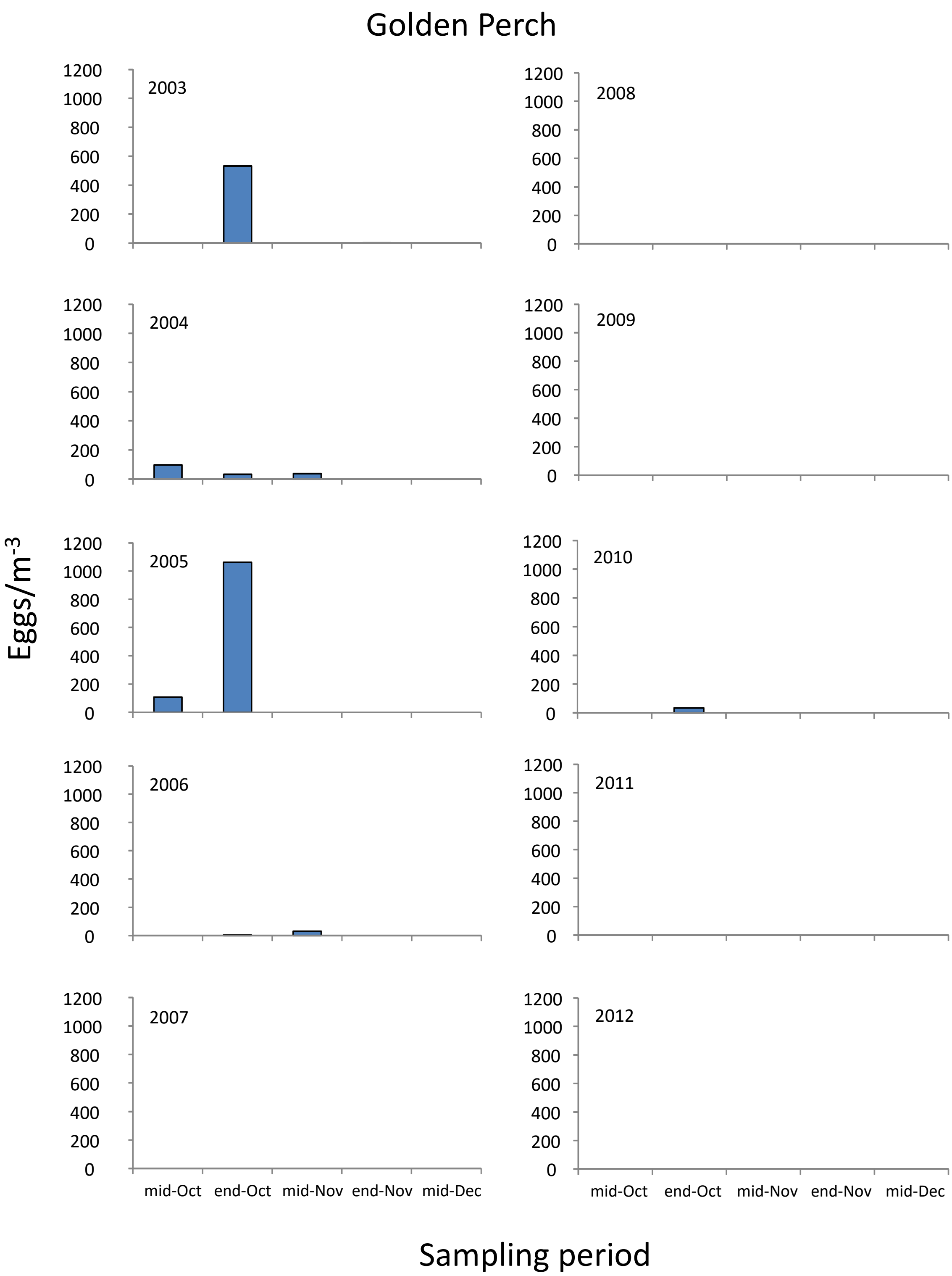


Figure 22. Mean densities (per m^{-3}) of drifting Golden Perch larvae/eggs collected from the Murray River, 2003 - 2012.

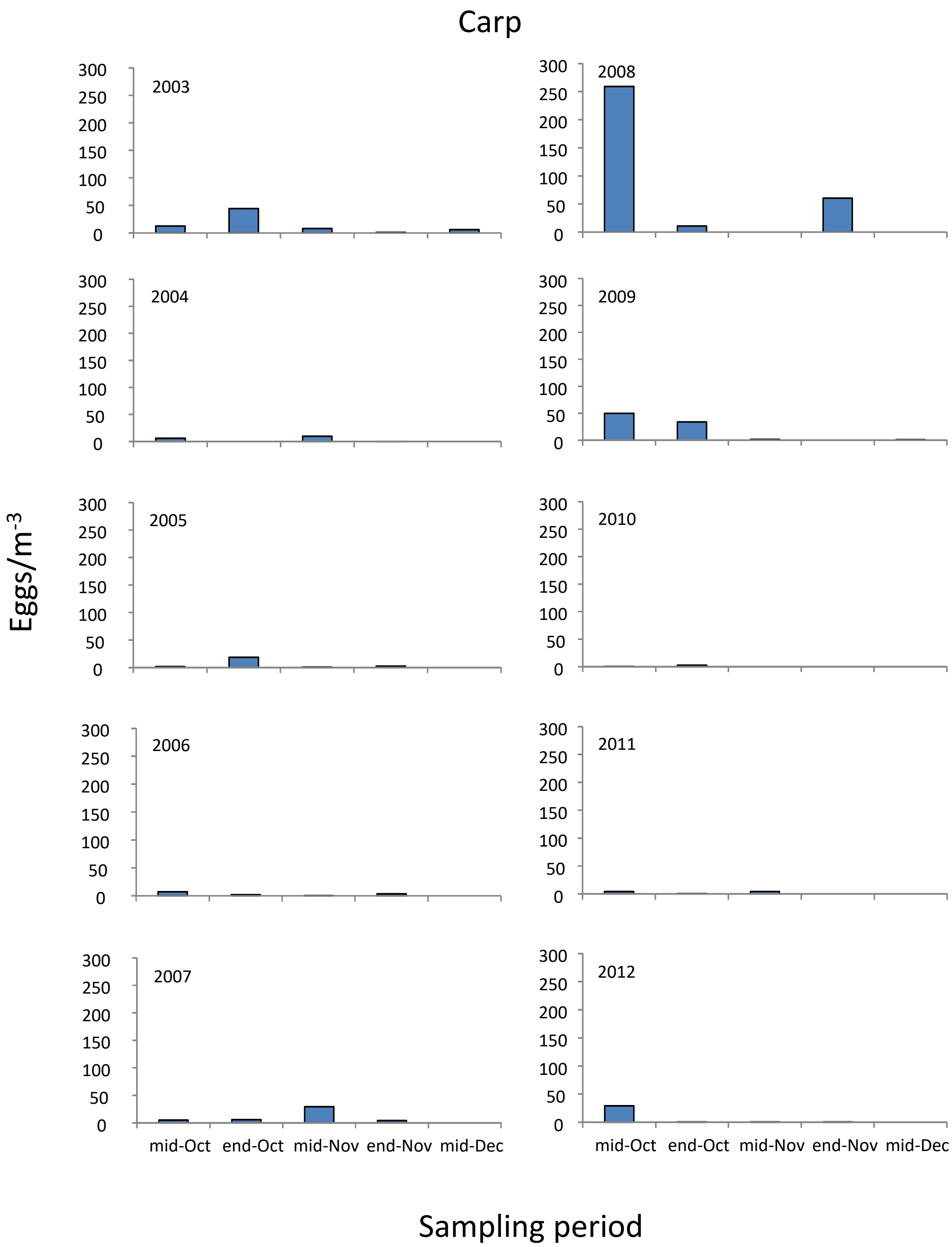


Figure 23. Mean densities (per m^{-3}) of drifting Common Carp larvae collected from the Murray River, 2003 - 2012.

4 Discussion

The condition monitoring program has provided valuable data to benchmark the variability of the fish community in the B-MF. B-MF was flooded for the third consecutive year in 2012/13 following ten years of drought in the region . The first year of widespread and protracted floods triggered a hypoxic blackwater event in the Murray River (mid-November to mid-March 2010/11), while the second and third year of floods represented higher than average flows and did not create water quality issues. The capacity of the project to correlate changes in fish assemblage to flooding has been hampered by the blackwater event. Similarly, the effect of hypoxia creates difficulties in assessing the resilience of the B-MF fish community to drought-breaking flows. However, the project does describe changes in the fish assemblage following a significant blackwater event followed by two years of higher than average flows. Flows, habitat connectivity and differences in fish physiology and behaviour, and differences in fishing gear efficiency are used to help explain the variation in fish assemblages within and between habitats over time.

Over the course of this study from 2007 to present, the observed to expected (OE) metric only approached the 75% target for rivers in 2010, and has since declined to 40% of expected species present in 2013. This decline in native species abundance in rivers is of concern. However, the result is largely due to a decline in small-bodied species (r-selected species) that are prone to large fluctuations in population size (MacArthur and Wilson, 1967). While the number of observed to expected species in wetlands and lakes have also declined in recent years (20% and 0% respectively), this is likely a result of the expected species index that has been developed for river and anabranches habitats. Thus, the low observed numbers in wetlands and lakes are likely an underestimate. Overall, there are many species that were historically present in B-MF that are now locally extinct including; Freshwater Catfish, River Blackfish, Short-headed Lamprey, Macquarie Perch, Murray Hardyhead, Southern Pygmy Perch, Purple Spotted Gudgeon, Flathead Galaxias, Mountain Galaxias and Olive Perchlet. For many of these species, particularly the small-bodied wetland specialists, the only hope for recovery is reintroduction coupled with regular wetland watering to provide the conditions needed for spawning and recruitment. While most of these species have been absent for many years, the Southern Pygmy Perch has not been sampled since 2008 (Tonkin and Rourke 2008). This species is a wetland specialist and it is likely that the prolonged absence of conditions required for successful recruitment, combined with a short life-span (Tonkin et al. 2008), has directly contributed to its disappearance from the B-MF. Theoretically, higher water levels over the past three years could allow this species to recolonise from sites upstream of the B-MF, though the species' largely sedentary behaviour and the presence of intervening barriers, makes this unlikely. If the species fails to re-establish populations in B-MF, a stocking program may be considered. Ideally, this would occur in an area that can be readily provided with environmental water over the spawning season (Tonkin et al. 2008), to maximise the chance of successful spawning and recruitment.

The proportion of recruits (as defined in Table 3) was highly variable between years for creeks and wetlands, with a substantial increase in 2011 and 2012. This was primarily due to the abundance of Eastern gambusia, most likely a result of successful spawning and recruitment following the 2010, 2011 and 2012 flooding. In contrast, the river sites have shown a general decline in recruits over the course of the study, as well as a reduction in the number of sites and taxa with recruits (though all three metrics had a slight improvement in 2013). The general decline in recruits was largely due to the decline of small-bodied species (classified as recruits regardless of body size due to their short life-cycle). This may be due to conditions in the river becoming less suitable to many small-bodied species due to increased flows in recent years, decreased electrofishing efficiency during higher water levels, the preference of small-bodied natives for slower flowing waters or a result of blackwater induced death.

The Recruitment and Expectedness metrics cannot be applied to data collected from lakes given these metrics rely on RCF species lists that were developed specifically for the Murray River and its anabranches. If the SRA methodology is used in future analyses, it would be beneficial to develop a non-river channel species list to improve the accuracy of wetland results and to include lakes.

4.1 Rivers

The riverine fish assemblage differed among years with notable differences in abundance before and after 2010/11. In general, the proportion of native fish (abundance) was stable from 2007 to 2010, and declined thereafter. This was largely attributed to reduced abundances of small-bodied fish such as Un-specked Hardyhead, Australian Smelt, Murray-Darling Rainbowfish and increasing abundances of alien Common Carp post 2010. These changes in abundance are likely to be related to flooding / blackwater induced death or recruitment success, and / or altered sampling efficiency due to differing water height and flow among years.

Fluctuations in abundance and presence/absence of small-bodied natives may be a result of natural variation in the fish community between years, which is not unusual in fish community studies. However, this pattern of decline occurred in three species, and suggests that conditions in the river were genuinely unsuitable for these species. Alternately, conditions in river habitats were unsuited to the capture of small-bodied species.

The four large-bodied native fish species known to inhabit the B-MF region were recorded from the Murray River in all sample years. However, Golden Perch were captured in greater numbers in flood years while Murray and Trout Cod abundances post-flood declined when compared with previous years. Higher water levels may have resulted in an increase in Golden Perch abundance as this species relies on increased flows to spawn and may have been attracted to the region. The decline in Murray and Trout Cod abundance during flooding is possibly an artefact of decreased electrofishing efficiency during higher water levels. This assertion is supported by Lyon et al. (2011) who recorded significant reductions in the electrofishing efficiency of cod within the Murray River during increased water levels in early 2011. As both cod species have shown high site fidelity and a preference for large woody debris (Koehn and O'Connor 1990), their habitats were significantly deeper during flood years compared with previous drought years when water levels were much lower. This suggests that higher water levels may have resulted in an underestimate of the cod population in the past three years compared with surveys during drought years. While capture efficiency and natural variability between sampling years may be used to explain some of the recent reduction in cod numbers, the blackwater event may have reduced the cod population through emigration, food availability, poor water quality and/or death. The B-MF Murray Cod population was represented by a breadth of age/size cohorts throughout the study and by significant numbers (200+) of drifting larvae, suggesting that the population is self-sustaining.

Over the seven year study, one Young-Of-Year (YOY) Silver Perch (2010) and two YOY Golden Perch (2009; 2010) were collected from the Murray River. Lyon et al. (2008) and King et al. (2009) found it difficult to collect YOY Golden and Silver Perch, even following flood events. While this could be related to equipment inefficiencies for collecting this life stage (Dolan and Miranda 2003; Erős et al. 2009), it is possible that recruits for these species are in low abundance or recruitment is occurring in areas not sampled. Silver Perch eggs were collected from all three drift sites in all years, with the exception of 2010/11 where no eggs were captured, indicating that these regions and the habitats and/or flows and temperatures directly above these sites were suitable spawning grounds for this species.

River sites have supported high numbers of Common Carp throughout the condition monitoring program, with greater numbers in 2011 to 2013 than previously. However, less than 5% of Common Carp in the river were one plus aged fish (>150 mm fork length) in 2012 and 2013 compared with 44-80% YOY (<150 mm fork length) fish in previous years. The highest abundances of YOY Common Carp were recorded in 2010/11 and 2011/12. These results indicate that the large flood event of 2010/11 was responsible for the increased recruitment. Large-scale Common Carp recruitment in B-MF during flooding has been reported by other studies (Crook and Gillanders 2006). The large number of adult Common Carp post-flood is cause for concern as these fish have now reached maturity and will spawn once conditions are suitable. This species can successfully spawn and recruit in the river channel during non-flood years when there is a rise in water level for irrigation, and it can also quickly exploit creeks, wetlands and lakes when floods occur (reference). The movement of YOY Common Carp spawned in B-MF downstream could possibly lead to greater abundances of Common Carp within the Murray River at large (Crook and Gillanders 2006; Jones and Stuart 2009).

This project has now amassed seven years of catch data on Murray Crayfish, a species restricted to riverine habitats. Raw catch of this species ranged from five individuals in 2011 to 52 in 2009. In the two years following flooding, fewer total numbers of this species were caught. While sampling variation may be responsible for fluctuations in numbers, it is of concern that this species was not captured from the two most downstream sites in 2011 and 2012 which were impacted by blackwater, with only a single individual caught in 2013. Sampling was also recently carried out upstream of Morning Glory by another study and no Murray Crayfish were present (Martin Asums, pers comm. 2013). The blackwater event resulted in large numbers of Murray Crayfish leaving the water due to low dissolved oxygen levels (King et al. 2012). While they are exposed on the banks they are at risk of predation and collection by recreational anglers. Thus, it is reasonable to suggest that the population in blackwater affected areas was substantially reduced and that the species is yet to recover in these areas. Recovery is likely to be slow given Murray Crayfish have a small home range and limited dispersal (Ryan 2005; Gilligan et al. 2007), and take between six to 10 years to mature (Gilligan et al. 2007). The increas in total number of crayfish caught this year upstream of blackwater affected areas is more likely related to sampling variation rather than population change. A distribution-wide study is currently underway to benchmark current distribution and abundance (mark-recapture methodology), assess reproductive condition, and to determine whether new fishing regulations assist in the recovery of populations.

4.2 Creeks, lakes and wetlands

The B-MF creek fish assemblage is largely driven by small-bodied fish and Common Carp. The occurrence of at least four major (>20,000 ML/d) flood events from July to November 2011 and again in March and June to October 2012 coincided with the likely breeding period of many small-bodied native fish and as such would have made them vulnerable to dispersing flows. High flows may also have contributed to their inability to recolonise and/or build up population numbers prior to sampling in February 2013.

Common Carp numbers within the creeks has remained relatively stable over the past seven years with the exception of 2010/11, when numbers increased by an order of magnitude. This increase was probably due to the first floods in six years triggering a significant spawning event in late spring/early summer 2010. It is likely that downstream dispersal of YOY Common Carp (Crook and Gillanders 2006) resulted in the rapid decline in their abundance from 2011 to 2012.

The total abundance of fish captured from lakes was extremely variable over the course of this study and were largely driven by changes in the abundance of Australian Smelt, Common Carp, Eastern Gambusia and Goldfish. Australian Smelt are typically captured from faster flowing waters along river margins and as such, were most likely washed into lake habitats during high river flows in 2011 and declined with lower water heights prior to sampling in 2012 and 2013. The rapid increase in Common Carp and Goldfish numbers in 2011 was attributed to increased spawning (as noted by the large number of YOY) while reduced numbers in 2012 may have been the result of downstream displacement. The increase in Common Carp numbers in lakes and the absence of native fish from this system in 2013 suggests that conditions are better suited to alien fish. It also suggests that the return of small-bodied native fish species may be hindered in the coming years as a result of increased competition for resources with alien species, and/or due to alien species predating upon native fish eggs and larvae.

The abundance of fish within B-MF wetlands has fluctuated over the last seven years due to varying abundances of Carp Gudgeons and Eastern Gambusia. The preference of Carp Gudgeon for slow flowing waters (Lintermans 2007) may explain the fluctuations in their population over the past six years. For example, they dominated the wetland fish assemblage during drought conditions, declined as flows increased, and increased in abundance as flows and water levels subsided over the past two years. Lack of connectivity between the river and wetlands next season

(2013/14) may result in an increase in the abundance of Carp Gudgeons in the B-MF. Changes in water volume within wetlands, and consequently availability of specific habitats, is likely responsible for the fluctuations in Eastern Gambusia abundance over the course of the project. Their preference for shallow marginal water levels, vegetation and higher temperatures suitable for breeding (Lintermans 2007) may have been accentuated prior to the sampling of wetlands in 2010/11, when water levels were below those required for floodplain inundation (11,000 ML/d). The species ability to rapidly colonise newly inundated habitats (Tonkin et al. 2011a) is likely to have contributed to their dominance over native species during lower water levels in 2011. However, similar environmental conditions in 2012 did not elicit the same increase in the Eastern Gambusia population. It is possible that previous displacement of the population caused by multiple flood events during late 2011 impacted heavily on the Eastern Gambusia population within B-MF wetlands.

4.3 Riverine spawning assessment

The seventh year of egg/larval sampling has shown that the main channel of the Murray River is a spawning habitat for seven species of native fish, including three large-bodied native species (Murray Cod, Trout Cod and Silver Perch). No Golden Perch eggs were recorded in 2011 or 2012 even though previous research indicates that spawning in this species is cued by flooding (King et al. 2007, 2008 and 2009). Silver Perch eggs were present at all three larval drift sites in the two years before and after the 2010 floods indicating that Silver Perch either did not spawn in that year or that conditions for the collection of their eggs was unsuitable. The presence of Murray Cod larvae at Morning Glory in 2011 and 2012 indicates that Murray Cod spawned within or directly upstream of this site following an absence of larvae in 2010, possibly due to blackwater. Murray Cod may have moved back into this section of the river following the abatement of threats associated with blackwater. Comparatively higher abundances of Murray Cod larvae at blackwater-unaffected sites in 2010 and from Ladgroves Beach and Barmah Lake in 2012 suggests that either; some adult Murray Cod may have moved further upstream to spawn in the last two years in response to altered environmental conditions, or that higher flows may have dislodged more larvae from their nests. The decrease in the abundance of Murray Cod larvae at Morning Glory indicates that either adults have been slow to recolonise affected sites, or that the fitness and consequent fecundity of resident adults has decreased. In either case, the change in larval abundance of Murray Cod highlights the potential impact of blackwater on the spawning of large-bodied native fish as noted by the reduction in drifting larvae/eggs of the four large-bodied native fish species post 2010.

Murray Cod larvae were predominantly collected in late November 2011, similar to 2010 data and consistent with numerous other studies (Humphries 2005; Koehn and Harrington 2006; King 2009). Average densities have changed relatively little over the seven year study, supporting the findings of previous studies which indicate that flow conditions have little influence on the presence and densities of Murray Cod larvae (Humphries 2005; Koehn and Harrington 2006; King et al. 2008).

5 Conclusion

The condition of the fish community in B-MF has varied over the course of this study, and was highly dependent on habitat type. The river community appears to have been in decline in terms of number of species present and native fish abundance for the last three years, but this may improve if the system is returned to a more stable flow regime. Creeks have remained somewhat stable in the number of species and abundance of native fish, while lakes and wetlands have been much more variable and are the most susceptible habitats to modified flow and introduced species. While there was a low ratio of observed to expected species within B-MF as a result of the absence of many small-bodied native species, all (with the exception of Southern Pygmy Perch) were absent prior to the commencement of the project and are largely locally extinct and thus their absence was not unexpected. Consequently, with the exception of rivers, the fish community as a whole has not undergone a dramatic improvement or decline over the course of the study, despite an improvement in flow conditions in recent years. There are clearly wide variations in the abundances of individual species in each habitat, and these are a reflection of the dynamic conditions in the B-MF. These fluctuations in numbers should only raise concerns when it affects species that have habitat requirements/conditions that are rarely met or a life-cycle that makes their recovery difficult. For example, Southern Pygmy Perch have not been recorded in the B-MF since 2008 and are a short-lived species and are therefore likely to be locally extinct. Continued condition monitoring in B-MF will enable long-term changes in the fish community to be documented. Whilst the Barmah-Millewa Forest Icon Site Condition Monitoring Plan (2011) contains a range of objectives relating to the fish community, objectives need to be consolidated into one or two clearly defined objectives with measurable targets. This would allow the current broad objectives of the condition monitoring program (see introduction) to be refined and the sampling program to be adapted to ensure those objectives are met. The current program has provided valuable data that can be used to assist in developing a more robust sampling program to address new more clearly defined objectives.

6 References

Allen, G.R., S.H. Midgley, and M. Allen. (2003). Field guide to the freshwater fishes of Australia (Revised Edition). Quality Press, Perth, Western Australia.

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

Clarke, K.R. and Gorley, R.N. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Crook, D.A. and Gillanders, B.M. (2006). Use of Otolith chemical signatures to estimate carp recruitment sources in the mid-Murray River, Australia. *River Research and Applications* **22:** 871-879.

Dolan, C. R. and L. E. Miranda (2003). Immobilization thresholds of electrofishing relative to fish size. *Transactions of the American Fisheries Society* **132:** 969-976.

Erős, T., A. Specziár and P. Bíró (2009). Assessing fish assemblages in reed habitats of a large shallow lake - A comparison between gillnetting and electric fishing. *Fisheries Research* **96:** 70-76.

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

Humphries, P., Serafini, L. G. and King, A. J. (2002). River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47(7):** 1307-1331

Jones, M. J. and I. G. Stuart (2009). Lateral movement of common carp (*Cyprinus carpio* L.) in a large lowland river and floodplain. *Ecology of Freshwater Fish* **18(1):** 72-82.

King, A.J. (2005) Fish and the Barmah-Millewa Forest: history, status and management challenges. *Proceedings of the Royal Society of Victoria* **117:** 117-125

King, A.J., Beesley, L., Petrie, R., Nielsen, D., Mahoney J. and Tonkin Z. (2011) Monitoring fish recruitment, water quality and secondary production in Barmah-Millewa Forest, 2010/11. Unpublished client report 2011. Arthur Rylah Institute for Environmental Research,. Department of Sustainability and Environment.

King, A.J., Tonkin, Z., and Mahoney, J. (2007). Assessing the effectiveness of environmental flows on fish recruitment in Barmah-Millewa Forest. Prepared by Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment. Murray-Darling Basin Authority Commission Project No. BMF 2004.09.

King, A.J., Tonkin, Z., and Mahoney, J. (2008). Assessing the effectiveness of environmental flows on fish recruitment in Barmah-Millewa Forest, 2007/08 Progress report. Unpublished Report to Murray-Darling Basin Commission. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment.

King, A.J., Tonkin, Z and Mahoney, J. (2009). Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. *River Research and Applications* **25:** 1205-118.

King, A.J., Tonkin, Z and Lieshcke, J. (2012). Short-term effects of a prolonged blackwater event on aquatic fauna in the Murray River, Australia: considerations for future events. *Marine and Freshwater Research* **63:** 576-586.

Koehn, J.D. and Harrington, D.J. (2006). Environmental conditions and timing for the spawning of Murray Cod (*Maccullochella peelii peelii*) and the endangered Trout Cod (*M. macquariensis*) on south eastern Australian rivers. *River Research and Applications* **22:** 327-342.

Lintermans M. (2007) Fishes of the Murray-Darling Basin: an introductory guide. Murray-Darling Basin Authority, Canberra

Lyon, J., Bird, T., Nicol, S. and Kearns, J. (2011). Electrofishing efficiency: the great unknown? Spoken presentation. Australian Society for Fish Biology 2011 Conference, Townsville, 22 - 24th July 2011.

Lyon, J., Nicol, S., Kearns, J. and O'Mahony, J. (2008). Monitoring of resnagging between Lake Hume and Yarrawonga - Milestone Report to MDBA TLM Program - December 2008. Unpublished report prepared for the Murray-Darling Basin Commission. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment.

MacArthur, Robert H.; Edward O. Wilson (1967). *The Theory of Island Biogeography*. Princeton, N.J.: Princeton University Press. pp. 203.Murray-Darling Basin Authority. (2012). Barmah-Millewa Forest: Environmental Water Management Plan 2012.

Murray Darling Basin Commission. (2004). Fish Theme Pilot audit Technical Report. Sustainable Rivers Audit. Canberra, Murray-Darling Basin Commission.

Murray Darling Basin Authority. (2013). www.mdba.gov.au/programs/tlm

Muschal, M., Turak, E., Miller, J., Gilligan, D., Sayers, J. and Healey, M. (2010). Technical Support Document – Riverine Ecosystems: NSW State of the Catchments 2008. NSW MER technical report series. NSW Officer of Water, Parramatta.

Peoples, B.K. and Frimpong, E.A. (2012). A snapshot analysis of age distributions of fishes in urban and forested Virginia streams. *Urban Ecosystems* **15:** 927-937.

Raymond, S., Beesley, L. and Robinson, W. (2012). Barmah-Millewa fish condition monitoring: 2010/11 annual report. New South Wales Department of Primary Industries and Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria. Unpublished report submitted to the Murray-Darling Basin Authority.

Raymond, S., Rourke, M. and Tonkin, Z. (2011). Barmah-Millewa fish condition monitoring: 2010/11 annual report. New South Wales Department of Primary Industries and Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria. Unpublished report submitted to the Murray-Darling Basin Authority.

Robinson, W. A. (2012). Calculating statistics, metrics, sub-indicators and the Sustainable Rivers Audit Fish theme index: a Sustainable Rivers Audit Technical Report. Consultancy to the Murray-Darling Basin Authority, 4th April 2012.

Rourke, M., Tonkin, Z. and Raymond, S. (2010). Barmah-Millewa fish condition monitoring: 2010 Annual Summary. NSW Department of Primary Industries and Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria. Unpublished report submitted to the Murray-Darling Basin Authority.

Ryan, K. (2005). The home range behaviour of the Murray crayfish, *Euastacus armatus* (Decapoda: Parastacidae), in the Murrumbidgee River, Australian Capital Territory. Unpublished Honours Thesis, University of Canberra, Australian Capital Territory.

Serafini, L. and Humphries, P. (2004). Preliminary guide to the identification of larvae of fish, with a bibliography of their studies, from the Murray-Darling Basin. Identification and Ecology Guide No. 48. Cooperative Research Centre for Freshwater Ecology, Albury, Australia.

The Living Murray. www.mdba.gov.au/programs/tlm

Tonkin, Z. and Baumgartner, L. (2007). Barmah-Millewa icon site fish monitoring protocol - 2007 annual data summary. Unpublished report to Murray-Darling Basin Commission. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment.

Tonkin, Z. and Rourke, M. (2008) Barmah-Millewa Fish Condition Monitoring - 2008 annual summary and refuge habitat report. Unpublished report submitted to the Murray-Darling Basin Authority. Arthur Rylah Institute for Environmental Research Department of Sustainability and Environment and New South Wales Department Primary Industries.

Tonkin Z., King AJ. and Mahoney J. (2008). Effects of flooding on recruitment and dispersal of the southern pygmy perch (*Nannoperca australis*) at a Murray River floodplain wetland. *Ecological Management and Restoration* **9:** 196-201

Tonkin, Z., Macdonald, J., Ramsey, D., Kaus, A., Hames, F., Crook, D. and King, A. (2011a). Assessing the recovery of fish communities following removal of the introduced eastern gambusia, *Gambusia holbrooki*. Final report submitted to the Murray-Darling Basin Authority. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria.

Tonkin Z. D., King, A. J., Robertson A. I. and Ramsey D.S.L (2011b). Early fish growth varies in response to components of the flow regime in a temperate floodplain river. *Freshwater Biology* **56:** 1769-1782

Whitworth, K.L., Baldwin, D.S. and Kerr, J.L. (2012). Drought, floods and water quality: Drivers of a severe hypoxic blackwater event in a major river system (the southern Murray–Darling Basin, Australia). *Journal of Hydrology* Vol: **450-451:** 190-198.

Appendix 1.

Total catch (caught + observed) and species richness for eight river sites sampled in 2012/13.

Species name	MR Barmah - Lake	ER 5km DS regulator	ER DS Gulpa Creek	MR Ladgroves Beach	MR Morning Glory	Murray River @ Gulf Creek	MR Picnic Point	MR Woodcutters	**Total**
Silver Perch	1				7			1	**9**
Goldfish								1	**1**
Un-specked Hardyhead		9	68						**77**
Common Carp	349	83	25	13	27	74	160	52	**783**
Murray Crayfish	1	2		11		4	9	3	**30**
Eastern Gambusia			1						**1**
Carp Gudgeon		1	7						**8**
Golden Perch	6	3	5	6	5	9	6	5	**45**
Trout Cod	1			2	1		4	1	**9**
Murray Cod	4		2			3	1	2	**12**
Australian Smelt		22	12	45	38	6	2	7	**132**
Grand Total	**362**	**120**	**120**	**77**	**78**	**96**	**182**	**72**	**1107**

Appendix 2.

Raw catch data using all sample methods (caught and observed) for individual sites from 2007 to 2013. NS; site not sampled.

Sitename	Fullcode	_2007	_2008	_2009	_2010	_2011	_2012	2013
Aratula Creek	CARAUR	1	15	3	3	66		
Aratula Creek	CRASTE				2	5		
Aratula Creek	CYPCAR	13	25	3	3	3	3	1
Aratula Creek	GAMHOL	89	21		434	14	13	31
Aratula Creek	HYPSPP	2	47	23	806	15	36	5
Aratula Creek	MELFLU				11	1		
Aratula Creek	MISANG		17		2	24	1	
Aratula Creek	PHIGRA	4			15		3	
Aratula Creek	RETSEM	13				139	1	
Barmah - Moira Lake area	BIDBID	1	5	1	1	6	1	1
Barmah - Moira Lake area	CARAUR				4	1		
Barmah - Moira Lake area	CRASTE	1	10		31			
Barmah - Moira Lake area	CYPCAR	58	46	32	9	6	5	349
Barmah - Moira Lake area	EUAARM	1	4		1			1
Barmah - Moira Lake area	GAMHOL		3		7			
Barmah - Moira Lake area	HYPSPP		17		1			
Barmah - Moira Lake area	MACAMB	4		3		22	2	6
Barmah - Moira Lake area	MACMAC	4	6	4	6			1
Barmah - Moira Lake area	MACPEE	1	4	1	6	8		4
Barmah - Moira Lake area	MELFLU		6		41			
Barmah - Moira Lake area	RETSEM	43	375	47	566	77	8	
Barmah Lake	BIDBID						3	
Barmah Lake	CARAUR	29	20	3	149	1	35	7
Barmah Lake	CRASTE			11		1		
Barmah Lake	CYPCAR	15	60	44	2	327	13	118
Barmah Lake	GAMHOL			2		116		
Barmah Lake	HYPSPP				5	3		
Barmah Lake	MELFLU			2		2		

Barmah Lake	MISANG	2					1		
Barmah Lake	RETSEM	6		102	3	54	1		
Budgee Creek	BIDBID				1				
Budgee Creek	CARAUR		16	11	1		8		1
Budgee Creek	CRASTE			14					
Budgee Creek	CYPCAR	26	38	4	39		10		48
Budgee Creek	GAMHOL	1	1	26	2		13		2
Budgee Creek	HYPSPP	1	6	39	24		3		7
Budgee Creek	MACAMB	1							
Budgee Creek	MACPEE		1					1	
Budgee Creek	MELFLU		1	2					
Budgee Creek	MISANG						13		2
Budgee Creek	RETSEM	99	98	66	25		20		33
Edward River 5km DS regulator	BIDBID			1		1	1		
Edward River 5km DS regulator	CARAUR	9	3	9	9	32	1		
Edward River 5km DS regulator	CRASTE	82	436	7	512				9
Edward River 5km DS regulator	CYPCAR	8	15	36	42	217	23		98
Edward River 5km DS regulator	GAMHOL			15	1	50			
Edward River 5km DS regulator	HYPSPP	1	19	152	5	1	1		1
Edward River 5km DS regulator	MACAMB	1	3	4	3	1	2		3
Edward River 5km DS regulator	EUAARM								2
Edward River 5km DS regulator	MACMAC	8			1		1		
Edward River 5km DS regulator	MACPEE	9	2	5	6		1		
Edward River 5km DS regulator	MELFLU	207	2	33	1	35			
Edward River 5km DS regulator	PERFLU				1				
Edward River 5km DS regulator	PHIGRA			1					
Edward River 5km DS regulator	RETSEM	33	9	7	50	1	1		22
Edward River DS Gulpa Creek	BIDBID		2						
Edward River DS Gulpa Creek	CARAUR	12	2	4	2	149			
Edward River DS Gulpa Creek	CRASPP			1				78	
Edward River DS Gulpa Creek	CRASTE	23	7	5	8				
Edward River DS Gulpa Creek	CYPCAR	15	27	17	27	53	15		25
Edward River DS Gulpa Creek	GAMHOL			5	1	2		1	
Edward River DS Gulpa Creek	HYPSPP	1	2	21	14			7	

Edward River DS Gulpa Creek	MACAMB	5		5	3	2	1	5
Edward River DS Gulpa Creek	MACMAC			3	1			
Edward River DS Gulpa Creek	MACPEE	2	1	8	6	5		2
Edward River DS Gulpa Creek	MACSPP			1				
Edward River DS Gulpa Creek	MELFLU	1	3	12	5			
Edward River DS Gulpa Creek	MISANG						2	
Edward River DS Gulpa Creek	RETSEM	105	10	11	18	98	6	13
Fishermans Bend Lagoon	CRASTE	91	1		2			
Fishermans Bend Lagoon	CYPCAR	9			2	1	3	6
Fishermans Bend Lagoon	GAMHOL	8	14	23	450	9	6	
Fishermans Bend Lagoon	HYPSPP	6	346	101	428	20	48	28
Fishermans Bend Lagoon	MELFLU						1	
Fishermans Bend Lagoon	MISANG	1		1		1		1
Fishermans Bend Lagoon	NANAUS	1						
Fishermans Bend Lagoon	PERFLU	47						
Fishermans Bend Lagoon	PHIGRA	3	9	4	19		34	1
Fishermans Bend Lagoon	RETSEM	101						
Flat Swamp	CARAUR	17				12	1	ns
Flat Swamp	CRASTE					6		ns
Flat Swamp	CYPCAR	12				16	10	ns
Flat Swamp	GAMHOL	80				73	4	ns
Flat Swamp	HYPSPP	660				1	5	ns
Flat Swamp	MELFLU					21		ns
Flat Swamp	MISANG	155				1	2	ns
Flat Swamp	NANAUS	4						ns
Flat Swamp	PERFLU	4						ns
Flat Swamp	PHIMAC	2						ns
Flat Swamp	RETSEM	2				150		ns
Gulf Creek @ Four Mile	CARAUR	3		42	68		49	ns
Gulf Creek @ Four Mile	CRASTE			1		1		ns
Gulf Creek @ Four Mile	CYPCAR	13		73	26	1	19	ns
Gulf Creek @ Four Mile	GAMHOL	2		401	283	3	62	ns
Gulf Creek @ Four Mile	HYPSPP	42		246	120	1	3	ns
Gulf Creek @ Four Mile	MISANG	10		57	22	3	18	ns

Gulf Creek @ Four Mile	NANAUS	7						ns
Gulf Creek @ Four Mile	PERFLU	1						ns
Gulf Creek @ Four Mile	RETSEM	2		8		30	29	ns
Gulpa Creek	CARAUR	1	6	10	1	218	3	18
Gulpa Creek	CRASTE	2				2		
Gulpa Creek	CYPCAR	7	7	2	4	176	38	12
Gulpa Creek	GAMHOL					160		
Gulpa Creek	HYPSPP		1	7		32	9	1
Gulpa Creek	MACAMB		1					
Gulpa Creek	MACPEE	1	1	1	3			1
Gulpa Creek	MELFLU	1		1		2		
Gulpa Creek	MISANG					2		
Gulpa Creek	RETSEM	6	54	1		25	4	3
Hut Lake	CARAUR					2	12	ns
Hut Lake	CRASTE					4	5	ns
Hut Lake	CYPCAR					3	3	ns
Hut Lake	GAMHOL					5	170	ns
Hut Lake	HYPSPP						7	ns
Hut Lake	MELFLU					4	1	ns
Hut Lake	RETSEM					1	11	ns
Ladgroves Beach	BIDBID		1		2		1	
Ladgroves Beach	CARAUR		2		12	2		
Ladgroves Beach	CRASTE	33	508	164	474			
Ladgroves Beach	CYPCAR	33	64	15	58	9	1	13
Ladgroves Beach	EUAARM	1	4		5		1	11
Ladgroves Beach	GAMHOL				1			
Ladgroves Beach	HYPSPP	7			1		1	
Ladgroves Beach	MACAMB	4		1		1	1	6
Ladgroves Beach	MACMAC	1	15	6	10	1	2	2
Ladgroves Beach	MACPEE	7	24	5	14	6	1	
Ladgroves Beach	MELFLU		4		30	2		
Ladgroves Beach	RETSEM	264	254	121	811	257	4	45
Moira Lake	BIDBID	1						
Moira Lake	CARAUR	6			10	7		

Moira Lake	CYPCAR	21			80	5	2	
Moira Lake	GAMHOL				8		20	12
Moira Lake	HYPSPP	24			2	1	5	
Moira Lake	MISANG						1	
Moira Lake	RETSEM	27				187	2	
Morning Glory	BIDBID	1	2	2	2	2	1	7
Morning Glory	CARAUR		17	26	84	85	1	
Morning Glory	CRASTE		19	22	163			
Morning Glory	CYPCAR	26	29	10	35	591	1	27
Morning Glory	EUAARM	3	10	39	5			
Morning Glory	GAMHOL		1			1		
Morning Glory	HYPSPP	3	2		2	1		
Morning Glory	MACAMB		3	3	1	2	1	5
Morning Glory	MACMAC		3	1	2			1
Morning Glory	MACPEE	1	9	3	7		1	
Morning Glory	MELFLU		13					
Morning Glory	MISANG		1					
Morning Glory	NEMERE				5			
Morning Glory	PERFLU	1			1			
Morning Glory	RETSEM	26	171	6	209	13	1	38
Murray River @ Gulf Creek	BIDBID		11	7	3	2	1	
Murray River @ Gulf Creek	CARAUR		14		20	6	1	
Murray River @ Gulf Creek	CRASTE	90	442	92	1941			
Murray River @ Gulf Creek	CYPCAR	43	117	78	153	14	13	74
Murray River @ Gulf Creek	EUAARM	2	1	5	3		1	4
Murray River @ Gulf Creek	HYPSPP	2	4		1			
Murray River @ Gulf Creek	MACAMB	4	14	8	9	2	1	9
Murray River @ Gulf Creek	MACMAC		4	6	2	1		
Murray River @ Gulf Creek	MACPEE	8	14	13	15	3	2	3
Murray River @ Gulf Creek	MELFLU		38	5	240			
Murray River @ Gulf Creek	MISANG			2				
Murray River @ Gulf Creek	NEMERE				53			
Murray River @ Gulf Creek	RETSEM	52	177	933	424	79	3	6
Picnic Point	BIDBID		1			2	1	

Picnic Point	CARAUR		1	11	8		0	
Picnic Point	CRASTE	4	145	58	337			
Picnic Point	CYPCAR	20	25	29	49	12	24	160
Picnic Point	EUAARM	1		1	8	5	1	9
Picnic Point	GAMHOL				1			
Picnic Point	HYBRID		1					
Picnic Point	HYPSPP	1	26	36	3			
Picnic Point	MACAMB	2		1	2	1	1	6
Picnic Point	MACMAC	3	9	4	7		1	4
Picnic Point	MACPEE		6	2	19	6	1	1
Picnic Point	MACSPP		1					
Picnic Point	MELFLU		11	7	157			
Picnic Point	NEMERE				1			
Picnic Point	RETSEM	45	157	300	990	180	1	2
Pinch Gut Lagoon	CARAUR					1	7	
Pinch Gut Lagoon	CRASTE					1		
Pinch Gut Lagoon	CYPCAR					15	3	5
Pinch Gut Lagoon	GAMHOL	67				423	2	226
Pinch Gut Lagoon	HYPSPP	309		2		16	8	248
Pinch Gut Lagoon	MELFLU					1		
Pinch Gut Lagoon	MISANG					5	7	
Pinch Gut Lagoon	NANAUS	1						
Pinch Gut Lagoon	PHIGRA	1						
Pinch Gut Lagoon	RETSEM	2				26	5	
Tongalong Creek	BIDBID			1		8		
Tongalong Creek	CARAUR	3	79	2	7	41	4	1
Tongalong Creek	CRASTE	11	1	56	3	45		3
Tongalong Creek	CYPCAR	8	59	5	26	294	84	31
Tongalong Creek	GAMHOL		5	25	1	57	3	8
Tongalong Creek	HYPSPP	2	1		10	3	11	29
Tongalong Creek	MACAMB	1	1		1	5		
Tongalong Creek	MACPEE		1	3		11		3
Tongalong Creek	MELFLU			2	2	18		
Tongalong Creek	MISANG					12		1

Tongalong Creek	RETSEM	72	45	100	15	121	44	23
Toupna Creek	CARAUR	7	2		22	14		
Toupna Creek	CYPCAR	1			45	5	10	11
Toupna Creek	GAMHOL	51	204		147	85	1	1
Toupna Creek	HYPSPP	512	40		60	1	1	12
Toupna Creek	MELFLU	1			17	1		
Toupna Creek	MISANG	9	8			5		
Toupna Creek	NANAUS	33						
Toupna Creek	PHIGRA	20						
Toupna Creek	RETSEM					12		
Tullah Creek	CARAUR	79				110	4	ns
Tullah Creek	CYPCAR	33				1	11	ns
Tullah Creek	GAMHOL	76				143	4	ns
Tullah Creek	HYPSPP	159					6	ns
Tullah Creek	MELFLU					1		ns
Tullah Creek	MISANG	48					10	ns
Tullah Creek	PERFLU						1	ns
Tullah Creek	PHIGRA	5						ns
Tullah Creek	RETSEM	4				257	20	ns
Woodcutters	BIDBID	2	2		1		1	1
Woodcutters	CARAUR		6	1			0	1
Woodcutters	CRASTE	12	376	76	32			
Woodcutters	CYPCAR	14	130	15	8		22	52
Woodcutters	EUAARM	1	9	7	2		3	3
Woodcutters	GAMHOL	1	3		21			
Woodcutters	HYPSPP	344	615	34	7			
Woodcutters	MACAMB	4					3	5
Woodcutters	MACMAC		10	1	5		1	1
Woodcutters	MACPEE		27	4	9		1	2
Woodcutters	MACSPP		1					
Woodcutters	MELFLU		2	1	1			
Woodcutters	PHIGRA		9					
Woodcutters	RETSEM	40	197	30	1186		3	1