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Pike Anabranch Fish Intervention Monitoring: Progress Report 2015


C. M. Bice, S. L. Gehrig and B. P. Zampatti

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

The Pike Anabranch and Floodplain is one of three large anabranch systems in the Riverland region of the lower River Murray, South Australia. The Pike Anabranch bypasses Lock and Weir No. 5 and the resulting head differential (total >3 m), creates a diverse range of aquatic habitats across the system, comprised of permanently flowing creeks, lagoons and backwaters. Nonetheless, at present the system is degraded due to decreased frequency of floodplain inundation, limited capacity to vary flows within the system and multiple barriers to flow and fish passage.

As part of the *Riverine Recovery Project* (RRP) several management interventions have been undertaken within the Pike Anabranch system with the objective of improving capacity to vary flow to the inner part of the system (i.e. Deep Creek, Mundic Creek, Tanyaca Creek and Rumpagunyah Creek), increasing hydrological connectivity and mitigating barriers to fish passage. Specifically, the interventions have included an upgrade to the inlet regulator at Deep Creek, replacement/removal of a range of earthen banks (e.g. Coombs Bridge) and fishway construction on the Deep Creek Regulator. Ultimately, these interventions will result in increased capacity to vary flow to the Pike Anabranch, from ~300 $ML.day^{-1}$ up to ~1400 $ML.day^{-1}$, and significantly improve hydrological connectivity within the system and between the Pike Anabranch system and River Murray. On-ground works will be completed within 2015.

The current project was developed to assess the influence of interventions in the Pike Anabranch system as part of the RRP, on fish and fish habitats. It is hypothesised that increased flow to the system and accompanying increases in hydraulically diverse lotic habitat and increased connectivity, will result in significant changes to fish assemblage structure (i.e. species composition and abundance) and recruitment, habitat (vegetated and hydraulic) and fish-habitat associations, including increases in the abundance of species that prefer hydraulically diverse environments (e.g. Murray cod, *Maccullochella peelii,* and golden perch, *Macquaria ambigua ambigua*).

A before-after-control-impact (BACI) monitoring design was developed to assess the response of fish assemblages, instream habitat and hydraulic habitat to the planned interventions. This report presents data from ‘before’ intervention monitoring undertaken in 2015, including

comparison with previous data collected during 'before' intervention monitoring in 2013. 'After' intervention monitoring is planned for 2016.

A total of 18 sites were sampled, representative of three treatments: 1) impact sites (*n* = 9) – creeks within the Pike Anabranch system likely to experience changes in hydrology and hydraulic characteristics as a result of the interventions; 2) creek reference sites (*n* = 6) – creeks within the Pike Anabranch system unlikely to experience changes to hydrology and hydraulic characteristics as a result of the interventions; and 3) river reference sites (*n* = 3) – sites in the River Murray main channel unlikely to experience changes to hydrology and hydraulic characteristics as a result of the interventions. Each site was sampled with standardised boat electrofishing and microhabitat cover was quantitatively assessed. Hydraulic habitat characterisation was undertaken using an acoustic Doppler current profiler (ADCP) at a subset of impact and creek reference sites.

A total of 10,668 fish were sampled from 15 species in 2015. Bony herring (*Nematalosa erebi*) was the most abundant species sampled, followed by unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Australian smelt (*Retropinna semoni*) and Murray rainbowfish (*Melanotaenia fluviatilis*). The total number of fish sampled was substantially greater than 2013 (3,945) and assemblage structure was significantly different. The difference in assemblages between 2013 and 2015 was driven by substantial increases in the abundance of medium- and small-bodied generalist species (i.e. bony herring, unspecked hardyhead, Australian smelt and Murray rainbowfish), and decreased abundance of the large-bodied golden perch and common carp (*Cyprinus carpio*). These changes in abundance reflect a transition from a period of high-flow (2010–2013) to relatively low-flow (2013–2015) in the River Murray, and the influence of hydrology on habitat availability and critical life history processes.

A substantial increase in the cover of floating, submerged and emergent macrophytes in the Pike Anabranch, in association with current low-flow conditions, increased the area of favourable habitat for small-bodied generalist species and likely facilitated increased abundance. In contrast, a lack of elevated within-channel flow events and overbank floods in the years immediately preceding 2015 has likely resulted in lesser recruitment and subsequently lower abundance of golden perch and common carp in 2015, relative to 2013. This pattern of change in fish assemblage structure appears consistent among sites across the floodplain geomorphic region of the lower River Murray (e.g. Chowilla, Katarapko), indicating the scale of influence of hydrology on biotic patterns is greater than the '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 understanding this variability to elucidate potential intervention-induced alterations to biotic patterns in the future.

Juvenile Murray cod were sampled in the Pike Anabranch in 2015, following previous non-detection at the site. This suggests certain creeks within the Pike system may currently provide habitats favourable for local-scale recruitment of the species. Encouragingly, impact sites, those where flow stands to be increased through interventions under RRP, are characterised by high proportions of cover of woody debris; lotic habitats with high levels of cover of woody debris are preferred habitat for all life stages of Murray cod.

Data collected on fish assemblages, recruitment, habitat availability, fish–habitat associations and hydraulics in 2013 and 2015 provide a basis for assessing change in these parameters following completion of interventions under RRP. Furthermore, the current data and methodology will provide a means of assessing ongoing site ‘condition’ in regards to fish-related targets under the South Australian Riverland Floodplain Integrated Infrastructure Project (SARFIIP).

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 (e.g. Maheshwari *et al.* 1995). The construction of a series of low-level weirs along the main channel of the lower River Murray 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 (e.g. Walker 2006). The frequency and duration of floodplain inundation has decreased, whilst periods of elevated within-channel flow have also been reduced (e.g. 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 weeping willow (*Salix babylonica*)) (Walker 1985, Walker and Thoms 1993).

The Pike Anabranch and Floodplain is one of three large (~6,700 ha) anabranch systems (Chowilla, Katarapko and Pike) in the Riverland region of the lower River Murray, South Australia. The Pike Anabranch is fed by two inlet creeks (Margaret Dowling Creek and Deep Creek) that flow from the Lock 5 weir pool into Mundic Creek, before flowing through a series of creeks and lagoons, and finally re-entering the River Murray downstream of Lock 5 via the lower Pike River. As the anabranch system bypasses Lock 5, a head differential (>3 m) is created across the system, resulting in a diverse range of aquatic habitats, including fast-flowing creeks, slow-flowing creeks and backwaters. Flowing water habitats such as these are now absent under regulated conditions in the lower River Murray main channel.

Whilst the Pike Anabranch supports a diverse fish assemblage (Beyer *et al.* 2010) it is nevertheless considered to be highly degraded due to the impacts of river regulation. On a catchment-scale, river regulation and water abstraction in the MDB has reduced flooding frequency and duration, with various accompanying impacts (e.g. decline in condition of floodplain trees). On a local-scale, flow to the system is limited by the operational constraints of the inlet structures (i.e. Margaret Dowling inlet and Deep Creek inlet and associated bridges) and further fragmented by a range of additional structures (i.e. banks B, C, D, E, F, F1, G, H, Snake Creek stock crossing and Coombs Bridge). 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 Pike Anabranch system is now the focus of substantial environmental rehabilitation effort under both the *Riverine Recovery Project* (RRP; *Murray Futures Program*) and *South Australian Riverland Floodplain Integrated Infrastructure Project* (SARFIIP). Management interventions under RRP are primarily focused upon instream outcomes, including improving connectivity and the capacity to vary flow to the system, whilst interventions under SARFIIP are largely focused upon the installation and upgrade of specific structures to allow broad-scale engineered floodplain inundation. On-ground works under RRP commenced in 2013 and will be completed in 2015. Major interventions under SARFIIP are expected to be ongoing from 2016 to 2019. Specific interventions under RRP include,

1. Early Works program: Upgrade of Deep Creek inlet regulator and associated bridge to improve hydraulic connectivity, increase flow volumes and facilitate fish passage (includes fishway construction on the Deep Creek Regulator).
2. Stage 1: Improved connectivity and fish passage throughout the Pike Anabranch system through removal/upgrades of Banks D, E, F, F1, H, G and Coombs Bridge.
3. Stage 2: Improved anabranch hydraulics during natural flood events through the replacement of Banks B, B2 and C (includes construction of fish friendly culverts).

The proposed works under RRP will result in increased capacity to vary flow to the Pike Anabranch system (from ~300 $ML.day^{-1}$ to ~750 $ML.day^{-1}$), thereby influencing the area of hydraulically complex lotic habitat and potentially altering vegetated microhabitats. Furthermore, the removal of banks and construction of fishways will improve connectivity and capacity for fish movement. The interventions will predominantly influence the inner part of the system (i.e. Deep Creek, Mundic Creek, Tanyaca Creek and Rumpagunyah Creek), potentially increasing the area of favourable habitat for a range of native fish species within the Pike system and facilitating fish movement within and between the Pike Anabranch and main channel. Whilst most interventions under RRP have now been completed, flow to the system is yet to be altered from that prior to the upgrade of the Deep Creek regulator, and will not be increased until components of SARFIIP are completed.

An understanding of the influence of management interventions under RRP on fish assemblage structure and recruitment, movement, habitat and fish–habitat associations, is fundamental to inform system operation and management. A four–year fish monitoring program, adopting a before-after-control-impact (BACI) experimental design, was initiated in 2013 (Bice *et al.* 2013), to investigate these parameters, as part of a broader package of investigations that also includes the assessment of the newly constructed Deep Creek fishway (to be conducted in spring/summer 2015/16). The current report presents the findings of the second year of fish assemblage monitoring for the above project. Due to changes in management interventions and system operation, monitoring in 2015 represents a second year of 'before' intervention data collection. Furthermore, the data collected throughout this project (2013–2016) will represent 'reference' data to assess changes in site 'condition' in regards to fish-related objectives and targets under SARFIIP.

1.2. Objectives

The objectives of the project are to investigate: 1) spatio-temporal variation in fish assemblage structure (i.e. species composition and abundance); 2) recruitment; and 3) habitat (vegetated and hydraulic) and fish-habitat associations, within the Pike Anabranch system in relation to the interventions. It is hypothesised that increases in lotic habitat and increased connectivity will result in significant changes to fish assemblage structure and recruitment, habitat (vegetated and hydraulic) and fish-habitat associations, including increases in the abundance of species that prefer hydraulically diverse environments (e.g. Murray cod, golden perch).

2. METHODS

2.1. Site selection

A range of reference (creek reference, *n* = 6 and river reference, *n* = 3) and impact (*n* = 9) sites were selected from the Pike Anabranch system and adjacent River Murray, to be sampled before and after the completion of interventions under RRP, congruent with the BACI experimental approach (Table 1; Figure 1). Impact sites were selected on creeks within the Pike Anabranch system most likely to experience alteration to connectivity, hydrology and hydraulic characteristics as a result of the interventions under the RRP. In contrast, reference sites were selected where hydrology was unlikely to be influenced by interventions over the study period and included sites on creeks within the Pike Anabranch (creek reference sites) and sites on the main river channel (river reference sites). In 2013, Sites 1–16 were sampled; these sites were monitored again, whilst Sites 17 (Deep Creek) and 18 (Margaret-Dowling Creek) were added in 2015. Where possible, site selection followed Beyer *et al.* (2010). All sites were initially assigned to a mesohabitat category (i.e. fast-flowing habitats, slow-flowing habitats, backwaters and River Murray main channel habitats) by visual estimation following Beyer *et al.* (2010), but some were later quantified and, if necessary, revised following hydraulic habitat characterisation. Sites were categorised based on mean water velocity (*sensu* Zampatti *et al.* 2011), where fast-flowing habitats were characterised as having mean velocities >0.18 m s^{-1}, slow-flowing habitats 0.05–0.18 m s^{-1} and backwaters <0.05 m s^{-1}. Sites in the River Murray are classified as 'main channel' mesohabitats (Table 1).

Table 1. Site number, site name, treatment (impact, creek reference and river reference sites), latitude and longitude and flow type (1 = fast flowing anabranches, 2 = slow flowing anabranches, 3 = backwaters, 4 = main channel) for sites sampled within the Pike Anabranch system in 2013. *indicates sites where ADCP transects were undertaken.

Site no.	Site name	Treatment	Latitude	Longitude	Flow type
1	Mundic H Bank access	Impact	S34˚12.984'	E140˚47.105'	3
2	Downstream Bank D	Impact	S34˚13.599'	E140˚46.203'	3
3	Tanyaca Creek*	Impact	S34˚13.388'	E140˚45.495'	3
4	Tanyaca Creek (d/s horseshoe)*	Impact	S34˚14.404'	E140˚45.074'	2
5	Lower Pike*	Impact	S34˚15.580'	E140˚45.554'	2
6	Lower Pike (Simarloo)*	Impact	S34˚16.459'	E140˚43.974'	2
7	Lower Pike (d/s of Lyrup Rd)	Impact	S34˚15.712'	E140˚41.223'	3
8	Mundic to Pike Cutting*	Reference (creek)	S34˚11.966'	E140˚47.624'	1
9	Upper Pike (d/s) Pike Lagoon	Reference (creek)	S34˚12.927'	E140˚48.020'	2
10	Coomb's Bridge (d/s bridge)*	Reference (creek)	S34˚13.435'	E140˚48.537'	2
11	Lower Snake Creek	Reference (creek)	S34˚14.267'	E140˚46.262'	3
12	Upper Pike (cliffs)	Reference (creek)	S34˚14.262'	E140˚49.550'	2
13	Pike River (downstream of Col Col)	Reference (creek)	S34˚15.304'	E140˚46.153'	3
14	Main channel Murray (u/s Lock 5)	Reference (creek)	S34˚11.028'	E140˚46.421'	4
15	Main channel Murray (d/s Lk 5)	Reference (creek)	S34˚13.550'	E140˚44.150'	4
16	Main channel Murray (d/s Pike Junction)	Reference (creek)	S34˚15.268'	E140˚40.646'	4
17	Deep Creek	Impact	S34˚11.455'	E140˚46.506	1
18	Margaret-Dowling Creek	Impact	S34˚11.169'	E140˚47.097	1

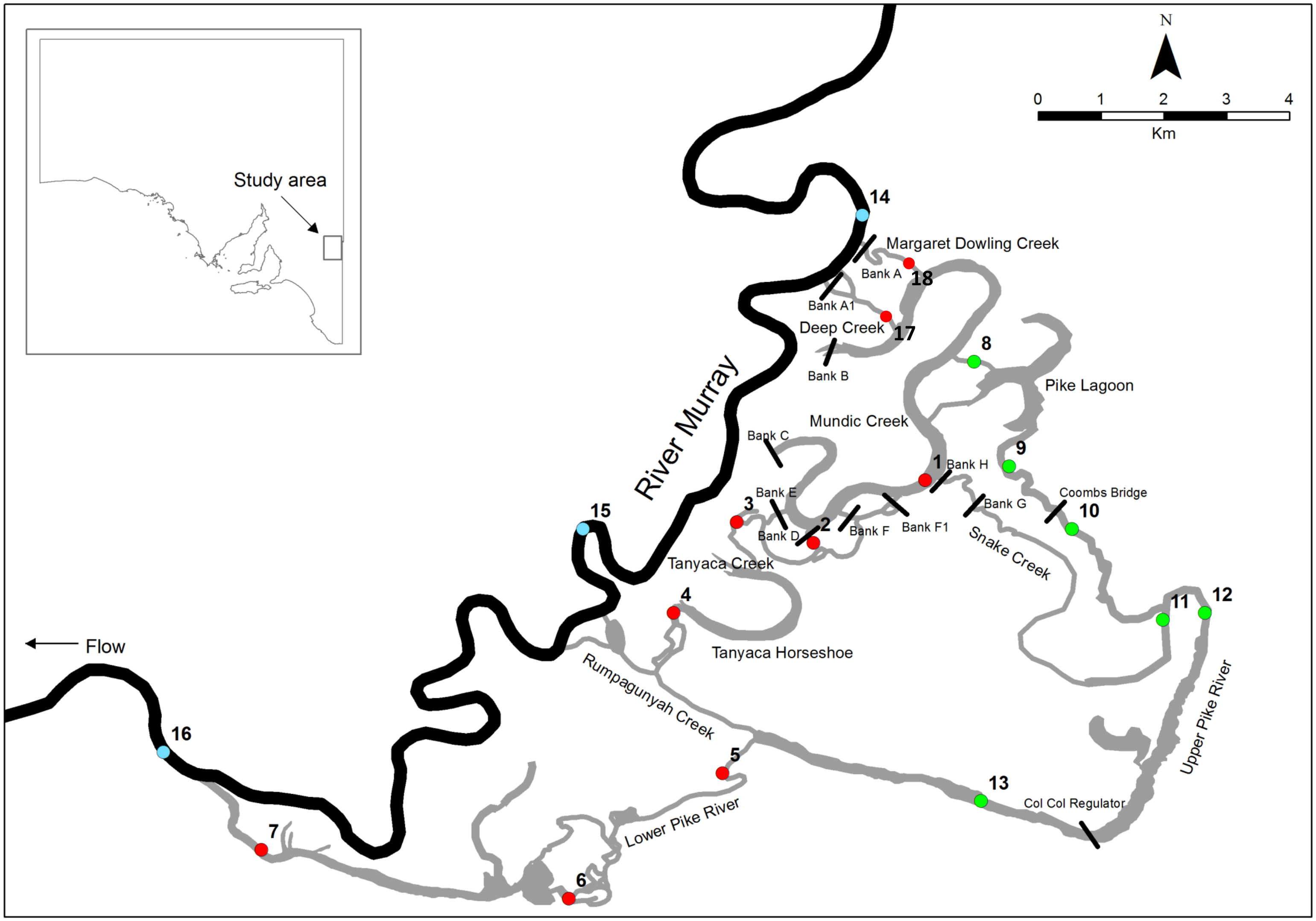

Figure 1. Map showing the location of impact (red circles), creek reference (green circles) and river reference (blue circles) sites sampled in the Pike Anabranch and adjacent River Murray in 2013 and 2015. NOTE: sites 17 and 18 were only sampled in 2015.

2.2. Data collection

Fish assemblage structure and recruitment

Fish assemblages at all sites were sampled from 07/04/2015–23/04/2015 using standardised boat electrofishing. This 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. Only 8 shots could be conducted at Site 18 due to a snag obstructing the upstream portion of the creek. For each electrofishing shot, all sampled fish were identified, enumerated and a sub-sample of 20 individuals per species measured for fork length (FL) or total length (TL) (mm). Any positively identified fish unable to be dip netted were recorded as 'observed' and included in abundance measures.

Instream habitat availability

Simultaneous to electrofishing surveys, quantitative visual assessments of percentage cover of instream microhabitat types (vegetation and structural elements) were undertaken within the area of each electrofishing shot. Vegetation was recorded to individual taxa and categorised based on the following functional groups: emergent, submerged, floating, amphibious, terrestrial and floodplain taxa (modified from classification framework devised by Brock and Casanova (1997) to suit plant communities of the lower River Murray). Where necessary, submerged vegetation was sampled using a van Veen grab to verify identification to species. Woody debris, tree roots, rock and man-made pontoons were classified as 'structural' microhabitats. Woody debris was further categorised depending on the size of the wood (i.e. WD 1: twigs and branches with diameters < 1 cm, WD 2: branches with diameters 1–5 cm and WD 3: branches and trunks with diameters > 5 cm). The remaining area that was neither vegetated nor contained structural habitat was classified as 'open water'.

Hydraulic habitat characterisation

In 2015, hydraulic habitat characterisation followed a refined methodology to that of 2013. Cross-sectional velocity profiles were measured at seven sites (five impact and two creek reference) (Table 1) using a boat mounted SonTek River Surveyor M9 acoustic Doppler current profiler (ADCP) and at each site, three transects were undertaken separated by approximately 100 m (in 2013, one transect was undertaken per site). For specific details on the operation of ADCP units see Shields and Rigby (2005). The ADCP records various data including depth, heading, echo intensity and velocity, in several planes, and can generate cross-sectional velocity profiles of streams with velocity readings provided across grided ‘cells’. These data can also be used to investigate complex flow phenomena such as turbulence and circulation or flow rotation (e.g. eddies) (Crowder and Diplas 2002), which may be biologically relevant to fish assemblage patterns and vegetation cover.

Data generated from ADCP transects were first viewed in the SonTek ADCP software package RiverSurveyor Live. Data were then exported to the numerical computing program MATLAB (The Mathworks Inc. 2010) and interpolated across grids with equal cell sizes using the Delaney triangulation scattered data function, to produce cross-sectional velocity plots. Output data were then used to calculate the following hydraulic metrics 1) discharge ($m^3.s^{-1}$), 2) mean depth (m), 3) cross-sectional area (m^2), 4) mean velocity (U, $m.s^{-1}$), 5) modified vertical circulation metric (M_3, s^{-1}), 6) modified horizontal circulation metric (M_4, s^{-1}), 7) Reynolds number (Re), and 8) Froude number (Fr).

The vertical and horizontal modified circulation metrics are spatial hydraulic metrics developed by Crowder and Diplas (2000) to quantify flow complexity over a defined area; in this case, river cross-sections as measured by ADCP transects. The modified circulation metrics expand on the point calculation of vorticity, which is defined as twice the rate at which a fluid rotates about its vertical axis (Crowder and Diplas 2000, 2002). Vorticity is a point measure, but the modified circulation metrics (M_3 and M_4) (after Shields and Rigby 2005) build upon the calculation of vorticity and represent a weighted average of absolute vorticity (i.e. flow rotation) in the vertical and horizontal planes per unit area, transverse to the channel, and are a measure of the strength and frequency of eddies in a river cross-section (Figure 2). Calculation of M_3 is explained by Equation 1, where w represents velocity in the vertical plane z and v represents velocity in the lateral plane y. Calculation of M_4 is explained by Equation 2 where v represents velocity in the lateral plane y and u represents velocity in the lateral plane x. Absolute values of velocity are used so that the direction of calculation (i.e. clockwise or counter-clockwise) does not result in the cancellation of eddies of equal strength in opposing directions. Higher values of M_3 and M_4 indicate greater frequency and strength of eddies or greater levels of circulation (i.e. flow rotation) within a cross-section. Crowder and Diplas (2002) present an example of utilising M_3 to describe the hydraulic habitat surrounding a series of brown trout (*Salmo trutta*) redds (i.e.

spawning sites) relative to reaches without redds. Furthermore, this metric has been adopted by Shields and Rigby (2005) to analyse river habitat quality and found to be a good discriminator of differences in hydraulic conditions between modified and natural stream reaches.

Equation 1. $$M_3 = \frac{\Sigma\left|\left(\frac{\Delta w}{\Delta y} - \frac{\Delta v}{\Delta z}\right)\right| * \Delta y * \Delta z}{\Sigma \Delta y * \Delta z}$$

Equation 2. $$M_4 = \frac{\Sigma\left|\left(\frac{\Delta v}{\Delta x} - \frac{\Delta u}{\Delta y}\right)\right| * \Delta x * \Delta y}{\Sigma \Delta x * \Delta y}$$

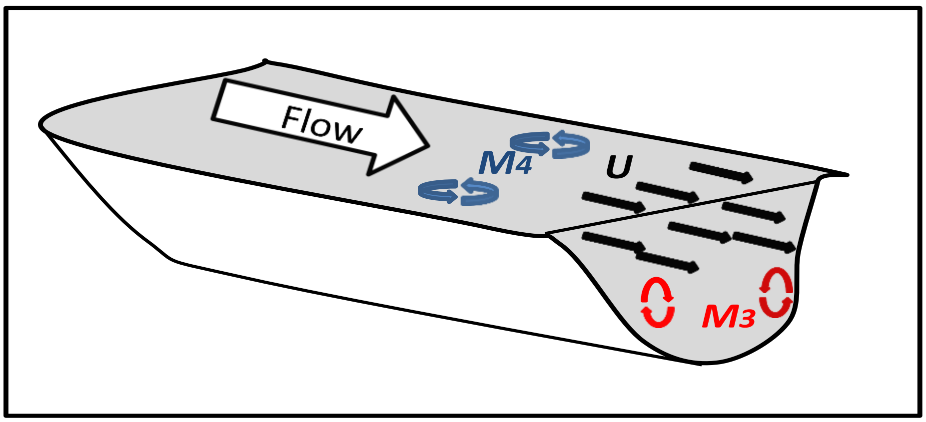

Figure 2. Schematic representation of a river reach and a subset of the hydraulic metrics measured (after Shields and Rigby 2005), downstream cross-sectional velocity (*U*) and vertical (M_3) and horizontal (M_4) modified circulation metrics, which represent the area weighted frequency and strength of eddies within a cross-section.

Reynolds number (*Re*) is a dimensionless metric that indicates whether flow in a channel is laminar or turbulent. In any open stream, flow is almost never laminar and thus the transition from laminar to turbulent flow is not of great importance (Gordon *et al.* 2004). Nonetheless, greater values of Reynolds number indicate greater levels of turbulence. Reynolds number is calculated using Equation 3, where *U* represents downstream cross-sectional velocity, *L* represents the hydraulic radius of a cross section (i.e. the cross-sectional area of the channel divided by the wetted perimeter (the river bed)) and *v* represents kinematic viscosity of water.

Equation 3. $$Re = \frac{U * L}{v}$$

Froude number (*Fr*) is a dimensionless metric that indicates the ratio of inertial to gravitational forces, where gravity encourages water to flow down an elevation gradient and inertial forces indicate the waters compulsion to follow this path (Gordon *et al.* 2004). The Froude number is calculated using Equation 4 where *U* represents downstream cross-sectional velocity, *D* represents average channel depth and *g* acceleration due to gravity (i.e. 9.81 $m.s^{-1}$). Values of *Fr* > 1 indicate supercritical or 'rapid' flow, whilst values < 1 indicate subcritical or 'tranquil' flow (Gordon *et al.* 2004). Much flow in large rivers like the lower River Murray, particularly under low flow, is likely to be subcritical, but higher relative values indicate a greater prevalence of faster flowing habitats and in streams can indicate a greater prevalence of 'riffles' over 'pool' habitat (Lamouroux and Souchon 2002).

Equation 4. $$\boldsymbol{Fr = \frac{U}{\sqrt{g * D}}}$$

2.3. Data analysis

Spatio-temporal variation in both fish assemblage structure (i.e. species composition and abundance) and microhabitat cover (i.e. microhabitat type and proportional cover) was investigated using two-factor (i.e. year and treatment) permutational mulitvariate 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). Analyses were performed on fish relative abundance data ($fish.minute\ of\ electrofishing^{-1}$) and microhabitat cover proportions, which were fourth root and arcsine transformed, respectively. 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 and microhabitat cover from different treatments (i.e. impact, creek reference, river reference). 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 or microhabitat cover between treatments, 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 and microhabitat cover between years and treatments, Indicator Species Analysis (ISA) (Dufrene and Legendre 1997) was also used to determine what fish species and microhabitat types characterised the assemblage/microhabitat cover in certain years and treatments, 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). A perfect indicator 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). This test produces indicator values (IV) for each species or microhabitat type in each group on the basis of the standards of the 'perfect indicator'. Perfect indication (100%) would occur when a species is always present in a statistical group and not in any other groups. Only species and microhabitats with an IV > 20 were accepted. Statistical significance ($\alpha = 0.05$) 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).

ISA was also used to investigate if the presence or absence of specific fish species was significantly positively or negatively associated with particular microhabitat types within each treatment (impact, creek reference, river reference). This test was used to determine whether a microhabitat type had a significantly greater proportion of cover when a fish species was either present or absent. Fish–microhabitat associations were investigated with all treatments pooled, and all microhabitats that contributed mean proportional cover of <0.01% and fish species with <5 individuals sampled were excluded from analyses. This analysis was undertaken separately for each fish species. Only microhabitats deemed significant ($\alpha = 0.05$) and with IV > 20 were considered to represent potential fish–microhabitat associations.

3. RESULTS

3.1. Hydrology

River Murray discharge to South Australia (QSA) has been highly variable since 2010 (Figure 3). Following an extended period of low discharge from 1997–2010, discharge increased dramatically in late 2010, peaking at ~93,000 $ML.day^{-1}$ in February 2011, and resulting in widespread overbank flooding in the lower River Murray. This was followed by a subsequent smaller overbank flood in autumn 2012 and generally elevated discharge throughout much of 2012. Sampling in autumn 2013 occurred immediately following these high flow events, but during discharge (mean = 7432 $ML.day^{-1}$) that approximated summer entitlement flow. Discharge from autumn 2013 to autumn 2015 was generally lower than the preceding years and characterised by 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 subsequent sampling in autumn 2015, approximated summer entitlement flow (mean = 6427 $ML.day^{-1}$).

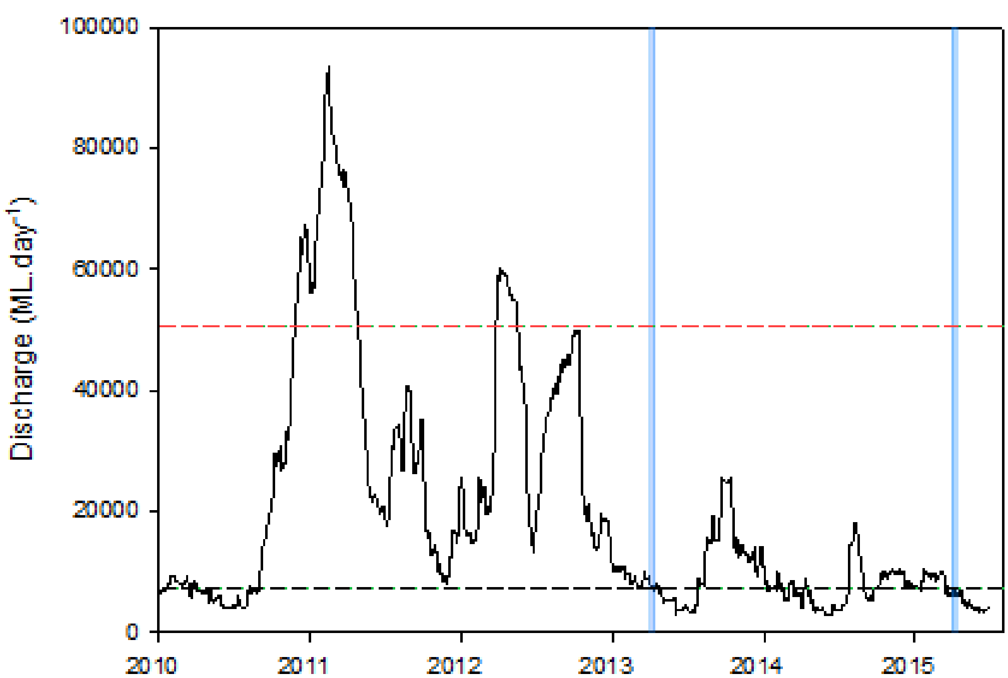

Figure 3. Daily River Murray discharge ($ML.day^{-1}$) to South Australia (QSA) from January 2010 to June 2015. Sampling events are indicated by the vertical blue lines. Dashed red line indicates approximate ‘bank-full’ flow in the lower River Murray, beyond which floodplain inundation occurs and the dashed black line represents summer ‘entitlement’ flow (~7000 $ML.day^{-1}$).

3.2. Catch summary

In autumn 2015, a total of 10,668 fish were sampled from 15 species (Table 2). Standardised abundance was least at impact sites (410 fish.site^{-1}), but similar at river reference (709 fish.site^{-1}) and creek reference sites (809 fish.site^{-1}). Bony herring (*Nematalosa erebi*) was the most abundant species sampled, comprising approximately 59% of the total catch, followed by unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*; ~11%), Australian smelt (*Retropinna semoni*; ~9%) and Murray rainbowfish (*Melanotaenia fluviatilis*; ~7%). The remaining 11 species comprised <15% of the total catch.

Species richness was greatest at impact sites (*n* = 15) and creek reference sites (*n* = 14), and least at river reference sites (*n* = 11). Most species were widespread and sampled from ≥13 sites with the exception of freshwater catfish (*Tandanus tandanus*) and flat-headed gudgeon (*Philypnodon grandiceps*) (*n* = 4 sites), silver perch (*Bidyanus bidyanus*) (*n* = 3 sites), and Murray cod (*Maccullochella peelii*), redfin perch (*Perca fluviatilis*) and dwarf flat-headed gudgeon (*Philypnodon macrostomus*) (*n* = 2 sites). Murray cod were only sampled from fast and slow-flowing mesohabitats and freshwater catfish only from fast-flowing and river mesohabitats.

Table 2. Summary of species and total numbers of fish captured across 18 sampling sites in Pike 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.

		Creek reference						River reference			Impact									
	Site No.	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**17**	**18**	**Total**
	Mesohabitat	**F**	**S**	**S**	**B**	**S**	**B**	**R**	**R**	**R**	**B**	**B**	**B**	**S**	**S**	**S**	**B**	**F**	**F**	
Common name	**Scientific name**																			
Murray cod	*Maccullochella peelii*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Golden perch	*Macquaria ambigua ambigua*	16	9	0	0	0	0	9	8	9	5	0	5	8	12	6	2	1	3	93
Silver perch	*Bidyanus bidyanus*	1	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5
Freshwater catfish	*Tandanus tandanus*	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	4
Bony herring	*Nematalosa erebi*	1535	159	495	112	866	77	73	1002	130	11	111	54	187	209	298	47	599	375	6340
Australian smelt	*Retropinna semoni*	127	61	64	71	114	31	2	199	20	54	8	7	38	4	22	3	124	55	1004
Murray rainbowfish	*Melanotaenia fluviatilis*	137	69	38	9	42	0	120	88	48	11	0	18	69	7	19	17	37	74	803
Flat-headed gudgeon	*Philypnodon grandiceps*	0	0	2	0	0	0	0	0	0	2	0	1	0	0	2	0	0	0	7
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	77	65	108	28	79	34	21	222	85	41	21	27	159	8	37	58	11	67	1148
Carp gudgeon complex	*Hypseleotris spp*	27	7	27	3	13	0	1	0	2	13	20	19	1	0	3	1	3	1	141
Common carp*	*Cyprinus carpio*	23	26	23	6	21	7	22	32	6	10	28	22	8	7	24	14	34	13	326
Eastern gambusia*	*Gambusia holbrooki*	9	7	4	0	4	0	4	2	0	1	114	7	7	5	2	0	0	9	175
Goldfish*	*Carassius auratus*	114	53	28	11	1	8	2	7	9	11	156	73	22	7	36	22	55	1	616
Redfin perch*	*Perca fluviatilis*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
	Total number	**2069**	**456**	**791**	**240**	**1141**	**157**	**254**	**1563**	**309**	**160**	**458**	**233**	**499**	**259**	**449**	**165**	**865**	**600**	**10668**
	Species richness	**13**	**9**	**10**	**7**	**9**	**5**	**9**	**10**	**8**	**11**	**7**	**10**	**9**	**8**	**10**	**9**	**9**	**11**	**15**

3.3. Spatio-temporal variability in fish assemblage structure

Data from Site 13 in 2013 (creek reference, Pike River downstream of Col Col) represented a statistical outlier due to the few species and low numbers of fish sampled; subsequently, those data were removed from analyses as they may mask differences between years and treatments. MDS ordination of fish assemblage data exhibited grouping of samples by year (Figure 4), supported by PERMANOVA, which detected significant differences between years (*Pseudo-*$F_{1,\ 32}$ = 8.86, p < 0.001) and treatments (*Pseudo-*$F_{2,\ 32}$ = 2.09, p = 0.027), with no significant interaction (*Pseudo-*$F_{2,\ 32}$ = 1.04, p = 0.426). Pairwise comparisons revealed that impact and river reference sites were significantly different (t = 1.59, p = 0.017; B–Y method corrected α = 0.027), but impact and creek reference sites were similar (t = 1.28, p = 0.150), as were creek reference and river reference sites (t = 1.49, p = 0.060).

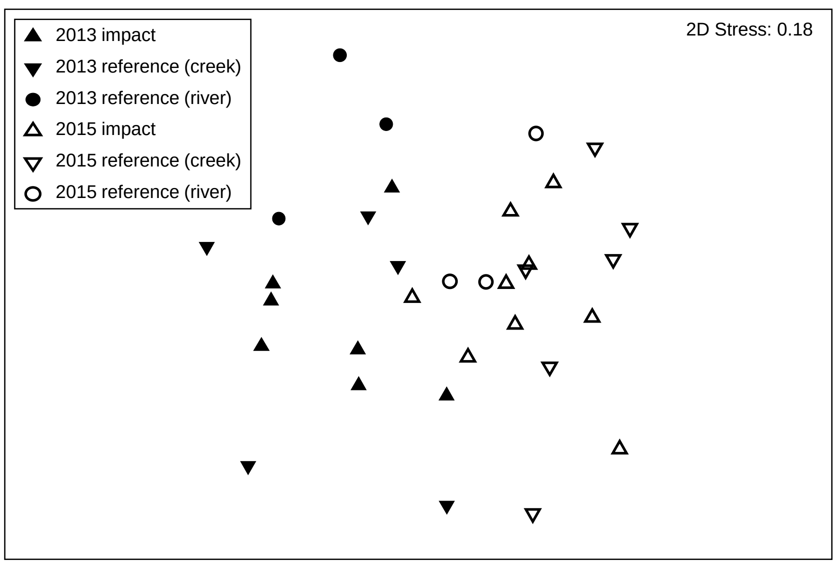

Figure 4. Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled using electrofishing from impact (triangles), creek reference (inverted triangles) and river reference sites (circles) during autumn 2013 (closed symbols) and 2015 (open symbols).

SIMPER (adopting a 40% cumulative contribution cut-off) indicated that the difference in assemblages between years was due to greater abundances of Australian smelt, unspecked hardyhead, Murray rainbowfish and goldfish (*Carrassius auratus*) in 2015, relative to 2013 (Figure 5a). ISA determined the assemblage in 2013 was characterised by greater abundance of golden perch (*Macquaria ambigua ambigua*, Indicator Value (IV) = 57.4, p = 0.030) and common carp (*Cyprinus carpio*, IV = 56.1, p < 0.001), whilst the assemblage in 2015, was characterised by greater abundance of Australian smelt (IV = 74.9, p < 0.001), unspecked hardyhead (IV = 66.1, p < 0.001), goldfish (IV = 66.2, p = 0.004) and carp gudgeon (*Hypseleotris* spp.) (IV = 53.6, p = 0.047) (Figure 5a).

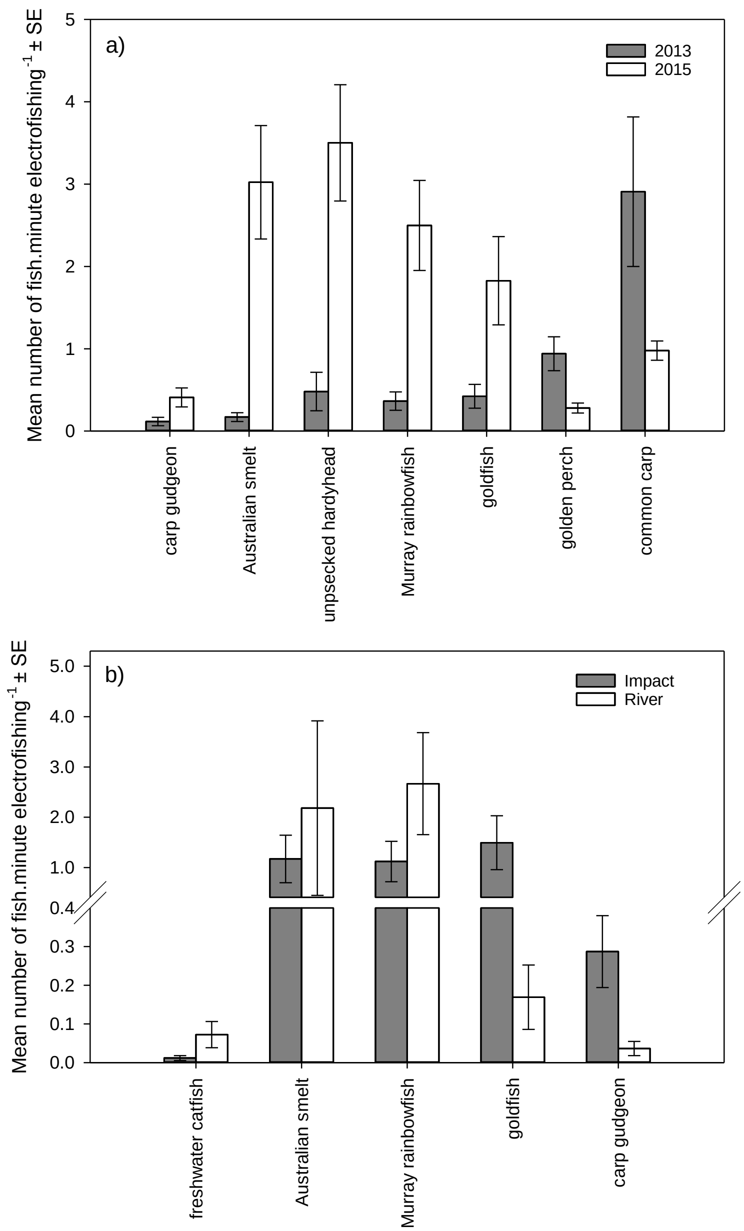

Figure 5. Relative abundance (number of fish.minute electrofishing^{-1}.electrofishing shot^{-1} ± standard error (SE)) of species determined to contribute to differences between fish assemblages (SIMPER) or characterise the assemblage (ISA) between a) 2013 (grey bar) and 2015 (white bar) and b) impact (grey bar) and river reference (white bar) treatments.

SIMPER indicated differences in assemblages between river control and impact sites was due to greater abundances of Australian smelt and Murray rainbowfish at river sites, and greater abundance of goldfish at impact sites (Figure 5b). Furthermore, river reference sites were characterised by greater abundance of freshwater catfish (IV = 57.3, $p = 0.015$) and impact sites by goldfish (IV = 84.2, $p = 0.014$) and carp gudgeon (IV = 72.1, $p = 0.045$) (Figure 5b).

3.4. Fish recruitment

The small-bodied (adult length <100 mm) carp gudgeon (19–44 mm TL), Murray rainbowfish (21–90 mm FL), unspecked hardyhead (14–73 mm FL) and Australian smelt (22–67 mm FL) all exhibited broad length distributions and large proportions of individuals (typically >50%) likely to represent newly recruited young-of-the-year (YOY) cohorts (i.e. <40 mm length) (Figure 6). The length distributions of these species were similar across treatments (with the exception of carp gudgeon; sampled in only low abundance from river sites), suggesting recent successful recruitment for these species within the Pike Anabranch and the adjacent River Murray.

Bony herring exhibited similar length distributions across treatments, with broad size ranges (e.g. 28–360 m FL) and large proportions (>80%) of likely newly recruited YOY (<80 mm FL) (Figure 7a). Golden perch also exhibited similar length distributions across treatments, ranging 167–438, 204–441, and 205–426 mm TL at impact, creek reference and river reference sites, respectively, with no YOY sampled (Figure 7b). Two distinct size-classes of fish were present across all sites ranging 200–300 mm TL and 350–420 mm TL.

Common carp exhibited a broad range of lengths across all treatments ranging 70–583, 92–700 and 57–640 mm FL at creek reference, river reference and impact sites, respectively (Figure 7c). Nonetheless, the length distribution at creek reference sites, was different to the other treatments, with a dominant cohort of fish ranging 260–380 mm FL. Fish ≤120 mm FL, in all treatments, likely represented newly recruited individuals.

Similarly, length-frequency distributions of goldfish were different between creek reference sites and both river reference and impact sites; all distributions were unimodal, but with a mode of 100–120 mm FL at creek reference sites, and 60–80 mm FL in the other treatments (Figure 7d). Nevertheless, recent recruitment was evident in all treatments.

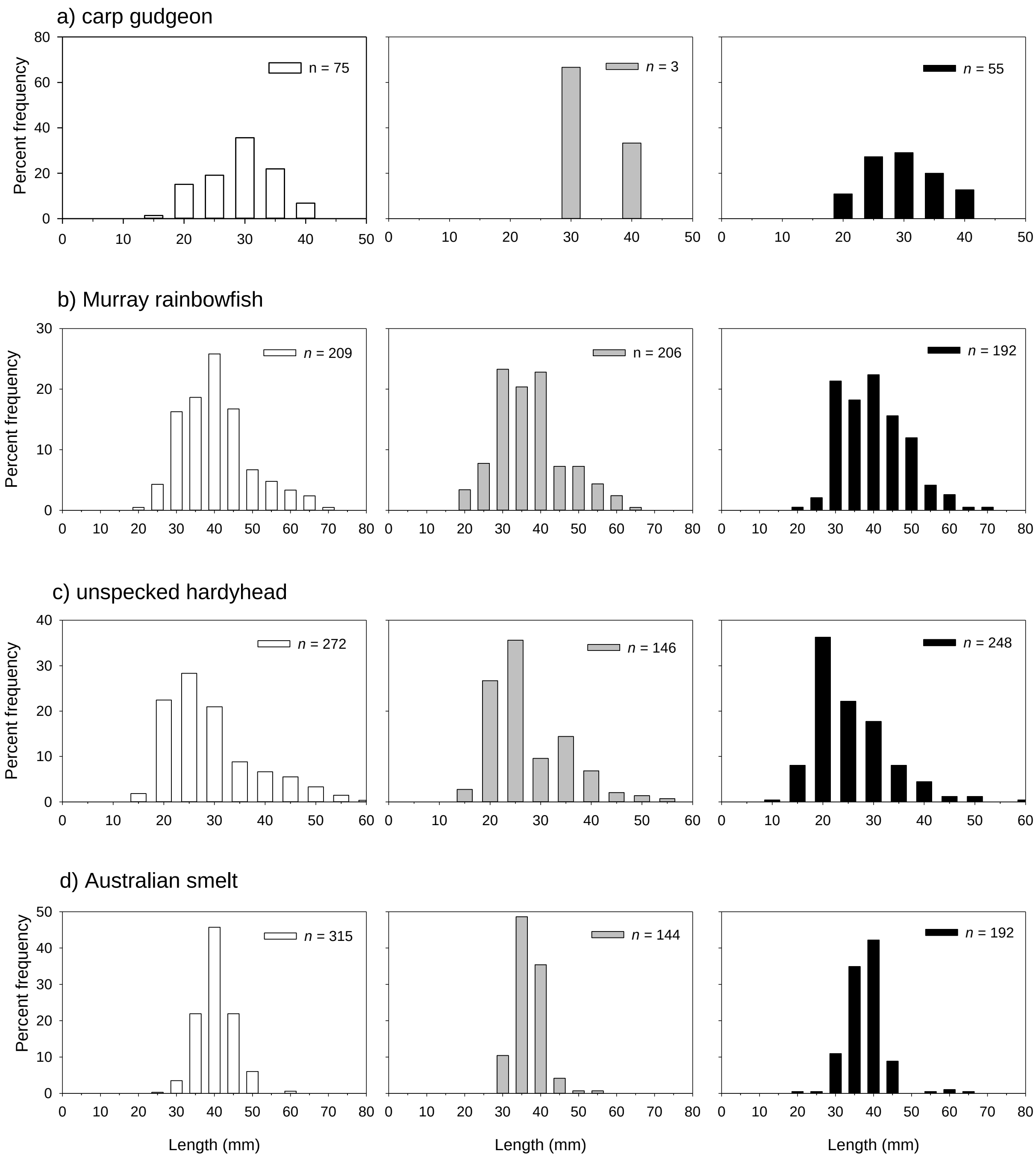

Figure 6. Length frequency distribution of a) carp gudgeon (TL), b) Murray rainbowfish (FL), c) unspecked hardyhead (FL) and d) Australian smelt (FL) at creek reference (white bar), river reference (grey bar) and impact (black bar) sites in autumn 2015.

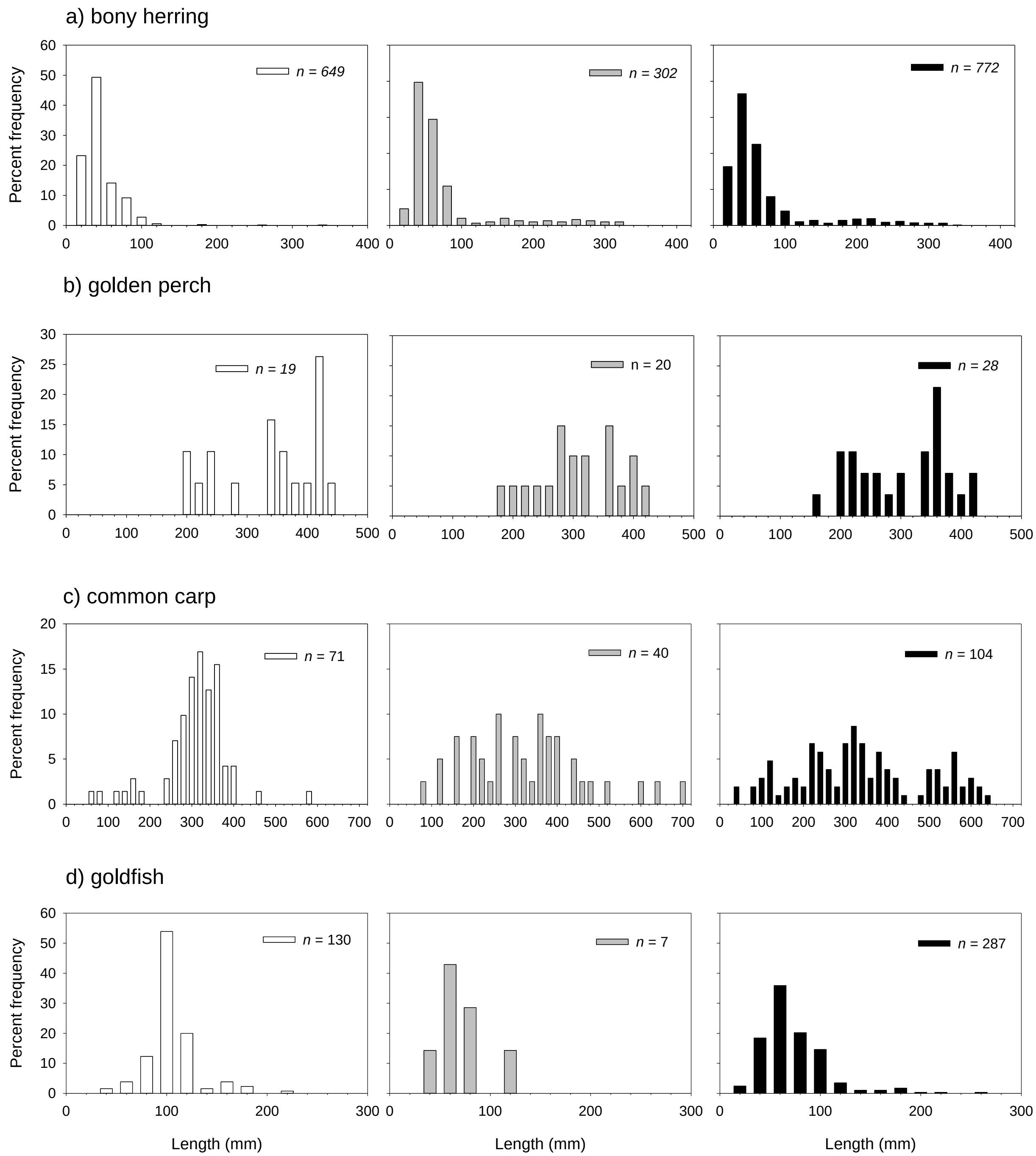

Figure 7. Length frequency distribution of a) bony herring (FL), b) golden perch (TL), c) common carp (FL) and d) goldfish (FL) at creek reference (white bar), river reference (grey bar) and impact (black bar) sites in autumn 2015.

Individual freshwater catfish, silver perch and Murray cod were sampled from impact, creek reference and/or river reference treatments (Figure 8). The two Murray cod sampled were <135 mm TL, indicating they were likely YOY (Figure 8a). All freshwater catfish and silver perch sampled were adults >280 mm in length (Figure 8b and c).

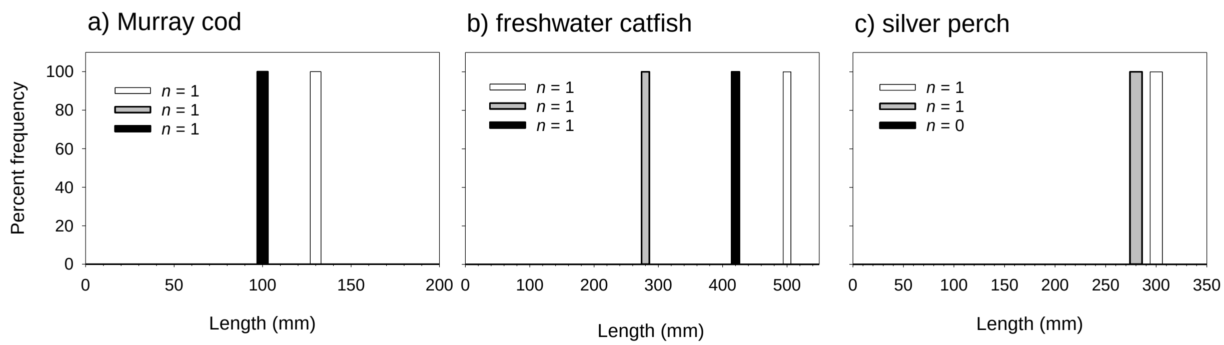

Figure 8. Length frequency distribution of a) Murray cod (TL), b) freshwater catfish (TL) and c) silver perch (FL) at creek reference (white bar), river reference (grey bar) and impact (black bar) sites in autumn 2015.

3.5. Microhabitat cover

A total of 30 different microhabitat types were observed in autumn 2015 across six different functional groups (Table 3). The greatest number of different microhabitats were observed at impact (26 microhabitats, six functional groups) and creek reference sites (23 microhabitats, six functional groups), and the least from river reference sites (19 microhabitats, six functional groups). The most common microhabitat types across all sites in 2015 were open water, woody debris (WD; categories 1–3 combined), the emergent *Typha domingensis* and submerged *Myriophyllum verrucosum*. A greater number of microhabitat types were present in 2015, relative to 2013, due to the presence of several species of submerged macrophytes.

Table 3. Mean cover (mean proportional (%) cover.electrofishing shot^{-1} ± standard error) of microhabitats and functional types at creek reference, river reference and impact sites in 2013 and 2015. Recruit = seedlings/saplings.

Microhabitat	Functional Type	2013			2015		
		Creek reference	River reference	Impact	Creek reference	River reference	Impact
Azolla filiculoides	Floating	0.72 ± 0.25	-	0.20 ± 0.13	0.55 ± 0.55	6.41 ± 0.0.66	6.88 ± 0.52
Myriophyllum verrucosum	Submerged	-	-	0.21 ± 0.1	5.59 ± 0.68	11.86 ± 2.13	4.38 ± 0.65
Potamogeton crispus	Submerged	-	-	-	-	1.61 ± 0.49	0.52 ± 0.16
Potamogeton tricarinatus	Submerged	-	-	-	-	4.86 ± 1.12	1.41 ± 0.32
Vallisneria australis	Submerged	-	-	-	4.13 ± 0.90	3.28 ± 1.15	3.15 ± 0.52
Bolboschoenus caldwellii	Emergent	-	-	0.001	-	0.67 ± 0.36	1.34 ± 0.32
Cyperus gymnocaulos	Emergent	0.03 ± 0.03	-	-	0.04 ± 0.04	-	0.05 ± 0.05
Juncus usitatus	Emergent	-	0.19 ± 0.15	0.05 ± 0.05	0.13 ± 0.08	-	0.06 ± 0.04
Phragmites australis	Emergent	1.50 ± 0.44	0.53 ± 0.32	0.05 ± 0.03	2.93 ± 0.51	6.31 ± 1.38	5.61 ± 1.16
Salix babylonica	Emergent	0.15 ± 0.10	11.36 ± 4.57	-	0.04 ± 0.04	7.89 ± 3.09	-
Schoenoplectus validus	Emergent	3.68 ± 1.01	0.89 ± 0.62	0.63 ± 0.23	4.54 ± 1.02	0.56 ± 0.39	1.34 ± 0.43
Typha domingensis	Emergent	10.63 ± 1.55	11.03 ± 3.50	1.64 ± 0.50	17.43± 1.52	7.17 ± 2.03	9.93± 1.60
Aster subulatus	Amphibious	0.03 ± 0.02	-	0.01 ± 0.01	-	-	-
Cotula coronopifolia	Amphibious	-	-	-	0.14 ± 0.09	-	-
Crassula helmsii	Amphibious	-	-	0.01 ± 0.01	0.23 ± 0.12	-	0.19 ± 0.02
Duma florulenta	Amphibious	0.15 ± 0.10	-	-	0.07 ± 0.66	-	0.23 ± .0.12
Ludwigia peploides	Amphibious	4.94 ± 0.69	0.19 ± 0.17	1.37 ± 0.35	2.49 ± 0.66	0.94 ± 0.39	3.46 ± 0.53
Persicaria lapathifolia	Amphibious	0.34 ± 0.19	-	0.19 ± 0.11	0.65 ± 0.23	-	0.18 ± 0.10
Rumex bidens	Amphibious	-	-	-	-	-	0.27 ± 0.14
Open water	N/A	64.23 ± 3.04	54.64 ± 5.37	52.56 ± 1.95	44.5 ± 2.52	31.22 ± 2.99	26.36 ± 1.47
WD 1	Structural	2.22 ± 0.47	2.89 ± 0.77	5.94 ± 0.54	0.63± 0.24	1.72 ± 0.54	4.03 ± 0.53
WD 2	Structural	3.60 ± 0.59	5.00 ± 0.91	10.42 ± 0.48	2.08 ± 0.44	3.61 ± 0.64	9.47 ± 0.69
WD 3	Structural	5.04 ± 0.89	8.67 ± 1.28	17.01± 1.03	3.19 ± 0.67	7.39 ±1.49	12.99 ± 1.05
Tree roots	Structural	2.53 ± 0.52	3.67 ± 0.87	6.88 ± 0.65	2.38 ± 0.58	2.67 ± 0.73	7.07 ± 0.68
Rock	Structural	-	-	0.07 ± 0.05	-	-	0.11 ± 0.09
Man-made	Structural	0.08 ± 0.08	0.47 ± 0.33	0.08 ± 0.06	-	0.17 ± 0.17	0.11 ± 0.07
Acacia stenophylla (adult)	Floodplain tree	-	0.33 ± 0.33	-	0.06 ± 0.06	1.19 ± 0.71	0.15 ± 0.11
Eucalyptus camaldulensis (adult)	Floodplain tree	-	-	2.24 ± 0.60	0.05 ± 0.05	-	-
Eucalyptus camaldulensis (recruit)	Floodplain tree	0.07 ± 0.07	-	0.04 ± 0.04	-	-	-
Lactuca serriola	Terrestrial	0.06 ± 0.06	-	-	-	-	-
Nicotiana glauca	Terrestrial	-	-	-	0.01 ± 0.01	-	-
Paspalum distichum	Terrestrial	-	0.14 ± 0.1	0.01 ± 0.01	0.21 ± 0.09	0.25 ± 0.18	0.30 ± 0.153
Stemodia florulenta	Terrestrial	-	-	-	-	-	0.06 ± 0.06
	Total Microhabitats	**18**	**14**	**23**	**23**	**19**	**26**

3.6. Spatio-temporal variability in microhabitat cover

MDS ordination of instream microhabitat data exhibited grouping of sites by year (Figure 9). This was supported by PERMANOVA, which detected significant differences between years ($Pseudo\text{-}F_{1,\ 33}$ = 9.82, p < 0.001) and treatments ($Pseudo\text{-}F_{2,\ 33}$ = 4.93, p < 0.001), with no interaction ($Pseudo\text{-}F_{2,\ 33}$ = 0.25, p = 0.981). Pairwise comparisons revealed that impact and river reference sites were similar (t = 1.52, p = 0.080; B-Y method corrected α = 0.027), but impact and creek reference sites were significantly different (t = 2.93, p < 0.001), as were creek control and river reference sites (t = 1.73, p = 0.022).

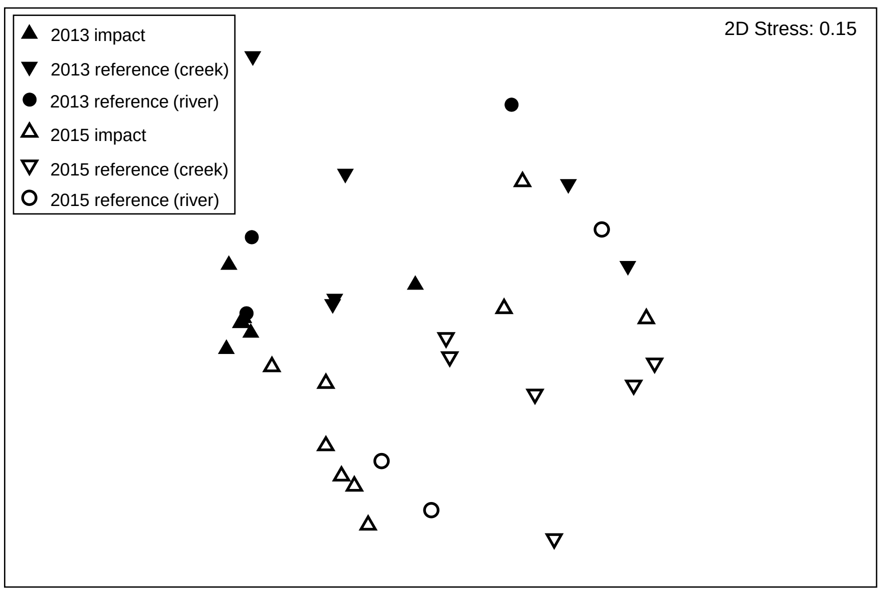

Figure 9. Non-metric multi-dimensional scaling (MDS) plot of proportional microhabitat cover measured during sampling of impact (triangles), creek reference (inverted triangles) and river reference site (circles) during autumn 2013 (closed symbols) and 2015 (open symbols).

SIMPER (adopting a 40% cumulative cut-off) indicated the difference in microhabitat cover between years was driven by decreases in the cover of open water and WD 3, and increases in cover of the floating *Azolla filiculoides*, submergent *Myriophyllum verrucosum* and emergent *Typha domingensis* (Table 3; Figure 10). ISA determined that overall microhabitat cover in 2013 was characterised by greater cover of open water (IV = 59.0, p < 0.001), whilst microhabitat cover in 2015 was characterised by greater relative abundance of a suite of submerged (*Myriophyllum verrucosum* (IV = 69.5, p < 0.001), *Potamogeton tricarinatus* (IV = 33.3, p =

0.019) and *Vallisneria australis* (IV = 83.3, p < 0.001)), emergent (*Bolboschoenus caldwellii*; IV = 32.9, p = 0.032 and *Phragmites australis* (IV = 75.6, p < 0.001)) and floating macrophytes (*Azolla filiculoides* (IV = 85.9, p < 0.001)) (Table 3; Figure 10). Of the submerged species, only *Myriophyllum verrucosum* was present in 2013, and in low abundance.

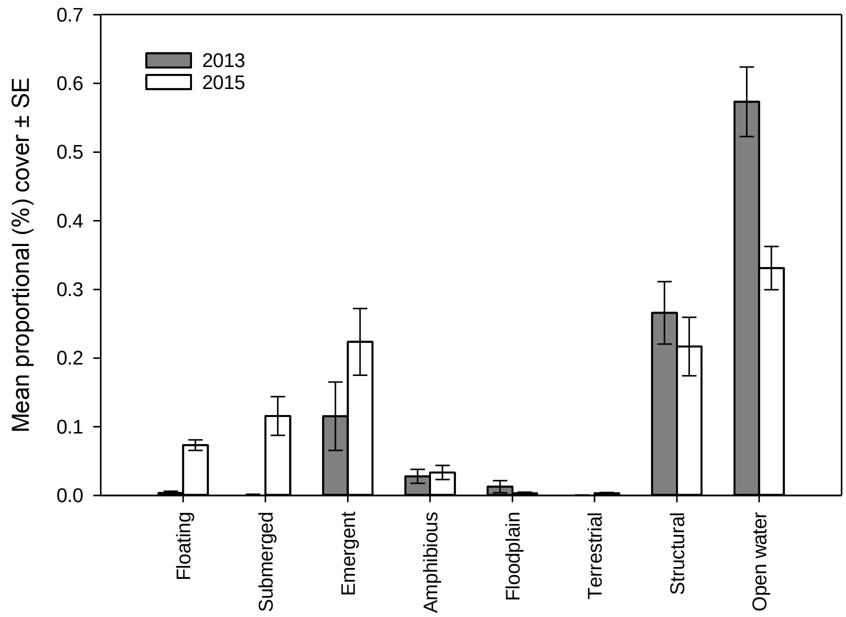

Figure 10. Mean proportional (%) cover per site ± standard error (SE) of microhabitat functional types across all sites sampled in 2013 (grey bar) and 2015 (white bar).

SIMPER (adopting a 40% cumulative cut-off) indicated differences in microhabitat cover between creek reference sites and other treatments, was due to typically greater cover of *Typha domingensis* and open water, and comparatively lower cover of WD 2 and WD 3, and the emergent tree *Salix babylonica* (Table 3). ISA determined that no microhabitat types characterised overall microhabitat cover at creek reference sites, but cover at impact sites was characterised by structural microhabitat types (WD1 (IV = 45.9, p = 0.049), WD2 (IV = 49.0, p = 0.002) and WD3 (IV = 47.0, p = 0.007)), whilst cover at river reference sites was characterised by greater abundance of the floodplain tree *Acacia stenophylla* (IV = 46.3, p = 0.005), the emergent tree *Salix babylonica* (IV = 63.1, p = 0.001) and man-made structures (e.g. pumps, concrete; IV = 35.1, p = 0.042) (Table 3).

3.7. Fish–microhabitat associations

Fish habitat associations were investigated with all treatments pooled. Microhabitats that contributed mean proportional cover of <0.01% and fish species with <5 individuals sampled (i.e. Murray cod, freshwater catfish, dwarf flat-headed gudgeon and redfin perch) were excluded from analyses. Of the remaining species, eight exhibited significant associations with specific microhabitat types. The presence of several species was positively associated with structural microhabitat types including silver perch (WD2), golden perch (WD2, WD3 and tree roots), carp gudgeon (WD2), goldfish (WD1, WD2 and tree roots) and eastern gambusia (*Gambusia holbrooki*) (WD3 and tree roots) (Table 4). Goldfish were also positively associated with the amphibious *Ludwigia peploides*, but negatively associated with the emergent *Phragmites australis.* Alternatively, eastern gambusia was positively associated with *Phragmites australis.* The presence of Murray rainbowfish was positively associated with two emergent species, *Typha domingensis* and *Phragmites australis*, but negatively associated with open water and the submergent *Vallisneria australis*. Carp gudgeon was also positively associated with *Typha domingensis,* but negatively associated with *Vallisneria australis.* Australian smelt was also positively associated with *Typha domingensis*, but was negatively associated with structural microhabitat types (i.e. WD1, WD2, and WD3), and *Phragmites australis.* The presence of bony herring was negatively associated with *Typha domingensis.* No significant microhabitat associations were detected for unspecked hardyhead, flat-headed gudgeon or common carp.

Table 4. Results of Indicator Species Analysis used to derive positive and negative fish–microhabitat associations during sampling in autumn 2015. Indicator Values (IV), the percentage of 'perfect indication' for a particular microhabitat and *p*-values (α = 0.05) are presented. Perfect indication (100%) occurs when a microhabitat type is always present when a given fish species is present (positive association) or always present when a given fish species is absent (negative association). Only those associations with IV > 20 and $p < 0.05$, were deemed as significant.

Common name	Microhabitat	Association	IV	*P* value
Silver perch	WD2	positive	64.0	0.024
Golden perch	WD2	positive	51.3	<0.001
	WD3	positive	52.4	<0.001
	Tree root	positive	37.3	0.002
Bony herring	*Typha domingensis*	negative	40.3	0.023
Australian smelt	*Typha domingensis*	positive	37.5	0.005
	WD1	negative	24.5	0.022
	WD2	negative	42.2	0.004
	WD3	negative	41.2	0.006
	Phragmites australis	negative	32.8	0.010
Murray rainbowfish	*Typha domingensis*	positive	34.8	0.017
	Phragmites australis	positive	32.5	0.011
	Open water	negative	52.6	0.022
	Vallisneria australis	negative	32.6	0.004
Carp gudgeon	WD2	positive	37.9	0.037
	Typha domingensis	positive	38.9	0.002
	Vallisneria australis	negative	34.4	0.002
Goldfish	WD 1	positive	22.1	0.042
	WD 2	positive	42.0	0.001
	Tree root	positive	31.0	0.017
	Ludwigia peploides	positive	27.8	<0.001
	Phragmites australis	negative	29.6	0.034
Eastern gambusia	WD3	positive	41.5	0.024
	Tree root	positive	32.2	0.049
	Phragmites australis	positive	34.3	0.029

3.8. Hydraulic habitat characterisation

Hydraulic data were collected in 2013 and 2015 to provide a reference against which to assess change in hydraulic conditions within the system, following the completion of interventions. In 2015, the methods were adapted to be more rigorous than those in 2013, and as such, results cannot be compared quantitatively. Nonetheless, data collected in 2015 are described and qualitatively compared with data from 2013.

Figure 11 presents an example of visual outputs from ADCP transects from Site 8; these data were then used to calculate hydraulic metrics. Most creeks in the system are narrow (7–50 m wide) and typically characterised by maximum depths <2 m (Table 5). Discharge varies between sites in association with position in the system, and differing contribution of flow sources. For instance, discharge at Site 5 comprises contributions from the entire upper part of the system (upper Pike River, Tanyaca Creek and Rumpagunyah Creek), whilst discharge at Site 4 only represents flow channeled through Tanyaca Creek. Varied creek morphology and proximity of regulatory structures (e.g. earthen banks), interacts with variable discharge, to create variable hydraulic characteristics at monitoring sites (Table 5). Mean site velocities ranged from 0.009 $m.s^{-1}$ at Site 3 (Tanyaca Creek) to 0.291 $m.s^{-1}$ at Site 17 (Deep Creek). Mean water velocity was also moderate at site 8 (Mundic to Pike Cutting, 0.157 $m.s^{-1}$), but at all other sites was <0.08 $m.s^{-1}$. Accordingly, the modified circulation metrics (M_3 and M_4), which represent measures of the frequency and strength of vertical and horizontal eddies, and both *Reynolds* and *Froude* numbers, measures of turbulence and the prevalence of 'fast-flowing habitat', were typically greatest at Sites 8 and 17, relative to all other sites.

As the method for calculating hydraulic metrics in 2015 was adapted to be more rigorous than that used in 2013, results are not directly comparable. Nonetheless, mean velocities measured from single transects at Sites 3 (0.01 $m.s^{-1}$), 4 (0.08 $m.s^{-1}$), 5 (0.10 $m.s^{-1}$), 6 (0.09 $m.s^{-1}$), 8 (0.19 $m.s^{-1}$) and 10 (0.06 $m.s^{-1}$) in 2013, were similar to mean velocities calculated from multiple transects in 2015 (Table 5). The hydraulic data generated in the current project and particularly that from autumn 2015, provides a means to determine changes in hydraulic complexity following the planned interventions and increased flow to the system.

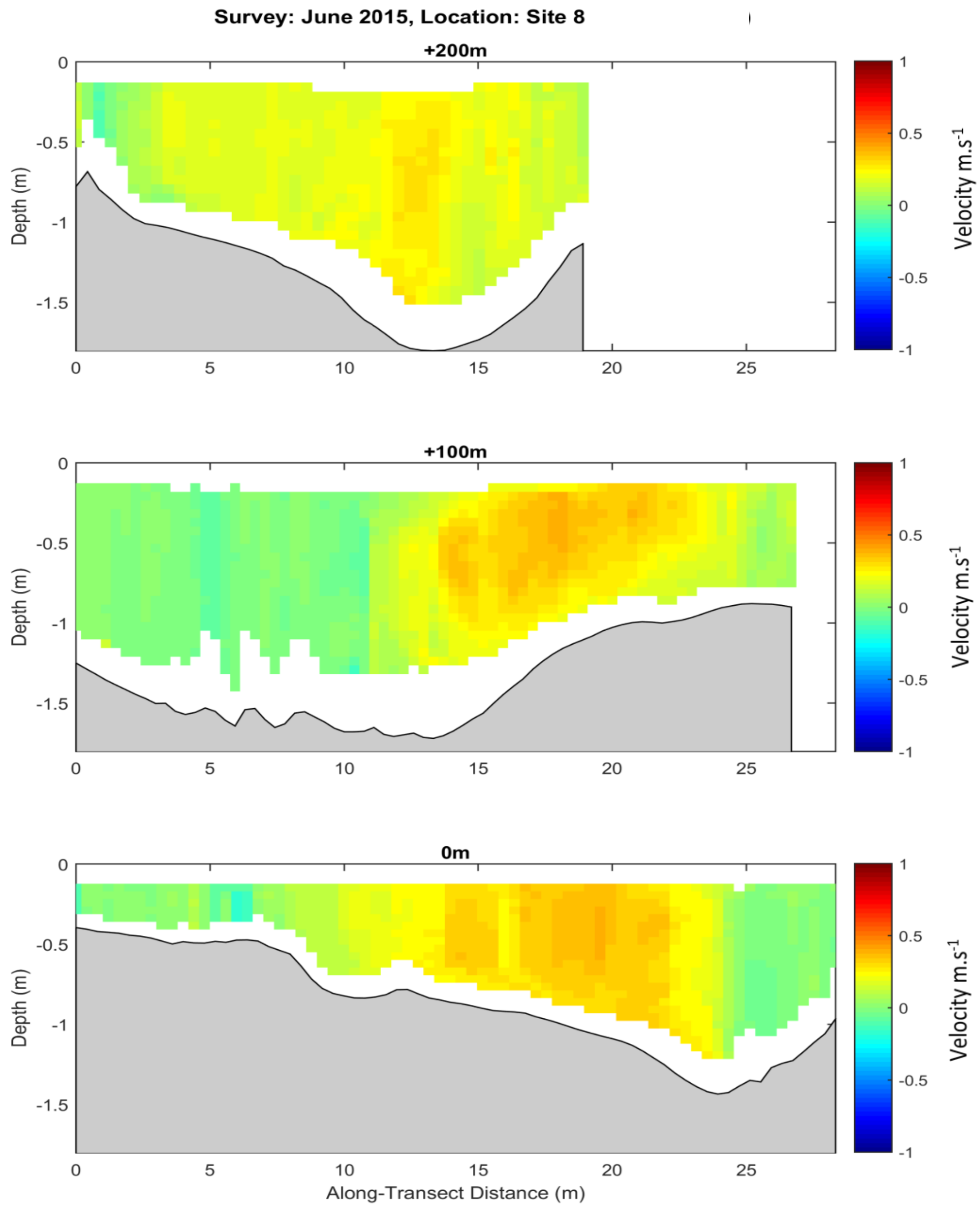

Figure 11. Cross-sectional water velocity profiles from three transects (+200 m, +100 m and 0 m) at Site 8 (Mundic to Pike Cutting) in autumn 2015. Cells are approximately 0.4 m long x 0.05 m high.

Table 5. Mean values (± SE) and ranges (in brackets) of hydraulic habitat metrics calculated from ADCP generated cross-sectional velocity profiles undertaken at sites in the Pike Anabranch in autumn 2015. Metrics presented are mean values of discharge ($m^3.s^{-1}$), transect length (m), max depth (m), cross-sectional area (m^2), downstream cross-sectional velocity (U, $m.s^{-1}$), the modified vertical circulation metric (M_3, s^{-1}), the modified horizontal circulation metric (M_4, s^{-1}), Reynolds number and Froude number calculated from three transects undertaken at each site.

	Impact					Reference	
Means	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 17**	**Site 8**	**Site 10**
Discharge ($m^3.s^{-1}$)	0.31 ± 0.02 (0.28–0.34)	1.89 ± 0.02 (1.85–1.93)	9.52 ± 0.03 (9.47–9.58)	3.00 ± 0.07 (2.90–3.13)	1.48 ± 0.03 (1.43–1.54)	3.21 ± 0.06 (3.12–3.31)	4.14 ± 0.05 (4.09–4.23)
Transect length (m)	35.22 ± 1.03 (33.20–36.59)	34.03 ± 3.08 (27.92–37.80)	50.51 ± 0.84 (49.32–52.13)	37.10 ± 1.55 (35.29–40.19)	7.56 ± 0.61 (6.59–8.69)	24.64 ± 2.90 (18.91–28.33)	53.09 ± 2.14 (49.30–56.67)
Max depth (m)	1.20 ± 0.05 (1.12–1.28)	1.87 ± 0.19 (1.51–2.10)	3.61 ± 0.05 (3.54–3.70)	2.64 ± 0.13 (2.40–2.85)	1.20 ± 0.07 (1.11–1.34)	1.65 ± 0.111 (1.44–1.80)	1.72 ± 0.04 (1.67–1.80)
Area (m^2)	38.09 ± 1.98 (34.88–41.71)	44.20 ± 1.87 (40.47–46.27)	143.47 ± 0.89 (142.15–145.15)	66.05 ± 2.95 (60.24–69.88)	7.97 ± 0.77 (6.69–9.35)	28.80 ± 3.72 (24.77–36.22)	74.93 ± 3.77 (68.11–81.11)
U ($m.s^{-1}$)	0.009 ± 0.001 (0.006–0.011)	0.057 ± 0.003 (0.053–0.062)	0.078 ± 0.006 (0.070–0.089)	0.065 ± 0.004 (0.058–0.074)	0.291 ± 0.013 (0.265–0.309)	0.157 ± 0.021 (0.115–0.180)	0.065 ± 0.003 (0.060–0.071)
M_3 (s^{-1})	0.083 ± 0.017 (0.061–0.117)	0.084 ± 0.006 (0.073–0.094)	0.030 ± 0.002 (0.027–0.033)	0.037 ± 0.001 (0.034–0.039)	0.198 ± 0.003 (0.194–0.202)	0.154 ± 0.011 (0.140–0.177)	0.061 ± 0.006 (0.050–0.072)
M_4 (s^{-1})	0.025 ± 0.003 (0.020–0.030)	0.024 ± 0.001 (0.021–0.026)	0.017 ± 0.003 (0.011–0.021)	0.017 ± 0.001 (0.016–0.018)	0.088 ± 0.004 (0.082–0.095)	0.047 ± 0.003 (0.044–0.053)	0.020 ± 0.003 (0.015–0.025)
Reynolds number	965 ± 135 (733–1202)	7527 ± 866 (6647–9258)	22061 ± 1646 (20090–25330)	11589 ± 606 (10798–12780)	30597 ± 1931 (26932–33487)	18404 ± 2881 (15444–24167)	9108 ± 424 (8357–9825)
Froude number	0.003 ± 0.000 (0.002–0.004)	0.016 ± 0.002 (0.014–0.019)	0.015 ± 0.001 (0.013–0.017)	0.016 ± 0.001 (0.013–0.018)	0.091 ± 0.008 (0.075–0.100)	0.047 ± 0.008 (0.031–0.060)	0.017 ± 0.001 (0.016–0.019)

4. DISCUSSION

Under the *Riverine Recovery Project* (RRP), several interventions are being undertaken in the Pike Anabranch with the aim of increasing capacity to vary flow to the system, including greater flow volumes, increasing hydrological connectivity and mitigating barriers to fish passage (DEWNR 2011). On-ground works are nearing completion, but flow to the system is yet to be altered from that prior to the upgrade of the Deep Creek regulator. Notwithstanding, once the suite of interventions are completed, it is hypothesised that enhanced hydrological connectivity and flow to the system, and accompanying increases in lotic habitat, will result in significant changes to fish assemblage structure and recruitment, habitat (vegetated and hydraulic) and fish-habitat associations, including increases in the abundance of fish species that prefer hydraulically diverse environments (e.g. Murray cod, golden perch). This report summarises results from the second year of 'before' intervention monitoring, undertaken in 2015. Furthermore, it presents a comparison with data collected during 'before' intervention monitoring in 2013 and thus, insight on natural variability in the above parameters. On-ground works are planned for completion in 2015, with 'after' intervention monitoring planned for 2016.

In 2015, total fish abundance (10,668) and species richness (15 species) were greater than recorded during corresponding monitoring in 2013 (3945 fish, 14 species) (Bice *et al.* 2013). The increase in species richness was due to the detection of Murray cod at Site 12 (upper Pike River) and Site 18 (Margaret-Dowling Creek). These represent the first formal records of this threatened species (*vulnerable* under the *Environment Protection and Biodiversity Conservation Act 1999*) from the Pike Anabranch and follow non-detection during previous monitoring events at the site in 2013 (Bice *et al.* 2013) and 2009 (Beyer *et al.* 2010). This suggests that in its current state, certain creeks within the Pike Anabranch likely provide favourable habitat for Murray cod and increased area of such habitat, following the completion of RRP, will likely benefit the species. Such a response would be of regional and State-wide significance.

The difference in total fish abundance and fish assemblage structure between years was driven by increased abundance of several small- and medium-bodied generalist species; bony herring were the most abundant species in both years, but abundance in 2015 was ~3-fold that of 2013, with similar or greater increases in abundance evident for Australian smelt (~15-fold), unspecked hardyhead (~7-fold), Murray rainbowfish (~6-fold), carp gudgeon (~4-fold) and goldfish (~4-fold). Alternatively, golden perch and common carp abundances were ~3-fold lesser in 2015 than 2013. Similar changes in fish assemblage structure were observed at both Chowilla (SARDI unpublished data) and Katarapko Anabranches (Bice *et al.* 2015) in 2015, and are likely related to the influence of variable hydrology on microhabitat availability and critical life history processes of different species. These changes are indicative of a transition from a period of high discharge (2010–2013) to a period of relatively low discharge (2013–2015 onwards), and are the inverse of patterns of change in assemblage structure observed in the region following the preceding transition from low (2005–2010) to high discharge (2010–2013) (Leigh *et al.* 2012, Wilson *et al.* 2012, Zampatti and Leigh 2013a, Bice *et al.* 2014).

Hydrology has a large influence on the distribution and cover of instream habitat (Resh *et al.* 1988). High flows often result in reductions in cover of submerged and emergent macrophytes due to increased water velocities and increased turbidity (Chambers *et al.* 1991). Conversely, low flows and subsequent stable water levels and low turbidity favour the proliferation of macrophytes. Several of the small-bodied species that increased in abundance in 2015 are typically associated with vegetated habitats (Balcombe and Closs 2004, Bice *et al.* 2014), and indeed several were significantly associated with the emergent *Phragmites australis* and *Typha domingensis* in 2015. The proportional cover of these emergent species, together with that of submerged and floating macrophyte species, increased substantially between 2013 and 2015. Furthermore, the 'low-flow recruitment hypothesis' proposes that the recruitment of many small-bodied native fish species is enhanced under low-flow conditions as a function of increased abundance and concentration of appropriate sized prey (Humphries *et al.* 1999). As such, a combination of increased area of favourable habitat and conditions for recruitment, likely resulted in the increases in abundance observed in these species.

Decreases in the abundance of golden perch and common carp are likely unrelated to flow-induced habitat alteration, but rather the influence of hydrology on spawning and recruitment. 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 as a result of spawning and dispersal of juveniles in association with flooding in 2010/11. There is also evidence of spawning and subsequent recruitment of this species in the lower River Murray from 2011/12 and 2012/13 (Ye *et al.* 2015a, 2015b). High discharge events and subsequently, favourable conditions for recruitment of golden perch and common carp, from 2010–2013, likely drove the elevated abundance observed in 2013. Low flow conditions and subsequent lack of significant spawning/recruitment events for these species in the previous two years, likely led to decreased abundance in 2015 relative to 2013.

Differences between treatments, related to fish assemblages and microhabitat cover, reflected typical differences between main channel and anabranch habitats in the lower River Murray. Murray rainbowfish, Australian smelt and freshwater catfish were most abundant in the main river channel, whilst goldfish and carp gudgeon were most abundant in anabranch habitats; these patterns of distribution are commonly observed in the lower River Murray (SARDI unpublished data). Furthermore, spatial differences in microhabitat were driven by greater relative cover of emergent *Salix babylonica* and the floodplain tree *Acacia stenophylla* at river reference sites, and greater cover of woody debris within anabranch habitats, particularly at impact sites. This result is unsurprising given the general high abundance of *Salix babylonica* in the littoral zone of the lower River Murray main channel (Gehrig 2010). The high proportion of structural elements at impact sites is encouraging in light of the prospective interventions; large-bodied native species, including golden perch and Murray cod, have previously been shown to be positively associated with structural elements, including in the current study, particularly when accompanied by flowing water in the case of Murray cod (Crook *et al.* 2001, Koehn 2009). As such, the 'physical template' of favourable habitat for large-bodied native species is present at impact sites within the Pike Anabranch, and it is hypothesised that provision of increased flow and hydraulic complexity at these sites will benefit these species.

Based on length-frequency distributions, all species, with the exception of golden perch, silver perch and freshwater catfish, exhibited signs of recent recruitment, although both silver perch and catfish were sampled in only low numbers. This includes Murray cod, with the two individuals sampled likely representing newly recruited young-of-the-year spawned the previous spring (2014). Murray cod spawn annually over a well-defined period in response to increasing water temperature, irrespective of flow conditions (Rowland 1998, Humphries 2005, Koehn and Harrington 2006). Nonetheless, broad-scale recruitment in the lower River Murray appears associated with years of elevated discharge, whilst low levels of local-scale recruitment may occur in permanent lotic anabranch habitats (e.g. Chowilla) (Zampatti *et al.* 2014). The capture of juvenile Murray cod in the Pike system suggests it may provide habitats favourable for local-scale recruitment of the species and is encouraging given interventions under RRP are likely to result in increases in the area of favourable habitat within the system.

5. CONCLUSIONS

The current report describes the results from the second year of 'before' intervention monitoring in the Pike Anabranch in 2015, to assist in assessing change in fish assemblage structure, recruitment and habitat availability, and fish–habitat associations, following interventions under RRP. A comparison with data from sampling in 2013 highlights the dynamic nature of fish assemblage structure and habitat availability of the lower River Murray as a function of variable hydrology. Furthermore, the consistency of these patterns among similar habitats across the region, including Chowilla (SARDI unpublished data) and Katarapko anabranches (Bice *et al.* 2015), suggests hydrology drives ecological patterns over large spatial-scales (100s km). This scale is far greater than the Pike Anabranch 'system-scale' and has implications for the management of this and other sites.

The disparity of fish assemblages and microhabitat cover between 2013 and 2015 indicates the importance of collecting multiple years of 'before' data. Assessing future changes in fish abundance and population dynamics, as well as habitat availability, will be reliant on differentiating change associated with interventions, and underlying changes associated with variable catchment hydrology. The collection of greater amounts of 'before' data, from periods of varying hydrology, provides greater power to differentiate the effects of interventions and catchment hydrology.

The sampling of Murray cod from the Pike Anabranch for the first time is encouraging given interventions under RRP will likely improve habitat quality for this species within the Pike system. The nature of fish habitat is fundamentally a product of the interplay between physical habitat and hydrodynamics; creeks in the Pike Anabranch system that will be subject to interventions, are characterised by high levels of cover of complex physical habitat, which upon increases in hydrodynamic variability, may favour native fish species, including Murray cod. The hydraulic data collected in 2015, and 2013 will provide a means to quantify purported increases in hydraulic complexity.

Whilst, the current project was initiated to investigate biotic responses to interventions under RRP, it will also fulfill the role of assessing changes in 'condition' in regards to fish-related system targets following the completion and operation of infrastructure under SARFIIP. The current sampling methodology is suitable for this purpose, but allied hypothesis-driven investigations will be required to determine cause–effect mechanisms driving biotic patterns.

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