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Fish assemblage condition monitoring in the Katarapko Anabranch system 2015

C. M. Bice, B. P. Zampatti and L. R. K. Suitor

SARDI Publication No. F2015/000634-1
SARDI Research Report Series No. 866

SARDI Aquatics Sciences
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September 2015

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This publication may be cited as:
Bice, C. M., Zampatti, B. P. and Suitor, L. R. K. (2015). Fish assemblage condition monitoring in the Katarapko Anabranch 2015. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000634-1. SARDI Research Report Series No. 866. 30pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.pir.sa.gov.au/research

Printed in Adelaide: September 2015

SARDI Publication No. F2015/000634-1
SARDI Research Report Series No. 866

Authors:	C. M. Bice, B. P. Zampatti and L. R. K. Suitor
Reviewers:	G. Giatas and J. Fredberg
Approved by:	Dr. Q. Ye Science Leader – Inland Waters & Catchment Ecology
Signed:	
Date:	25 September 2015
Distribution:	SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library
Circulation:	Public Domain

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ACKNOWLEDGEMENTS

This project has been funded by the Australian Government under the *South Australian Riverland Floodplain Integrated Infrastructure Project* (SARFIIP). SARFIIP is being implemented by the South Australian Government to improve the watering and management of floodplains of the River Murray in South Australia's Riverland region. The project was managed by Benita Dillon of the South Australian Department of Environment, Water and Natural Resources (DEWNR). The authors would like to thank the following SARDI staff who assisted with fieldwork and producing maps; Arron Strawbridge, Ian Magraith, Neil Wellman, George Giatas and Phillipa Wilson. Thanks also go to George Giatas and Josh Fredberg (SARDI), and Benita Dillon (DEWNR) for reviewing this document.

EXECUTIVE SUMMARY

The Katarapko Anabranch and Floodplain system is one of three large anabranch systems in the lower Murray River, South Australia. The anabranch bypasses Lock and Weir No. 4 generating a head differential of ~3.5 m between the main inlet through Eckert Creek (Bank J) and the confluence of Katarapko Creek and the River Murray. As such Katarapko comprises a series of diverse aquatic habitats including permanent fast-flowing and slow-flowing creeks, as well as backwaters. Such flowing water habitats are now rare in the lower River Murray main channel under low flow conditions. Nonetheless, the system is impacted by catchment-scale and local-scale flow regulation, resulting in reduced flooding frequency, limited capacity to vary flow to the system and fragmentation of anabranch habitats.

The Katarapko Anabranch system is now the subject of substantial environmental rehabilitation effort. Subsequent to interventions implemented under the 'Katfish Reach' initiative and Riverine Recovery Project (RRP; e.g. construction of the Eckerts Creek Log Crossing regulator and associated vertical-slot fishway), large-scale management interventions are planned under the *South Australian Riverland Floodplain Integrated Infrastructure Project* (SARFIIP). This includes the construction of a complex series of regulator structures and blocking banks to allow broad-scale engineered floodplain inundation in the absence of elevated discharge in the River Murray. The construction and operation of infrastructure under SARFIIP is primarily aimed at improving the condition of long-lived floodplain vegetation; however, it is recognised that managed inundations may present significant risks to ecological processes and other biota, including fish. An understanding of how operation of this infrastructure affects fish assemblage structure (i.e. species composition and abundance), movement and recruitment is vital to inform environmentally sensitive operation. Such an approach is reliant on contemporary data to provide a reference against which to assess change in fish-related metrics following implementation and operation of SARFIIP infrastructure.

This report summarises data from broad-scale sampling of the Katarapko Anabranch system and adjacent River Murray in autumn 2015, with the objective of collecting data on: 1) fish assemblage structure (species composition and abundance); and 2) recruitment success. These data will facilitate future assessment of changes in these parameters following operation of SARFIIP infrastructure. Furthermore, it presents these data in the context of comparisons with data from previous broad-scale sampling events in 2010 and 2011 to provide insight on recent changes in fish assemblage structure and the influence of catchment-scale hydrology.

A total of 18 sites were sampled, across four mesohabitat types (i.e. fast-flowing creeks, slow-flowing creeks, backwaters and main channel habitats). The majority of sites (12 sites) were sampled using standardised boat electrofishing, whilst at sites where efficient electrofishing was not possible (6 sites), fyke-nets were employed.

A total of 10,625 fish were sampled from 15 species. The native bony herring (*Nematalosa erebi*) was the most abundant species sampled, followed by a suite of small-bodied native species, namely, unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), carp gudgeon complex (*Hypseleotris* spp.), Murray rainbowfish (*Melanotaenia fluviatilis*) and Australian smelt (*Retropinna semoni*). Low numbers of individuals from species of State or national conservation significance were also sampled, namely Murray cod (*Maccullochella peelii*), silver perch (*Bidyanus bidyanus*) and freshwater catfish (*Tandanus tandanus*).

Total abundance and assemblage structure in 2015 were similar to that from sampling in 2010, but both years were significantly different from 2011. Differences between years were primarily driven by greater abundances of several species during 2011, specifically common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), eastern gambusia (*Gambusia holbrooki*), golden perch (*Macquaria ambigua ambigua*), Murray rainbowfish and carp gudgeon. Alternatively, bony herring were more abundant in 2010 and 2015, relative to 2011. These differences reflect the stark differences in hydrology between 2011 and 2010, and 2015, and the influence of catchment-scale hydrology on critical life history processes.

Golden perch are flow-cued spawners, relying on the coincidence of elevated discharge and temperature cues to stimulate spawning, whilst enhanced spawning and recruitment of common carp is associated with floodplain inundation. The advent of favourable conditions for spawning and recruitment of these species prior to sampling in 2011, and absence of such conditions immediately preceding sampling in both 2010 and 2015, likely led to the observed disparity in abundance. This pattern of change in abundance was consistent among sites across the floodplain geomorphic region of the lower River Murray (e.g. Chowilla, Pike), indicating the influence of catchment-scale hydrology on biotic patterns observed at a ‘site-scale’. This has important implications for the management of these sites. Furthermore, the disparity between sampling years highlights the dynamic nature of the lower River Murray ecosystem and importance of long-term monitoring in understanding this variability. An understanding of natural ecological variability in response to hydrology is vital for elucidating potential intervention-induced alterations to ecological patterns in the future.

To provide insight on changes in fish-related ‘site condition’ as influenced by the operation of SARFIIP infrastructure it is suggested that:

1) Further monitoring of fish assemblages is conducted to provide ‘reference data’, against which changes in condition will be assessed, that is broad in regards to temporal scope and hydrological variability; and

2) A range of fish related metrics be developed from the reference data collected in 2010, 2011, 2015 and any further sampling, relating to species distribution, abundance and recruitment. These metrics would assist in future assessments of condition and should be species-specific, and incorporate understanding of life history and regional-specific ecology.

Whilst the use of ‘reference data’ and specific metrics will enable the assessment of changes in site condition, allied hypothesis-driven investigations are required to elucidate cause–effect mechanisms of observed patterns.

1. INTRODUCTION

1.1. Background

River regulation and water abstraction in the Murray-Darling Basin (MDB) have dramatically altered the natural flow regime of the lower River Murray (Maheshwari *et al.* 1995). The construction of a series of low-level weirs along the main channel in the 1920s and 1930s transformed a dynamic lotic environment to one characterised by a series of lentic weir pools with limited hydraulic complexity and increased water level stability (Walker 2006). The frequency and duration of floodplain inundation has decreased, whilst periods of elevated within-channel flow have also been reduced (Maheshwari *et al.* 1995). Subsequently, the ecological character of the lower River Murray has transformed, with declines in species adapted to lotic flowing water environments (e.g. Murray cod (*Maccullochella peelii*) and the riverine mussel (*Alathyria jacksoni*)) and increased prevalence of generalist species or those adapted to stable environments (e.g. common carp (*Cyprinus carpio*) and willow (*Salix babylonica*)) (Walker 1985, Walker and Thoms 1993).

The Katarapko Anabranch and Floodplain system is one of three large anabranch systems (Chowilla, Katarapko and Pike) in the lower River Murray, South Australia. The Katarapko Anabranch bypasses Lock and Weir No. 4 generating a head differential of ~3.5 m between the main inlet through Eckert Creek (Bank J) and the confluence of Katarapko Creek and the River Murray. As such Katarapko comprises hydraulically diverse aquatic habitats including permanent fast-flowing and slow-flowing creeks, as well as backwaters. Flowing water habitats such as these are now largely absent under regulated conditions in the lower River Murray main channel.

Whilst the Katarapko Anabranch supports a diverse fish assemblage (Leigh *et al.* 2012, Wilson *et al.* 2013), the system is impacted by catchment-scale and local-scale flow regulation. On a catchment-scale, river regulation and water abstraction in the MDB has reduced flooding frequency and duration, with various accompanying impacts. On a local-scale, flow to the system is limited by the operational constraints of the inlet structures (e.g. Bank J) and further fragmented by a range of additional structures (e.g. Katarapko Stone Weir). Under low flows, these structures present barriers to fish passage, restricting the movement of fish both within the system and between the anabranch system and River Murray main channel.

The Katarapko Anabranch system is now the subject of substantial environmental rehabilitation effort. Under both the 'Katfish Reach' initiative (funded by the Murray-Darling Basin Authority's (MDBA) *Native Fish Strategy* (NFS)) and Riverine Recovery Project (RRP; *Murray Futures Program*) several interventions were planned and implemented with the objective of achieving instream outcomes, including improving hydrological connectivity and fish passage, and the capacity to reinstate wetting and drying phases to specific wetlands (e.g. construction of the Eckerts Creek Log Crossing regulator and associated vertical-slot fishway). More recently, under the *South Australian Riverland Floodplain Integrated Infrastructure Project* (SARFIIP), plans are in place to construct a complex series of regulator structures and blocking banks to allow broad-scale engineered floodplain inundation, in the absence of elevated discharge in the River Murray. The construction and operation of infrastructure under SARFIIP may have great influence on ecosystem function and the distribution and abundance of resident biota, including fish. An understanding of how the operation of this infrastructure affects fish assemblage structure (i.e. species composition and abundance), movement and recruitment is vital to inform environmentally sensitive operation.

Fish assemblages have been quantitatively monitored in the Katarapko Anabranch sporadically since 2007 (Leigh *et al.* 2007). Nonetheless, monitoring between years was performed against different objectives and therefore, with different levels of sampling effort, albeit with some overlap of sites. In 2010 and 2011, monitoring occurred at a range of sites distributed broadly across the Katarapko Anabranch system (Leigh *et al.* 2012), and represented 'before' intervention monitoring for several interventions. Alternatively, in 2012 and 2013, monitoring occurred at a subset of sites and represented 'before' intervention monitoring for specific interventions being undertaken on Eckerts Creek. As such, there has been no broad-scale monitoring of fishes of the Katarapko Anabranch system since 2011 and subsequently, little contemporary data with which to refine fish-related ecological objectives and targets under SARFIIP, or as reference data to assess change in fish-related metrics following implementation and operation of SARFIIP infrastructure.

1.2. Objectives

The primary objective of the project was to collect reference data on the 'condition' of fish assemblages broadly across the Katarapko Anabranch system to allow assessments of change in condition following implementation and operation of SARFIIP infrastructure. Specific objectives include:

1) Assessing fish assemblage structure (i.e. species composition and abundance) and recruitment success in 2015; and
2) Comparing data from 2015 with that of 2010 and 2011 (Leigh *et al.* 2012) to provide insight on recent changes in fish assemblage structure and the influence of catchment-scale hydrology.

2. METHODS

2.1. Site selection

Sites were selected across the Katarapko Anabranch system to provide: 1) broad spatial coverage of the system; 2) representation of all aquatic mesohabitat types (i.e. fast-flowing creeks, slow-flowing creeks, backwaters and main channel habitats) present in the system (sensu Leigh *et al.* 2009); and 3) concurrence with previous broad-scale monitoring events (2010 and 2011) in the system. Site numbering and names follow that from previous investigations (e.g. Leigh *et al.* 2009). In 2015 and 2010, a total of 18 sites were sampled (Table 1; Figure 1), whilst in 2011, all were sampled with the exception of Sites 1, 20 and 22, due to limited access.

Table 1. Site number, site name, sampling gear (electrofishing or fyke-neting), mesohabitat type and year sampled for sites in the Katarapko Anabranch and adjacent River Murray sampled in 2010, 2011 and/or 2015.

Site number	Name	Sampling gear	Mesohabitat type	Sampling year		
				2010	2011	2015
1	Eckert creek d/s weir	Electrofish	Fast-flowing	*		*
2	Eckert creek Wide Water	Electrofish	Backwater	*	*	*
3	Eckert creek u/s log crossing	Electrofish	Slow-flowing	*	*	*
4	Eckert creek d/s log crossing	Electrofish	Fast-flowing	*	*	*
5	The Splash	Electrofish	Backwater	*	*	*
6	Katarapko d/s weir	Electrofish	Slow-flowing	*	*	*
7	Katarapko Creek u/s (Katarapko Isl.)	Electrofish	Slow-flowing	*	*	*
9	Katarapko lower	Electrofish	Slow-flowing	*	*	*
10	Murray 3-4km d/s Lock 4	Electrofish	Main river channel	*	*	*
12	Murray d/s Katarapko junction	Electrofish	Main river channel	*	*	*
13	Eckert Creek below ford	Electrofish	Slow-flowing	*	*	*
14	Murray u/s Lock 4	Electrofish	Main river channel	*	*	*
17	Eckert Creek d/s	Fyke	Fast-flowing	*	*	*
19	Sawmill Creek	Fyke	Slow-flowing	*	*	*
20	Eckert widewater u/s	Fyke	Backwater	*		*
22	Eckert Creek immed d/s Eckert weir	Fyke	Fast-flowing	*		*
23	Eckert Northern Arm	Fyke	Slow-flowing	*	*	*
24	Eckert Southern Arm	Fyke	Slow-flowing	*	*	*

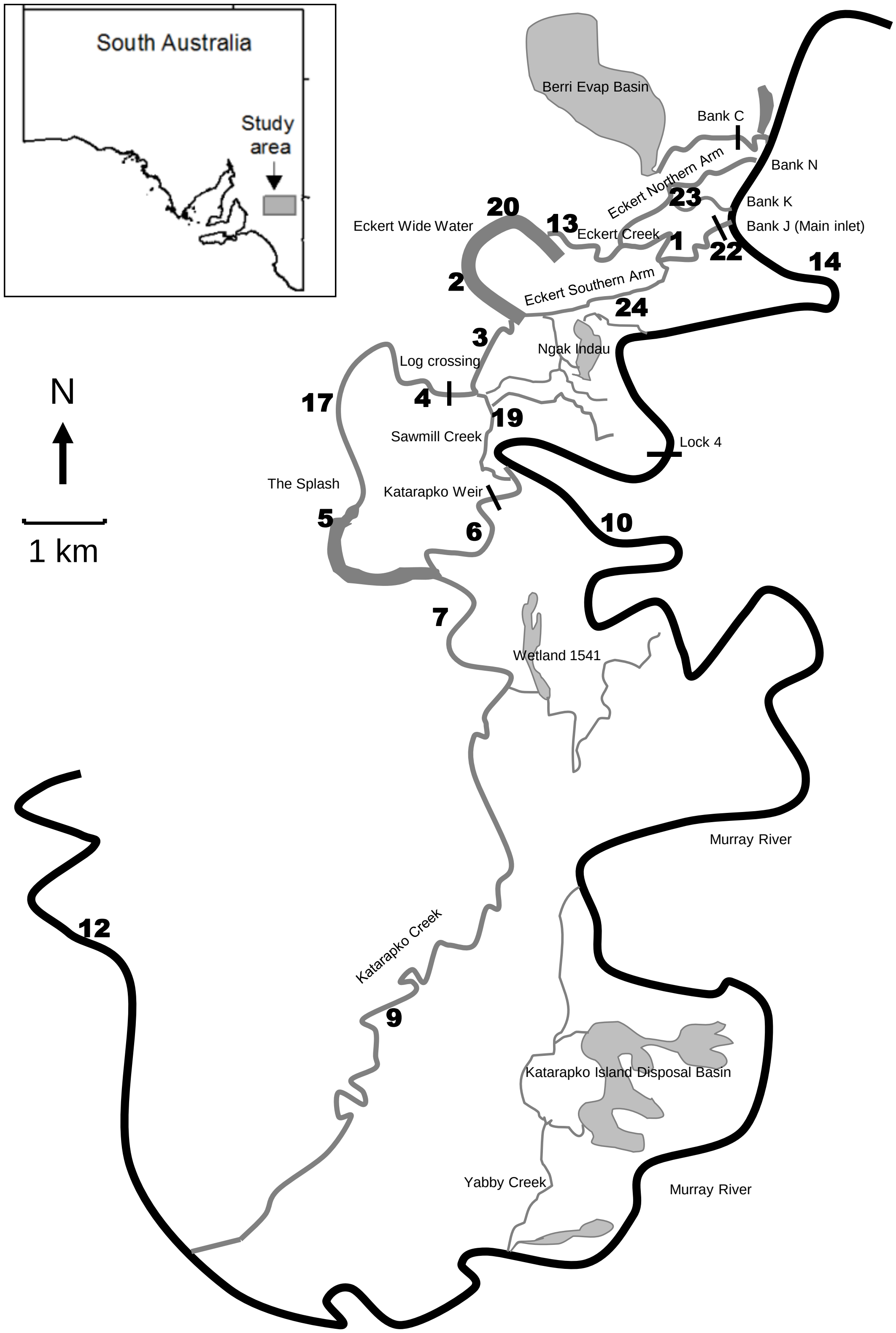

Figure 1. Map showing the location of sites sampled in the Katarapko Anabranch and adjacent River Murray in 2010, 2011 and 2015.

2.2. Fish sampling

Fish assemblages were sampled from 23/03/2015–08/04/2015 from the majority of sites (i.e. 1–14; Table 1) using standardised boat electrofishing. During all sampling years, at sites where efficient electrofishing was not possible (e.g. shallow water depth; i.e. Sites 17–24), fish assemblages were sampled using fyke-netting. Boat electrofishing is a proven method to effectively and rapidly sample both large and small-bodied fish in the littoral zone of turbid lowland rivers and creeks (Faragher and Rodgers 1997), and is commonly used in anabranches and the main channel of the lower River Murray (Baumgartner *et al.* 2008, Zampatti *et al.* 2011). Fish were sampled from the littoral zone using a Smith-Root® 5 kW electrofishing unit. At each site, 12 (six on each bank) x 90 second (power on time) 'electrofishing shots' were conducted during daylight hours and fish were dip-netted by a team of two netters and placed in a live well. For each electrofishing shot, all sampled fish were identified and enumerated. Any positively identified fish unable to be dip netted were recorded as 'observed' and included in abundance measures. Sampled fish were measured for fork length (FL) or total length (TL) (mm) and when large numbers of individual species were sampled, a random sub-sample of 20 individuals per species was measured.

Fyke-netting involved the use of nine single-winged fyke-nets (6 m wing length, 0.6 m entry diameter and 3 mm mesh), which were set over-night. Fyke-nets were used to sample littoral habitat and where possible were set perpendicular to the bank. All fish sampled were identified and enumerated. Length measurements (FL or TL, mm, depending on tail morphology) were recorded for up to 30 individuals per species per net.

Length-frequency distribution plots were generated for each species from all individuals measured during sampling (electro-fishing and fyke-netting data combined). Recruitment success in 2015 was assessed by interpreting length-frequency distribution plots with knowledge of likely lengths of young-of-the-year (YOY) cohorts from previous monitoring programs in the region (e.g. Zampatti *et al.* 2011, Leigh *et al.* 2012, Bice *et al.* 2013)

2.3. Data analysis

Spatio-temporal variability in fish assemblage structure (species composition and abundance) was investigated between sampling years (i.e. 2010, 2011 and 2015) and mesohabitat types (i.e. fast-flowing creeks, slow-flowing creeks, backwaters and main channel habitats). These comparisons were performed separately for sites sampled with electrofishing (Sites 1–14) and those sampled with fyke-netting (Sites 17, 19, 23 and 24). Sites 20 and 22 were excluded from analyses as they were only sampled with fyke-nets in 2015.

Variability in fish assemblage structure, based on electrofishing data, was investigated using two-factor (i.e. year and mesohabitat type) permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001, Anderson and Ter Braak 2003) in the software package PRIMER v. 6.1.12 (Clarke and Gorley 2006) and PERMANOVA+ (Anderson *et al.* 2008). Only temporal variability in fish assemblage structure could be investigated based on fyke-netting data, due to no replication of mesohabitat types other than 'slow-flowing' creeks (Table 1), and was undertaken using single-factor (i.e. year) PERMANOVA. Analyses were performed on fourth-root transformed relative abundance data from both electrofishing (fish.minute of electrofishing^{-1}.electrofishing shot^{-1}) and fyke-neting (fish.hour^{-1}). PERMANOVA was performed on Bray-Curtis similarity matrices (Bray and Curtis 1957). Non-Metric Multi-Dimensional Scaling (MDS), generated from the same matrices was used to visualise assemblages from different years, and mesohabitats in the case of electrofishing data. When significant differences occurred in main tests, pairwise comparisons were undertaken to determine 'groups' that were statistically different. To allow for multiple comparisons, a false discovery rate (FDR) procedure presented by Benjamini and Yekutieli (2001), hereafter the 'B–Y method' correction, was adopted ($\alpha = \sum_{i=1}^{n}(1/i)$; e.g. for $n_{comparisons}$ = 3, B-Y method α = 0.05/ (1/1 + 1/2 + 1/3) = 0.027) (Benjamini and Yekutieli 2001, Narum 2006). When differences occurred in fish assemblages between groups, Similarity Percentages (SIMPER) analysis was used to determine the fish species or microhabitat types contributing to these differences and a 40% cumulative contribution cut-off was applied.

When differences occurred in fish assemblages between years and mesohabitats, Indicator Species Analysis (ISA) (Dufrene and Legendre 1997) was used to determine fish species that characterised the assemblage in certain years and mesohabitats, using the software package PCOrd v 5.12 (McCune and Mefford 2006). ISA combines information on the concentration of species abundance in a particular group and the faithfulness of occurrence of a species in a particular group (McCune *et al.* 2002). The test produces indicator values (IV) for each species or microhabitat type in each group on the basis of the standards of the 'perfect indicator'. A perfect indicator (IV = 100%) of a particular group should be faithful to that group (always present) and exclusive to that group (never occurring in other groups) (McCune *et al.* 2002). Only species and microhabitats with an IV > 20 were accepted. Statistical significance (α = 0.05) of each indicator value was tested by the Monte Carlo (randomisation) technique, where the real data are compared against (in the case for this study) 5000 runs of randomised data (Dufrene and Legendre 1997).

3. RESULTS

3.1. Hydrology

River Murray discharge to South Australia (QSA) was highly variable over 2009–2015 (Figure 2). The period 1997–2010 was characterised by irregularly low discharge and preceding sampling in 2010, daily discharge had not exceeded 10,000 $ML.day^{-1}$ for >4 years. Discharge was ~6,760 $ML.day^{-1}$ during sampling in April 2010. Discharge increased dramatically in late 2010, peaking at ~93,000 $ML.day^{-1}$ in February 2011, resulting in widespread overbank flooding in the lower River Murray. Sampling in 2011, occurred immediately following the recession of the flood in May/June, during which time discharge was ~22,000 $ML.day^{-1}$.

A small overbank flood event occurred in autumn 2012, with generally elevated discharge throughout much of 2012 (Figure 2). Subsequently, discharge decreased through 2013–2015, with two small within-channel flow events of ~25,000 and 18,000 $ML.day^{-1}$ in September 2013 and August 2014, respectively. Nonetheless, discharge for much of this period was <10,000 $ML.day^{-1}$ and during sampling in autumn 2015, approximated summer entitlement flow (mean = 6,427 $ML.day^{-1}$).

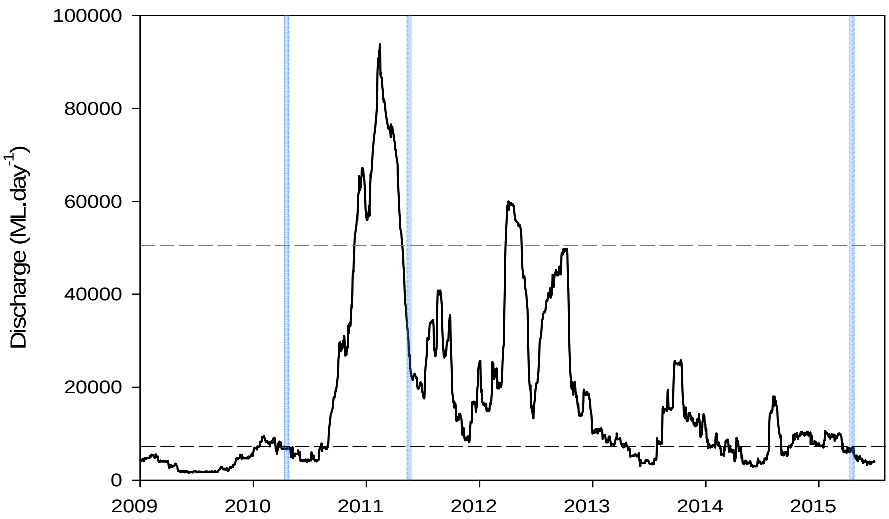

Figure 2. Daily River Murray discharge ($ML.day^{-1}$) to South Australia (QSA) from January 2009 to June 2015. Sampling events are indicated by the vertical blue lines. Dashed red line indicates approximate 'bank-full' flow in the lower River Murray, beyond which floodplain inundation occurs and the dashed black line represents summer 'entitlement' flow (~7,000 $ML.day^{-1}$).

3.2. Catch summary

In autumn 2015, a total of 10,625 fish were sampled from 15 species (Table 2), which included 8,022 fish from 15 species at sites sampled with electrofishing, and 2,602 fish from 12 species at sites sampled by fyke-netting. Bony herring (*Nematalosa erebi*) was the most abundant species sampled, comprising approximately 46% of the total catch, followed by unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*; ~25%), carp gudgeon complex (*Hypseleotris spp*; ~8%), Murray rainbowfish (*Melanotaenia fluviatilis*; ~6%) and Australian smelt (*Retropinna semoni*; ~4%). The remaining 10 species comprised approximately 10% of the catch.

Species richness within fast-flowing mesohabitats ranged 9–12, with typically lower numbers of species sampled from slow-flowing (6–11), backwater (7–11) and river mesohabitats (7–9). Most species were widespread and sampled from ≥12 sites, across most mesohabitat types, with the exception of flat-headed gudgeon (*Philypnodon grandiceps*) (*n* = 4 sites), and Murray cod (*Maccullochella peelii*), silver perch (*Bidyanus bidyanus*) and freshwater catfish (*Tandanus tandanus*) (*n* = 3 sites), and spangled perch (*Leiopotherapon unicolor*) and redfin perch (*Perca fluviatilis*) (*n* = 2 sites). Murray cod were restricted to slow-flowing and river mesohabitats, whilst freshwater catfish were only sampled from slow-flowing mesohabitats.

Table 2. Summary of species and total numbers of fish captured across 18 sampling sites in the Katarapko Anabranch system and adjacent River Murray in autumn 2015. Mesohabitats: F = fast-flowing, S = slow-flowing, B = backwater and R = river main channel. *denotes non-native species.

	Site Codes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**10**	**12**	**13**	**14**	**17**	**19**	**20**	**22**	**23**	**24**	**Total**
Common name	**Scientific name**	**F**	**B**	**S**	**F**	**B**	**S**	**S**	**S**	**R**	**R**	**S**	**R**	**F**	**S**	**B**	**F**	**S**	**S**	
Murray cod	*Maccullochella peelii*	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	**3**
Golden perch	*Macquaria ambigua ambigua*	4	1	5	0	0	10	13	5	25	8	1	6	2	10	2	5	2	1	**100**
Silver perch	*Bidyanus bidyanus*	1	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	**5**
Freshwater catfish	*Tandanus tandanus*	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	0	1	**6**
Bony herring	*Nematalosa erebi*	395	48	20	693	106	348	280	355	830	758	235	402	162	48	103	62	61	1	**4,907**
Australian smelt	*Retropinna semoni*	59	9	2	28	5	39	32	21	129	24	8	38	11	1	3	9	6	5	**429**
Murray rainbowfish	*Melanotaenia fluviatilis*	72	0	26	20	0	29	15	57	82	58	2	175	1	75	2	5	26	13	**658**
Flat-headed gudgeon	*Philypnodon grandiceps*	0	0	0	2	0	0	1	0	0	0	0	0	1	0	2	0	0	0	**6**
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	162	285	303	517	188	69	29	31	75	126	31	12	90	84	235	403	26	10	**2,676**
Carp gudgeon complex	*Hypseleotris* spp	8	0	2	1	2	3	1	0	3	2	3	0	5	12	127	567	81	2	**819**
Spangled perch	*Leiopotherapon unicolor*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**2**
Common carp*	*Cyprinus carpio*	21	14	122	32	14	113	9	1	28	5	8	4	5	15	19	1	3	1	**415**
Eastern gambusia*	*Gambusia holbrooki*	8	1	5	37	4	0	6	0	0	0	0	0	32	49	42	7	56	80	**327**
Goldfish*	*Carassius auratus*	42	26	33	73	18	5	1	0	34	0	8	0	2	12	7	1	6	0	**268**
Redfin perch*	*Perca fluviatilis*	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**
Total number of individuals		**774**	**384**	**518**	**1,405**	**337**	**623**	**387**	**470**	**1,207**	**981**	**296**	**640**	**311**	**307**	**543**	**1,060**	**267**	**114**	**10,625**
Species richness		**12**	**7**	**9**	**10**	**7**	**11**	**10**	**6**	**9**	**7**	**8**	**8**	**10**	**10**	**11**	**9**	**9**	**9**	**15**

3.3. Recruitment success

The small-bodied (adult length <100 mm) native species sampled all exhibited broad length distributions (i.e. carp gudgeon, 20–50 mm TL; unspecked hardyhead, 15–66 mm FL; Australian smelt, 23–65 mm FL; and Murray rainbowfish, 25–70 mm FL) and large proportions of individuals (typically >50%) considered likely to represent newly recruited YOY cohorts (i.e. <40 mm length) (Figure 3). Bony herring were also sampled from a broad range of lengths (i.e. 25–364 mm FL) with large proportions (~75%) of likely newly recruited YOY (<80 mm FL) (Figure 3e).

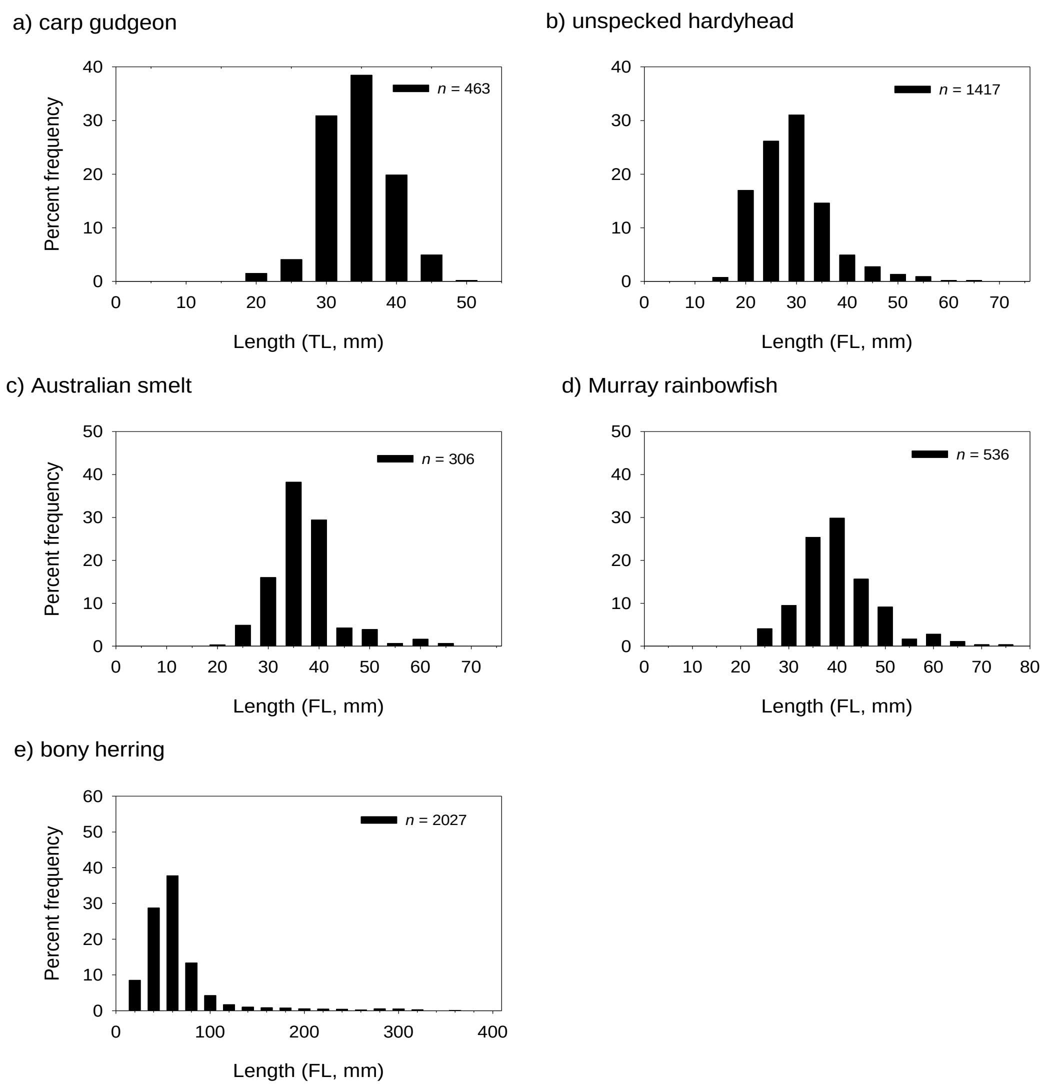

Figure 3. Length frequency distribution (expressed as percentage of fish measured) of a) carp gudgeon (TL), b) unspecked hardyhead (FL), c) Australian smelt (FL), d) Murray rainbowfish (FL) and e) bony herring (FL), sampled from the Katarapko Anabranch system and adjacent River Murray in autumn 2015. Electrofishing and fyke-net data are pooled.

Silver perch were sampled in low numbers, but from a broad range of lengths (118–370 mm FL) (Figure 4a). Golden perch (*macquaria ambigua ambigua*) were also sampled across a broad length distribution (75–482 mm TL) with a mode of 260–379 mm TL (Figure 4b). One individual <100 mm TL, may represent a newly recruited YOY. Two Murray cod were measured for length, representing juvenile (169 mm TL) and sub-adult (349 mm TL) individuals, respectively (Figure 4c). Freshwater catfish were also sampled in low numbers, with 60% of individuals representing reproductively mature fish (>400 mm TL), but two individuals (<65 mm TL) likely represented newly recruited YOY (Figure 4d).

Common carp (*Cyrinus carpio*) were sampled from a broad tri-modal length distribution (37–710 mm FL) with modes around 100, 250 and 400 mm FL (Figure 4e). Individuals <120 mm, which may represent newly recruited YOY, comprised ~25% of the population. Goldfish (*Carassius auratus*) sampled ranged 26–235 mm FL, with the population dominated (>50%) by newly recruited YOY (<80 mm FL) (Figure 4f).

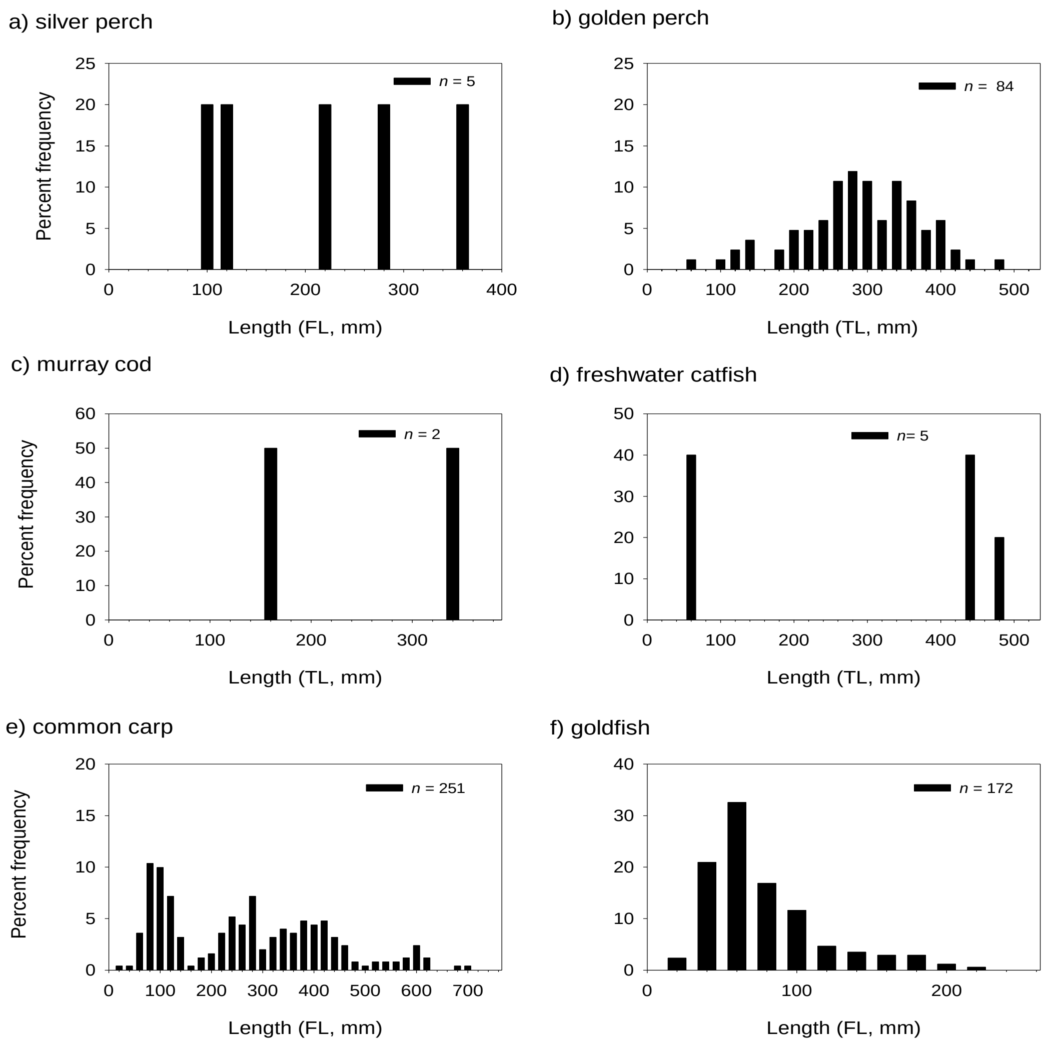

Figure 4. Length frequency distribution (expressed as percentage of fish measured) of a) silver perch (FL), b) golden perch (TL), c) Murray cod (TL), d) freshwater catfish (TL), e) common carp (FL) and f) goldfish (FL), sampled from the Katarapko Anabranch system and adjacent River Murray in autumn 2015. Electrofishing and fyke-net data are pooled.

3.4. Spatio-temporal variability in fish assemblages

Electrofishing data

MDS ordination of electrofishing data exhibited groupings of samples by year (Figure 5). PERMANOVA indicated fish assemblages were significantly different between years ($Pseudo\text{-}F_{2,\ 34} = 9.76$, $p < 0.001$) and mesohabitats ($Pseudo\text{-}F_{3,\ 34} = 3.18$, $p = 0.002$), with no significant interaction between these factors ($Pseudo\text{-}F_{6,\ 34} = 1.39$, $p = 0.119$). Pairwise comparisons revealed that assemblages in 2011, were significantly different from those of 2010 ($t = 4.10$, p <

0.001; B–Y corrected α = 0.027) and 2015 (t = 3.87, p < 0.001), but 2010 and 2015 were not significantly different (t = 1.04, p = 0.372). Furthermore, assemblages from backwater mesohabitats were significantly different from all other mesohabitats (p < 0.02 for all comparisons; B–Y corrected α = 0.02), whilst all other comparisons were non-significant (p > 0.02 for all comparisons).

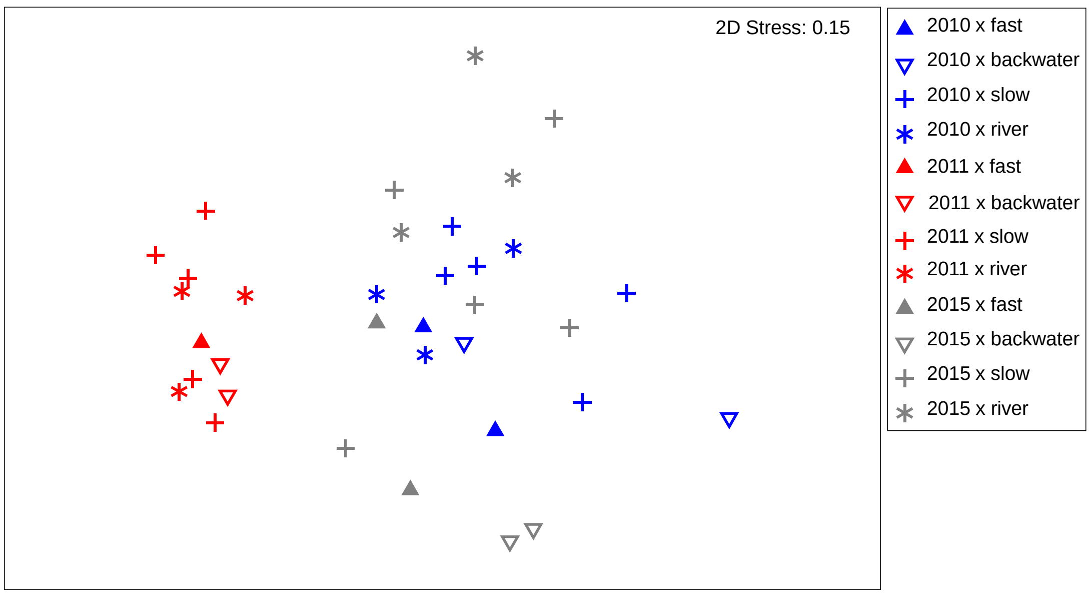

Figure 5. Non-metric multi-dimensional scaling (MDS) plots of fish assemblages sampled via standardised electrofishing from 12 sites in the Katarapko Anabranch system in 2010 (blue symbols), 2011 (red symbols) and 2015 (grey symbols). Sites from different mesohabitat types, namely, fast-flowing (triangles), backwater (inverted triangles), slow-flowing (crosses) and river channel (stars) are also indicated.

SIMPER indicated that temporal variability in assemblages was due to greater abundances of common carp and goldfish, and lower abundances of bony herring, in 2011, relative to both 2010 and 2015 (Figure 6a). Furthermore, ISA suggested assemblages from 2011 were characterised by greater abundance of common carp (Indicator value (IV) = 58.5, p < 0.001) and goldfish (IV = 51.3, p < 0.001), together with golden perch (IV = 47.6, p < 0.001) and Murray rainbowfish (IV = 47.0, p < 0.001), whilst there were no significant indicators of the assemblages from 2010 or 2015 (Figure 6a).

SIMPER suggested that spatial variability in assemblages was primarily driven by low abundances of Murray rainbowfish, Australian smelt and bony herring, but high abundances of common carp in backwaters, relative to all other mesohabitat types (Figure 6b). Furthermore, ISA suggested that fast-flowing sites were characterised by greater abundance of unspecked hardyhead (IV = 30.8, p = 0.035), whilst River Murray sites were characterised by greater abundance of Murray cod (IV = 28.1, p = 0.048) and Murray rainbowfish (IV = 33.0, p = 0.049) (Figure 6b).

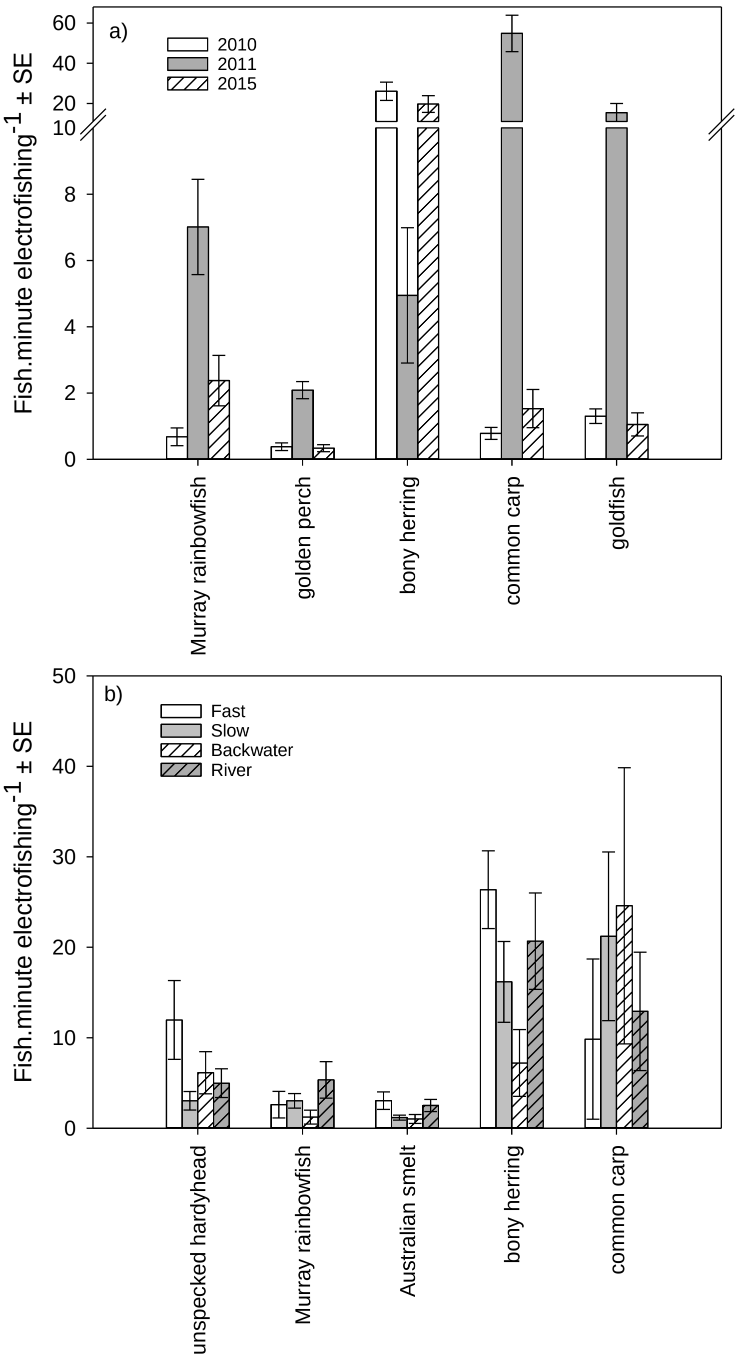

Figure 6. Relative abundance ± standard error (SE) of species from sampling via electrofishing (fish.minute electrofishing^{-1}.site^{-1}) determined to contribute to differences between fish assemblages (SIMPER) or characterise the assemblage (ISA) between a) 2010 (white bar), 2011 (grey bar) and 2015 (hashed white bar), and b) between fast-flowing (white bar), slow-flowing (grey bar), backwater (hashed white bar) and river channel (hashed grey bar) mesohabitats. NOTE: Murray cod are not included in plot b despite characterising 'river channel' mesohabitats, due to very low abundance.

Fyke-netting data

MDS ordination of fyke-netting data exhibited groupings of samples by year (Figure 7) and PERMANOVA indicated a significant difference in fish assemblages between years ($Pseudo\text{-}F_{2, 11}$ = 4.15, p < 0.001). Similar to the analyses of electrofishing data, assemblages sampled in 2011, were found to be significantly different from those sampled in 2010 (t = 1.52, p = 0.026; B–Y corrected α = 0.027) and 2015 (t = 2.45, p = 0.026), but 2010 and 2015 were not significantly different (t = 2.17, p = 0.036).

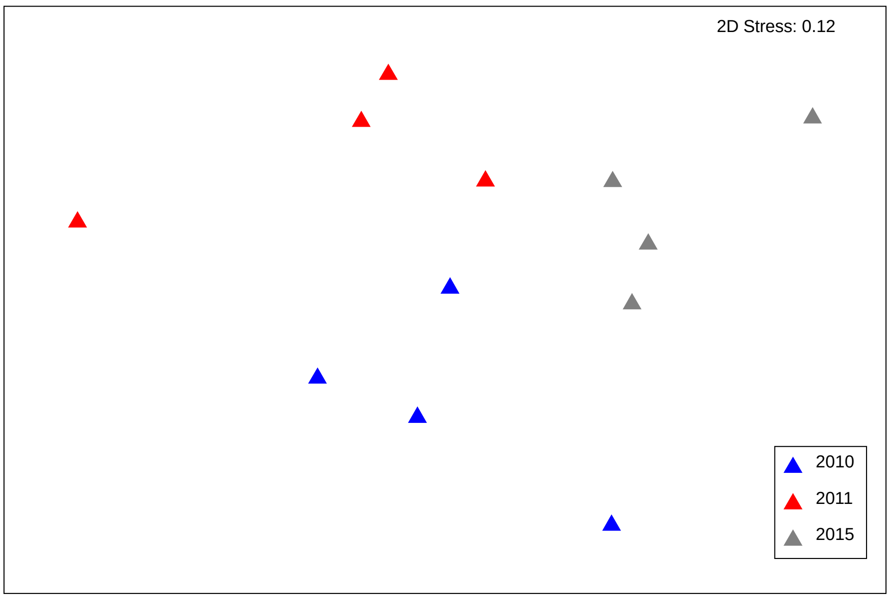

Figure 7. Non-metric multi-dimensional scaling (MDS) plots of fish assemblages sampled via standardised fyke-netting from four sites in the Katarapko Anabranch system in 2010 (blue symbols), 2011 (red symbols) and 2015 (grey symbols).

SIMPER indicated that differences in assemblages between years were primarily due to greater abundances of common carp, eastern gambusia (*Gambusia holbrooki*) and carp gudgeon in 2011, relative to both 2010 and 2015 (Figure 8). Furthermore, ISA suggested the assemblage sampled in 2011 was characterised by greater abundance of common carp (IV = 96.8, p = 0.007) and goldfish (IV = 76.6, p = 0.007).

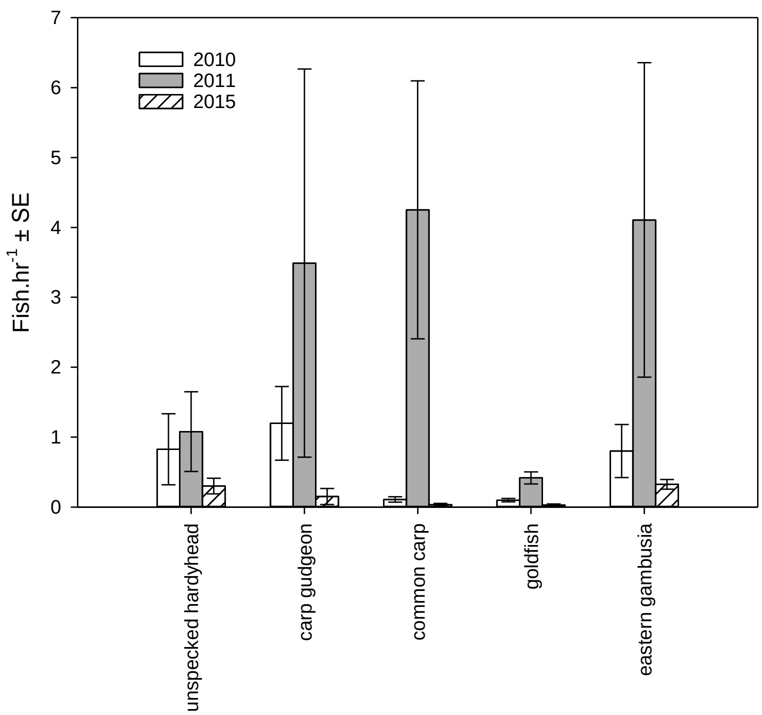

Figure 8. Relative abundance ± standard error (SE) of species from sampling via fyke-netting ($fish.hr^{-1}.site^{-1}$) determined to contribute to differences between fish assemblages (SIMPER) or characterise the assemblage (ISA) between 2010 (white bar), 2011 (grey bar) and 2015 (hashed white bar).

4. DISCUSSION

The construction and operation of infrastructure under SARFIIP represents a substantial alteration to the Katarapko Anabranch system and may have a large influence on ecosystem function and the distribution and abundance of resident biota, including fish. Fish represent a key ecological asset and target for management within the system; the Katarapko system was a ‘demonstration reach’ under the MDBA’s *Native Fish Strategy* and substantial investment has been made under the ‘Katfish Reach’ initiative and RRP specifically targeting fish-related outcomes including improvements to instream habitat quality and connectivity. Monitoring of fish assemblages has occurred at Katarapko since 2007 (Leigh *et al.* 2007), but monitoring has been performed against different objectives and therefore, with different levels of sampling effort. Broad-scale sampling of sites within the system was last undertaken in 2010 and 2011 (Leigh *et al.* 2012), and subsequently, there is no consistent long-term monitoring program and limited contemporary quantitative data on fishes of the system. Such data are required to refine fish-related ecological objectives and targets under SARFIIP and to provide reference data to assess change in fish-related metrics following implementation and operation of SARFIIP infrastructure. This report summarises data from broad-scale sampling of the Katarapko Anabranch system and adjacent River Murray in autumn 2015. Furthermore, it presents these data in the context of comparisons with data from previous broad-scale sampling events in 2010 and 2011 to provide insight on recent changes in fish assemblage structure and the influence of catchment-scale hydrology.

4.1. Fish assemblage structure and spatio-temporal variability

A total of 15 species were sampled in autumn 2015, comprising common small- and large-bodied species, as well as three large-bodied species of conservation significance. Silver perch (listed as *critically endangered* under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*) and freshwater catfish (*protected* under the South Australian *Fisheries Management Act 2007*) were sampled in low numbers, which is consistent with previous monitoring in the system (Leigh *et al.* 2007, 2009, 2012, Beyer *et al.* 2011, Wilson *et al.* 2012, 2013). Three individual Murray cod were sampled in 2015, with one individual captured in Katarapko Creek, the first record of this species from this creek since 2009 (Leigh *et al.* 2009).

Total and standardised abundance of fish in 2015 (10,625 and ~590 fish.site^{-1}) were similar to that from sampling in 2010 (13,523 and ~614 fish.site^{-1}), but less than recorded in 2011 (29,712 and ~1564 fish.site^{-1}). Additionally, fish assemblage structure was similar between 2010 and

2015, but both years were significantly different from 2011 based on data from both sampling methods (i.e. electro-fishing and fyke-netting). Differences between years were primarily driven by greater abundances of several species during 2011, particularly common carp, goldfish, eastern gambusia, golden perch, Murray rainbowfish and carp gudgeon. Alternatively, bony herring were more abundant in 2010 and 2015, relative to 2011. These differences reflect variability in hydrology between 2011 and the years 2010 and 2015.

The greater abundance of golden perch and common carp (and potentially goldfish) observed in 2011, is likely related to the influence of hydrology on spawning and recruitment for these species, as suggested by the dominance of YOY in this year (Leigh *et al.* 2012). Golden perch are flow-cued spawners, relying on the coincidence of elevated discharge and temperature cues to stimulate spawning (Mallen-Cooper and Stuart 2003, Zampatti and Leigh 2013b). Additionally, whilst common carp do not require elevated discharge to spawn and recruit, enhanced abundance of larvae and juveniles is associated with floodplain inundation (King *et al.* 2003, Stuart and Jones 2006). Zampatti and Leigh (2013a) presented data on increases in abundance of golden perch in the lower River Murray in 2011 as a result of spawning and dispersal of juveniles in association with flooding in 2010/11. Low flow conditions and subsequent lack of significant spawning/recruitment events for these species, prior to monitoring in 2015, and particularly 2010, likely led to low abundance relative to 2011. This pattern of variable abundance for golden perch and common carp was also evident at the Chowilla and Pike Anabranch systems (Bice *et al.* 2015; SARDI unpublished data).

Two small-bodied native species, Murray rainbowfish and carp gudgeon, and the non-native eastern gambusia, were also more abundant in 2011 relative to 2010 and 2015. This contrasts differences in the abundance of these species in the main river channel between pre- (2008) and post-flood (2012) periods (Bice *et al.* 2014), when small-bodied species were most abundant during low-flow and lowest following high flows. A combination of reduced cover of aquatic macrophytes and high water velocities in the main channel during high discharge likely render it an adverse habitat for small-bodied fishes (Bice *et al.* 2014), and under such conditions, off-channel habitats, like those within Katarapko, may be preferred. High abundance of eastern gambusia in 2011, following flooding, was also observed at Chowilla (Leigh and Zampatti 2012) and was likely a result of increased area of favourable shallow littoral habitat in that year due to floodplain inundation. A pattern of decreased abundance of carp gudgeon in 2015, relative to 2011, is the inverse of that from the Chowilla Anabranch (SARDI unpublished data) and Pike Anabranch (Bice *et al.* 2015). Nonetheless, carp gudgeon is one species for which fyke-netting is a more effective sampling technique than electro-fishing; >95% of carp gudgeon captured in the current project were sampled by fyke-nets. Fyke-nets were not employed during sampling at either Chowilla or Pike.

Differences in mesohabitat use were generally similar to patterns previously noted in the region (Leigh *et al.* 2009, Zampatti *et al.* 2011). Differences between the assemblages of backwaters and other mesohabitats were driven by relatively low abundances of native species and high abundances of common carp in backwaters. Typically considered generalists in regards to habitat use, common carp and goldfish are commonly found in high abundances in backwater habitats (Zampatti *et al.* 2011). Interestingly, assemblages at fast-flowing sites were characterised by high abundance of unspecked hardyhead, a species often associated with sheltered, vegetated habitats (Wedderburn *et al.* 2007, Bice *et al.* 2014). Nonetheless, the sites sampled in fast-flowing mesohabitats of Katarapko are in Eckerts Creek (i.e. downstream weir and downstream Log Crossing), a narrow watercourse, characterised by high habitat heterogeneity, including aquatic vegetation (Beyer *et al.* 2011). Consequently, whilst classified as fast-flowing, this creek provides a diversity of habitat favourable for species like unspecked hardyhead. Murray rainbowfish and Murray cod characterised main channel sites; similar associations have been noted before for both species in the region (Leigh *et al.* 2009, Zampatti *et al.* 2011).

4.2. Recruitment success

Assessment of recruitment success suggests the system supports the recruitment of a range of fish species. Young-of-the-year (YOY) cohorts were evident for all small-bodied species, as well as bony herring and non-native common carp and goldfish. Only small numbers of Murray cod, silver perch and freshwater catfish were sampled, but each exhibited length frequency distributions that suggested recruitment within the last two years. The sampling of a juvenile Murray cod in Katarapko Creek suggests this creek may provide suitable habitat for local-scale recruitment of this species. This is encouraging given the potential for improved flow through Eckert Creek and lower Katarapko Creek following completion of the Bank J upgrade, and upper Katarapko Creek with potential alteration to the Katarapko Stone Weir. Improved flows to these creeks are likely to improve habitat quality for Murray cod.

5. CONCLUSION

The current report describes the results of broad-scale monitoring of fish assemblages in the Katarapko Anabranch system in 2015. Importantly, comparison with data from sampling in 2010 and 2011 highlights the dynamic nature of fish assemblages of the lower River Murray as a function of variable hydrology. Similar patterns of variability in abundance for certain species, among similar habitats across the region, suggest hydrology drives ecological patterns over large spatial-scales (100s km). This scale is far greater than the Katarapko Anabranch 'site-scale' and has implications for the management of this and other sites.

The disparity of fish assemblages between 2010, 2011 and 2015 indicates the importance of long-term data collection in understanding hydrology-induced variability in ecological patterns, to elucidate potential intervention-induced alterations to ecological patterns in the future. Indeed the suitability of 'reference data', for assessing change in fish-related 'site condition' following operation of SARFIIP infrastructure, is reliant on these data being derived from a broad temporal period that comprises substantial hydrological variability. As such, we suggest annual monitoring of fish assemblages and recruitment, during the same season as that sampled in the current study, and generation of further 'reference data' prior to the operation of SARFIIP infrastructure.

Data generated from sampling in 2015, as well as 2010 and 2011, and any subsequent monitoring, should be utilised to develop fish-related metrics regarding species distributions, abundance and recruitment. Such metrics would be species-specific and incorporate region-specific knowledge of life history and ecology. Similar site-specific metrics are currently under development at 'Icon Sites' (e.g. Chowilla) of the MDB under *The Living Murray Program.* Such metrics, based on reference data, would provide the greatest means of assessing change in site condition with operation of SARFIIP infrastructure.

The generation of reference data and development of metrics will assist in assessing changes in site condition, but provide little insight on cause–effect mechanisms behind changes in biotic patterns. Rather, allied hypothesis-driven investigations are required to provide insight on cause–effect mechanisms and provide the greatest power to inform and adapt management of infrastructure to achieve the greatest ecological benefit with least impact.

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