Inland Waters &
Catchment Ecology

Pike
Fish Assemblage Condition Monitoring 2023


J. Fredberg and C. M. Bice

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EXECUTIVE SUMMARY

The Pike Anabranch is one of three large Anabranch systems that bypasses a weir in the Riverland region of the lower River Murray, South Australia. The system consists of a mosaic of aquatic habitats, including permanent lotic (flowing) streams; such lotic habitats are now rare in the main channel of the River Murray. The associated floodplains of the system also supports ecologically significant vegetation communities, including river red gum (*Eucalyptus camaldulensis*) woodlands. In recent years, under the Riverine Recovery Program (RRP) and South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP), a range of on-ground works (e.g., regulator/bank upgrade/construction and fishway construction) have been completed with the aim of: improved connectivity and extension of lotic habitats under normal operating conditions; and promoting more frequent floodplain inundation than would occur naturally under current conditions, by undertaking managed inundation events. The operation of this infrastructure is guided by the Pike Floodplain Operation Plan and a Monitoring, Evaluation, Reporting and Improvement (MERI) framework.

Fish are a key ecological attribute of the Pike Anabranch system that stand to be influenced by system management. As such, three fish-related ecological objectives have been developed for the system:

1. Restore and maintain resilient populations of large-bodied native fish – i.e., Murray cod (*Maccullochella peelii*) golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), and freshwater catfish (*Tandanus tandanus*);

2. Restore and maintain resilient populations of native foraging generalists – e.g., Australian smelt (*Retropinna semoni*), bony herring (*Nematalosa erebi*), Murray rainbowfish (*Melanotaenia fluviatilis*) and unspecked hardyhead (*Craterocephalus fulvus*); and

3. Minimise the recruitment of introduced species – e.g., common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*).

These Ecological Objectives are associated with six fish assemblage and species-specific Ecological Targets and allied indices. These targets relate to species diversity and extent, the abundance of large-bodied native fish and the recruitment of Murray cod, small-bodied generalist fishes and non-native fishes.

In April 2023, fish condition monitoring was undertaken at the Pike Anabranch to assess spatio-temporal variability in fish assemblage structure (i.e., species identity and abundance) relative to results from previous surveys (i.e., 2009–2022) and the current condition of fish assemblages with regard to the above Ecological Objectives and Targets. Standardised boat electrofishing was used to sample fish from the littoral zones of streams across 13 sites; all species captured were identified, enumerated and a sub-sample measured for length.

A total of 24,092 fish were captured from 13 species (9 native and 4 non-native). The most abundant native species were, bony herring (22.5%), Australian smelt (2.3%) and unspecked hardyhead (1.9%). Non-native common carp (61.9%) were the most abundant species sampled, while non-native goldfish, eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*) collectively comprised 9.9% of the total catch. Three species of conservation significance were sampled, namely: Murray cod (*vulnerable* under the *EPBC Act 1999*); silver perch (*Endangered* under the *EPBC Act 1999*); and freshwater catfish (*protected* under the South Australian *Fisheries Management Act 2007*).

In 2023, sampling followed a large, basin-wide, flooding event that peaked in the lower River Murray in December 2022 (~185,000 $ML.day^{-1}$). Fish assemblages were significantly different to those from preceding years (2009, 2015, 2016, 2020 and 2021) which were characterised by predominantly low within-channel flows (max annual discharge = 11,000–18,000 $ML.day^{-1}$), as well as previous years that were preceded by prolonged high flows (2013) or high within-channel flows (2022). These differences in assemblage structure in 2023 generally reflect decreases in abundance of several small- and medium-bodied generalist species and increases in large-bodied species (both native and non-native) whose reproduction is associated with high flows and flooding. Furthermore, certain species were consistently associated with specific mesohabitat types. Notably, Murray cod, freshwater catfish, bony herring, and Australian smelt were positively associated with lotic habitats.

All fish-related Ecological Targets were partially or fully achieved in 2023, except target six, where the relative abundance and biomass of common carp and goldfish increased . Species diversity exceeded the reference value, whilst extent indices were met for six of eleven target species. The abundances of Murray cod and golden perch exceeded reference values in 2023, while abundance of freshwater catfish and silver perch were both below the reference value. The recruitment target for Murray cod was partially met, with recruitment to the adult population evident, but recruitment to young-of-year (YOY) not detected. Recruitment was limited for all

common small- and medium-bodied species, except for bony herring, which was equivalent to the reference value. Common carp and goldfish exhibited elevated recruitment in association with the major flooding that occurred in spring/summer 2022/23 and recruitment indices for both species were the highest since monitoring began in 2009.

The results highlight the importance of flowing water habitats within the Pike Anabranch and potential positive responses (e.g., Murray cod metrics) to improvements to connectivity and hydrodynamics following works associated with RRP and SARFIIP. They also highlight potential negative outcomes of natural and artificial floodplain inundations (e.g., carp and goldfish recruitment). Continued monitoring will provide greater insight and inform adaptive management of the system.

Keywords: Pike, anabranch, diversity, extent, recruitment, flow, native species, Murray cod, flooding.

1. INTRODUCTION

1.1. Background

The Pike Anabranch and Floodplain (~6,700 ha) is one of three large anabranch systems that bypass a weir in the Riverland region of the lower River Murray, South Australia (the others being Chowilla and Katarapko). The Pike system is fed by two inlets (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 re-entering the River Murray downstream of Lock 5. As the Anabranch system bypasses Lock 5, a head differential (typically >3 m) is generated across the system, creating a mosaic of aquatic environments, including permanent lotic (flowing) habitats that are now rare in the main channel of the River Murray (Bice et al. 2017). Subsequently, the Pike system supports a diversity of native aquatic biota including fishes of conservation concern (e.g., Murray cod (*Maccullochella peelii*), freshwater catfish (*Tandanus tandanus*) and silver perch (*Bidyanus bidyanus*)) (Bice *et al.* 2016). The associated floodplains of the system also support ecologically significant vegetation communities that include river red gum (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) woodlands, lignum (*Duma florulenta*) shrublands, chenopod shrublands, herblands (incl. flood responsive ephemeral communities), grasslands and dunes (Nicol et al. 2015).

At the Pike system, the ecological communities of both aquatic and floodplain environments have been considered degraded for some time due to the impacts of river regulation (Beyer et al. 2010, Marsland 2010, Fredberg and Bice 2022a). Due to the declining condition of long-lived floodplain vegetation and a need to meet environmental objectives with limited water, the South Australian Riverland Floodplains Integrated Infrastructure Program (SARFIIP) was initiated to facilitate engineered (managed) floodplain inundation at the Pike system with the aim of restoring floodplain condition and function (DEWNR 2016). The program involved a range of on-ground works including: the upgrade, installation and replacement of banks and flow regulating structures, construction of fishways, floodplain groundwater and salinity management, and a range of complementary measures. SARFIIP works were completed in 2020 and followed on from the Riverine Recovery Program (RRP, Murray Futures; DEWNR 2011), which included various in-channel remediation works. Together, this infrastructure is being used to: 1) improve connectivity and extension of lotic habitats under normal operating conditions; and 2) promote more frequent floodplain inundation than would occur naturally under current conditions, by undertaking managed inundation events. The operation of this infrastructure is guided by the Pike

Floodplain Operations Plan (DEW 2020) and a Monitoring, Evaluation, Reporting and Improvement (MERI) framework.

Fish are a key ecological attribute of the Pike system that stand to be influenced by management. As such, within the Operations Plan, there are three primary ecological objectives for fish, namely to:

1. Restore and maintain resilient populations of large-bodied native fish – i.e., Murray cod, golden perch (*Macquaria ambigua*), silver perch, and freshwater catfish;

2. Restore and maintain resilient populations of native foraging generalists – e.g., Australian smelt (*Retropinna semoni*), bony herring (*Nematalosa erebi*), Murray rainbowfish (*Melanotaenia fluviatilis*) and unspecked hardyhead (*Craterocephalus fulvus*); and

3. Minimise the recruitment of introduced species (e.g., common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*)).

In association with these Objectives, six Ecological Targets were developed (Fredberg and Bice 2021), namely:

1. Maintain or enhance species diversity;

2. Maintain or enhance extent of species across the site as indicated by species-specific 'extent index';

3. Abundance (CPUE) of large-bodied native fish (i.e., Murray cod, freshwater catfish, golden perch and silver perch) exhibit a positive trajectory over a 5-year period from 2020;

4. Annual recruitment of foraging generalists is maintained or enhanced relative to historical levels, as indicated by species-specific 'recruitment index';

5. Recent recruitment of Murray cod to YOY and the adult population is evident as displayed by the presence of individuals <200 and 400–600 mm TL, respectively; and

6. Relative abundance and biomass of common carp and goldfish do not increase in the absence of meeting key targets under managed inundations (e.g., improved condition of long-lived floodplain vegetation).

1.2. Objectives

The objectives of the project were to:

1) collect fish assemblage data from the Pike Anabranch system in autumn 2023, including species composition, distribution, abundance and recruitment;

2) provide an assessment of spatio-temporal variability in fish assemblages (species composition and abundance) relative to the period 2009–2022; and

3) assess the *condition* of the fish community with reference to defined Ecological Objectives and Targets.

2. METHODS

2.1. Study sites

Standardised electrofishing surveys have occurred in the Pike Anabranch and adjacent River Murray on eight occasions: 2009, 2013, 2015, 2016, 2020, 2021, 2022 and 2023 (Beyer et al. 2010, Bice et al. 2013, 2015, 2016, Fredberg and Bice 2021, 2022a). In total, 10–19 sites have been sampled on an annual basis (Table 1 and Figure 1). Between 2009–2013, sites 1–16 were sampled, whilst sites 17 (Deep Creek) and 18 (Margaret-Dowling Creek) were added in 2015 and 2016 but were not surveyed between 2020–2023. All sites were 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), with several confirmed through hydraulic habitat characterisation (Bice et al. 2013). 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, year sampled and flow type (1 = fast flowing anabranches, 2 = slow flowing anabranches, 3 = backwaters, 4 = main channel) for sites sampled as a part of condition monitoring within the Pike Anabranch system between 2009–2023.

Site no.	Site name	2009	2013	2015	2016	2020	2021	2022	2023	Flow type
1	Mundic H Bank access	*	*	*	*	*	*	*	*	3
2	Downstream Bank D		*	*	*					3
3	Tanyaca Creek	*	*	*	*	*	*	*	*	3
4	Tanyaca Creek (d/s horseshoe)		*	*	*	*	*	*	*	2
5	Lower Pike	*	*	*	*	*	*	*	*	2
6	Lower Pike (Simarloo)	*	*	*	*	*	*	*	*	2
7	Lower Pike (d/s of Lyrup Rd)	*	*	*	*					3
8	Mundic to Pike Cutting	*	*	*	*	*	*	*	*	1
9	Upper Pike (d/s) Pike Lagoon		*	*	*	*	*	*	*	2
10	Coomb's Bridge (d/s bridge)	*	*	*	*					2
11	Lower Snake Creek	*	*	*	*					3
12	Upper Pike (cliffs)	*	*	*	*	*	*	*	*	2
13	Pike River (downstream of Col Col)	*	*	*	*	*	*	*	*	3
14	Main channel Murray (u/s Lock 5)	*	*	*	*		*	*	*	4
15	Main channel Murray (d/s Lk 5)	*	*	*	*		*	*	*	4
16	Main channel Murray (d/s Pike Junction)	*	*	*	*		*	*	*	4
17	Deep Creek			*	*					1
18	Margaret-Dowling Creek	*		*	*					1
19	Rumpagunyah Creek	*				*	*	*	*	2

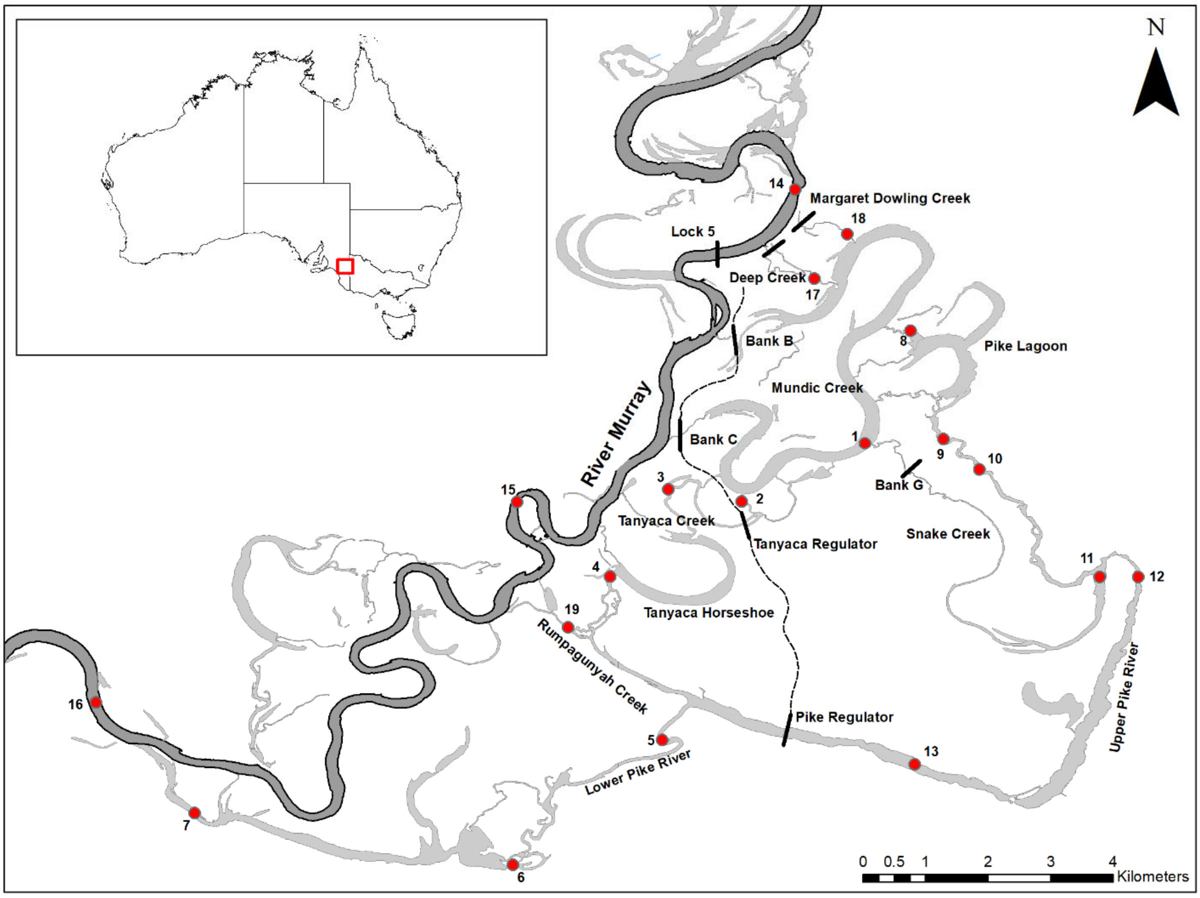

Figure 1. All 19 sites (*red circles*) sampled from 2009–2023 as a part of condition monitoring in the Pike Anabranch system.

2.2. Data collection

In 2023, fish assemblages were sampled from 3–17 April using standardised boat electrofishing (5 kW Smith Root Model GPP electrofishing system). 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 (Fredberg et al. 2021, Ye et al. 2021). At each site, 12 (6 on each bank) x 90 second (power on time) electrofishing shots were undertaken in the littoral zone during daylight hours and fish were dip-netted by a team of two netters and placed in a live well. Fish from each shot were identified, counted, measured for length (± 1 mm, caudal fork length, FL or total length, TL) and released after processing. Where large numbers of an individual species were collected a sub sample of 20 individuals were measured for length. Any positively identified fish unable to be dip netted were recorded as "observed" and included in the total catch.

2.3. Data analysis

Spatio-temporal variation in fish assemblages was investigated by assessing changes in total fish abundance (all species combined) and fish assemblage structure (i.e., species composition and individual species abundance). Differences in the relative abundance (catch per unit effort (CPUE), fish.min^{-1}) of fish sampled between years were analysed using univariate (similarity matrices calculated using Euclidean distances) single-factor PERMANOVA (permutational ANOVA) (Anderson and Ter Braak 2003) in the package PRIMER v. 6.1.12 and PERMANOVA+ (Anderson et al. 2008). When significant differences occurred in main tests, pairwise comparisons were undertaken to determine years that were statistically different. To allow for multiple comparisons, the B–Y method significance correction was adopted ($\alpha = \sum_{i=1}^{n}(1/i)$; e.g. for $n_{comparisons}$ = 12, B-Y method α = 0.05/ (1/1 + 1/2 + 1/3…..1/15) = 0.015) (Benjamini and Yekutieli 2001).

Differences in the structure of fish assemblages (i.e. species composition and abundance) was investigated using two-factor (i.e., year and mesohabitat) PERMANOVA (Anderson 2001, Anderson and Ter Braak 2003). Analyses were performed on Bray-Curtis similarity matrices (Bray and Curtis 1957) of fish relative abundance data (fish.minute of electrofishing^{-1}), which were previously fourth root transformed, and significance value of α = 0.05 was adopted. Non-Metric Multi-Dimensional Scaling (MDS) plots, generated from the same matrices were used to visualise assemblages from different years and mesohabitats (i.e., slow flowing, fast flowing and backwater). When significant differences occurred among mesohabitats in main tests, pairwise comparisons were undertaken to determine mesohabitats that were statistically different and the B–Y method significance correction was adopted.

To further investigate temporal variability in assemblage structure, group average clustering was performed on site pooled data (individual species CPUE, fish.min^{-1}), and a cut off score of 85% similarity was used to determine the cluster groups based on species abundance. When difference occurred, Similarity of Percentages (SIMPER) analysis was used to determine species contributing to differences in assemblages (a 50% cumulative contribution cut-off was applied). Additionally, Indicator Species Analysis (ISA) was undertaken with the software package PCOrd v. 5.12 (McCune and Mefford 2006) and used to determine species that characterised assemblages in different clusters (year groupings) and mesohabitats. 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 for each species in each group based on the standards of the perfect indicator and statistical significance of each indicator value is tested by a Monte Carlo (randomisation) technique, where the real data are compared (in this instance) against 5000 runs of randomised data (Dufrene and Legendre 1997).

2.4. Assessment of Ecological Targets

Fish-related Ecological Objectives and Targets were defined and associated indices developed by Fredberg and Bice (2021). This approach followed that applied at the Chowilla Anabranch under *The Living Murray Program* and guided by Robinson (2013). The below sections outline the calculation of ‘reference’ and ‘index’ values for each respective target.

Target 1: Maintenance or enhanced species diversity

The diversity reference and index were derived using an ‘expected vs predicted’ approach as adapted from the SRA method outlined in Robinson (2013). An expectedness weight was developed for each native species for each mesohabitat type based upon all sampling data from 2009–2023. Sampling conducted from 2009–2020 was used to calculate all reference values. This time period incorporates a range of hydrological conditions (drought and flood) and reference values derived from this dataset will likely prove suitable for assessing site condition through time. For each mesohabitat, the proportion of sites at which a species was sampled was calculated for every sampling year, and the mean of this value across years (hereafter called ‘expectedness ratio’) was used to calculate the ‘expectedness weight’ for each species (Table 2). Rarity scores were also assigned to each native species based upon expert opinion (Robinson 2013) (Table 2).

Table 2. Summary of rarity scores (*RS*), interpretation of expectedness ratio (*ER*) and expectedness weight to be assigned to fish species at the Pike Anabranch.

RS	Interpretation (expectedness ratio, *ER*)	Expectedness weight
1	Either rare or cryptic species. Expected to be collected in up to 20% of sites.	0.10
3	Locally abundant species. Expected to be collected in 20 to 70 % of sites.	0.45
5	Common and abundant species. Expected to be collected in 70 to 100% of sites.	0.85
0	Native species not historically recorded. Not included in expectedness calculations.	0

Rarity scores, mean expectedness ratio (i.e., proportional presence of native fish within mesohabitats) and associated expectedness weights for all native fish species using the standardised method are presented below in Table 3. These metrics are presented separately for each mesohabitat type. Non-native species are not included in diversity calculations.

The diversity index (*DI*) (i.e., no. species actually sampled/expected no. species) was calculated for each site within a mesohabitat. The mesohabitat diversity index presented in the results (Figure 7) is the mean of these site-specific indices from all sites within a particular mesohabitat. In turn, the site score is the mean of the mesohabitat indices. Values of *DI* >1.0 indicate diversity greater than the reference, whilst values <1.0 indicate diversity less than the reference.

Table 3. Rarity scores, expectedness ratio and expectedness weight for all native species sampled at the Pike Anabranch within fast-flowing, slow-flowing, main channel and backwater mesohabitats.

Species	Rarity score	Expectedness ratio	Expectedness weight
Fast-flowing			
Australian smelt	5	1	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	1	0.85
Dwarf flat-headed gudgeon	1	0.27	0.45
Flat-headed gudgeon	3	0.07	0.10
Freshwater catfish	3	0.4	0.45
Golden perch	5	0.8	0.85
Murray cod	3	0.33	0.45
Murray rainbowfish	5	0.9	0.85
Silver perch	3	0.47	0.45
Spangled perch	0	0	0
Unspecked hardyhead	5	1	0.85
	Predicted no. species		11
	Expected no. species		7
Slow-flowing			
Australian smelt	5	0.75	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.69	0.45
Dwarf flat-headed gudgeon	1	0	0
Flat-headed gudgeon	3	0.31	0.45
Freshwater catfish	3	0.23	0.45
Golden perch	5	0.72	0.85
Murray cod	3	0.07	0.1
Murray rainbowfish	5	0.89	0.85
Silver perch	3	0.21	0.45
Spangled perch	0	0	0
Unspecked hardyhead	5	0.93	0.85
	Predicted no. species		10
	Expected no. species		6.15
Main channel			
Australian smelt	5	0.92	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.67	0.45
Dwarf flat-headed gudgeon	1	0.17	0.10
Flat-headed gudgeon	3	0.5	0.45
Freshwater catfish	3	0.5	0.45
Golden perch	5	1	0.85
Murray cod	3	0.08	0.10
Murray rainbowfish	5	1	0.85
Silver perch	3	0.25	0.45
Spangled perch	0	0	0
Unspecked hardyhead	5	0.92	0.85
	Predicted no. species		11
	Expected no. species		6.25
Backwater			
Australian smelt	5	0.9	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.69	0.45
Dwarf flat-headed gudgeon	1	0.07	0.10
Flat-headed gudgeon	3	0.41	0.45
Freshwater catfish	3	0	0
Golden perch	5	0.48	0.45
Murray cod	3	0	0
Murray rainbowfish	5	0.55	0.45
Silver perch	3	0	0
Spangled perch	0	0	0
Unspecked hardyhead	5	0.9	0.85
	Predicted no. species		8
	Expected no. species		4.45

Target 2: Maintenance or enhanced extent of species across the site

An Extent Index (*EI*) was developed using the expectedness ratios calculated above (Table 3) as the 'reference value' (Robinson 2013). The expectedness ratio represents the mean distribution of individual native species across a mesohabitat type (i.e., proportion of sites within a mesohabitat where the species was sampled), annually across the entire study period (2009–2023).

The extent index is species-specific and is calculated as outlined below.

- *MH* = mesohabitat,
- R_{year} = ratio of sites sampled in given year,
- *ER* = expected ratio for each mesohabitat type,
- *EI* = Icon Site Extent Index,
- *EI* = mean $(MH_1(R_{year}/ER_{MH1}) + MH_2(R_{year}/ER_{MH2}) + MH_3(R_{year}/ER_{MH3}) + MH_4(R_{year}/ER_{MH4}))$,
    - *EI* = 0.75–1.25 represent stable extent/distribution
    - *EI* >1.25 represents increased extent/distribution
    - *EI* <0.75 represents decreased extent/distribution

Species with rarity scores of 0 were excluded. This was limited to spangled perch (*Leipotherapon unicolour*), a species that has been previously recorded in the lower Murray but is considered a vagrant from the Darling River (Ellis et al. 2015). Furthermore, Murray cod, silver perch, dwarf flat-headed gudgeon (*Philynodon macrostomus*) and freshwater catfish do not have an expectedness ratio in backwater mesohabitats, as they have never been sampled in this mesohabitat type during standardised electrofishing in the Pike Anabranch.

Target 3: Abundance (CPUE) of large-bodied native fish exhibit positive trajectories over a 5-year period from 2020

One of the key ecological targets for native fish in the Pike Anabranch system is to restore and maintain resilient populations of large-bodied native fish. Specifically, interventions that have improved flow in the Anabranch system over spatial scales of 1–10s km stand to improve habitat quality for Murray cod, freshwater catfish, golden perch, and silver perch. As such, specific targets were developed for these species that propose increasing trajectories of abundance relative to a reference value. For these species, this reference is the mean abundance (CPUE; fish.minute electrofishing^{-1}.site^{-1}) across sampling at the Pike Anabranch from 2009–2020, prior to major changes in system management. The species-specific reference values are as follows: Murray cod = 0.005 fish.minute electrofishing^{-1}.site^{-1}; freshwater catfish = 0.019 fish.minute electrofishing^{-1}.site^{-1}; golden perch = 0.339 fish.minute electrofishing^{-1}.site^{-1} and silver perch = 0.0128 fish.minute electrofishing^{-1}.site^{-1}.

Target 4: Annual recruitment of foraging generalists is maintained or enhanced

References and indices were developed for the following species, broadly representative of the small- to medium-bodied fishes of the lower River Murray:

- Unspecked hardyhead;
- Murray rainbowfish;
- Australian smelt; and
- Bony herring

The index for these species incorporates both age/size structure and abundance. These species are short-lived (1–5 years) and are thus reliant upon annual recruitment. In most species, fish comprising the YOY cohort in autumn will contribute to the reproductively mature adult population the following spawning season. Abundance is included in the index, as reliance on an age/size structure alone may result in years where few fish are sampled being classified as years of 'successful' recruitment. For these species, length is an appropriate surrogate for true measures of age (e.g. otolith increment counts).

The reference value (Table 4) is the mean abundance of the YOY cohort from baseline data collected from 2009–2020, and is calculated as:

- X = site abundance (fish.minute electrofishing^{-1}.site^{-1}),
- $r_{standard}$ = set proportion YOY* (*Values of $r_{standard}$ were calculated as the mean proportion of the population comprised of young-of-the-year from 2009–2020.),
- Reference value (RV) = mean((X_{2009}*$r_{standard}$) + (X_{2013}*$r_{standard}$) + (X_{2015}*$r_{standard}$) +…….. (X_{2020}*$r_{standard}$))

Table 4. Species, typical length of the YOY cohort during annual sampling (based upon knowledge of species biology), the mean proportion of the population comprised by the YOY cohort ($r_{standard}$) and the recruitment index reference value (*RV*).

Species	Length YOY	$r_{standard}$	RV
Unspecked hardyhead	<40 mm FL	84%	3.98
Murray rainbowfish	<40 mm FL	42%	0.46
Australian smelt	<40 mm FL	42%	0.92
Bony herring	<100 mm FL	71%	13.29

The recruitment index for small-bodied species was calculated as:

- X_{year} = annual abundance (fish.minute electrofishing^{-1}.site^{-1}),
- r_{year} = annual proportion of YOY
- Annual recruitment value *(AV)* = $X_{year} * r_{year}$
- Recruitment index (*RI*) = *AV*/*RV*
    - Values of *RI* >1.0 represent enhanced recruitment relative to reference
    - Values of *RI* <1.0 represent diminished recruitment relative to reference

Target 5: Recent recruitment of Murray Cod to YOY and the adult population is evident as displayed by the presence of individuals <200 and 400–600 mm TL, respectively.

The recruitment index for Murray cod incorporates length frequency data only. Abundance is not included due to the low numbers of fish typically sampled. Murray cod recruitment is measured as the proportion of fish ranging 400–600 mm TL. This length range corresponds to individuals 3–6 years of age in the lower River Murray (Zampatti et al. 2014) and subsequently the age at sexual maturity (Rowland 1998), and thus represents recruitment to the adult population. Recruitment to YOY was also assessed, as indicated by the proportion of fish <200 mm TL, and provides a useful measure of survival of recently spawned fish.

The reference value is the mean proportion of the population comprised of fish 400–600 mm TL and YOY <200 mm TL over baseline data collected from 2009–2020. These values are 6% and 43% for fish 400–600 mm TL and <200 mm TL, respectively.

Target 6: Recruitment events for common carp and goldfish do not occur in the absence of meeting other key targets under managed inundations (e.g., improved condition of long-lived floodplain vegetation)

The development of recruitment indices for the non-native species, common carp, and goldfish, followed the same approach as for small-bodied native species and incorporates size structure (as a proxy for age) and abundance. For common carp and goldfish, length is appropriate for discerning the annual YOY cohort from autumn sampling. Length, however, is not a surrogate for true measures of age (e.g., otolith increment counts) for older individuals.

The reference values for these indices are effectively the mean abundance of the YOY cohort for these species from 2009–2020. The reference values are species-specific (Table 5) and were calculated using the following equation where X = site abundance (fish.minute electrofishing^{-1}.site^{-1}), and $r_{standard}$ = set proportion YOY.

Reference value (*RV*) = mean((X_{2009}*$r_{standard}$) + (X_{2013}*$r_{standard}$) +…….. (X_{2020}*$r_{standard}$))

$r_{standard}$ was determined as the mean proportion of the population comprised of the YOY cohort across all previous sampling years (Table 5).

Table 5. Species, typical length of the YOY cohort during annual sampling (based upon knowledge of species biology), the mean proportion of the population comprised by the YOY cohort ($r_{standard}$) and the recruitment index reference value (*RV*) for select non-native fishes at the Pike Anabranch from 2009–2020.

		Pike	
Species	**Length YOY**	$r_{standard}$	***RV***
Common carp	<150 mm FL	20%	0.27
Goldfish	<100 mm FL	66%	0.89

To assess future trends in recruitment, for each future sampling year, recruitment index values (*RI*) will be calculated using the following equation, where X_{year} = annual abundance (fish.minute electrofishing^{-1}.site^{-1}), r_{year} = annual proportion of YOY.

Annual recruitment value *(AV)* = X_{year}*r_{year}

Recruitment index (*RI*) = *AV*/*RV*

- Values of *RI* >1.0 represent enhanced recruitment relative to reference
- Values of *RI* <1.0 represent diminished recruitment relative to reference

3. RESULTS

3.1. Hydrology

From 2007–2023, River Murray discharge to South Australia (QSA) has been highly variable (Figure 2). The period 2007–2010, represented the final years of the Millennium Drought and was characterised by very low within channel flow (<10,000 $ML.day^{-1}$). This was followed by significant flooding in summer-autumn 2010/11 (peak ~93,000 $ML.day^{-1}$), a smaller overbank flood in autumn 2012 (peak ~60,000 $ML.day^{-1}$) and generally elevated discharge throughout much of 2012. Discharge from 2013–2021, was characterised by predominantly within-channel flow (<12,000 $ML.day^{-1}$), punctuated by a large overbank flood that peaked at 95,000 $ML.day^{-1}$ in late 2016, and within-channel pulses of 15,000–25,000 $ML.day^{-1}$ in September 2013, August 2014, December 2017, October 2019, and November 2020. In 2021, discharge increased abruptly in August 2021 and was elevated throughout spring, before peaking in early January 2022 at ~37,500 $ML.day^{-1}$. Discharge remained >20,000 $ML.day^{-1}$ through much of autumn before increasing drastically through winter and peaking at ~185,000 $ML.day^{-1}$ in December 2022. This was the largest flood event in the lower River Murray since 1956 (~341,000 $ML.day^{-1}$). Sampling of fish assemblages at the Pike System has typically occurred during QSA of ≤7,500 $ML.day^{-1}$, except for 2022 (~23,600 $ML.day^{-1}$) and 2023 (~24,800 $ML.day^{-1}$) (Figure 2).

Prior to completion of upgrades to the Deep Creek and Margaret-Dowling inlet regulators (2016), under normal operating conditions and predominant within channel flows in the River Murray (i.e. <25,000 $ML.day^{-1}$), combined discharge through the Margaret-Dowling and Deep Creek regulators was ~300 $ML.day^{-1}$. The upgrades increased capacity for discharge into the system and following completion of the Tanyaca Creek and Pike Regulators (2020), discharge through the Pike system has ranged 500–1,200 $ML.day^{-1}$.

From 17 September–13 December 2020, 26 July–28 November 2021 and 4 July–12 October 2022, floodplain infrastructure was operated to promote managed inundation events at the Pike system. The Pike River Regulator was raised to a maximum height of 15.25 m AHD and 0.70 m above the normal operating height of 14.55 m AHD in 2020, to a maximum height of 15.8 m AHD and 1.25 m above the normal operating height in 2021 and to a maximum height of 16.2 m AHD and 1.65 m above the normal operating height in 2022 before operations were abandoned due to rising flood waters.

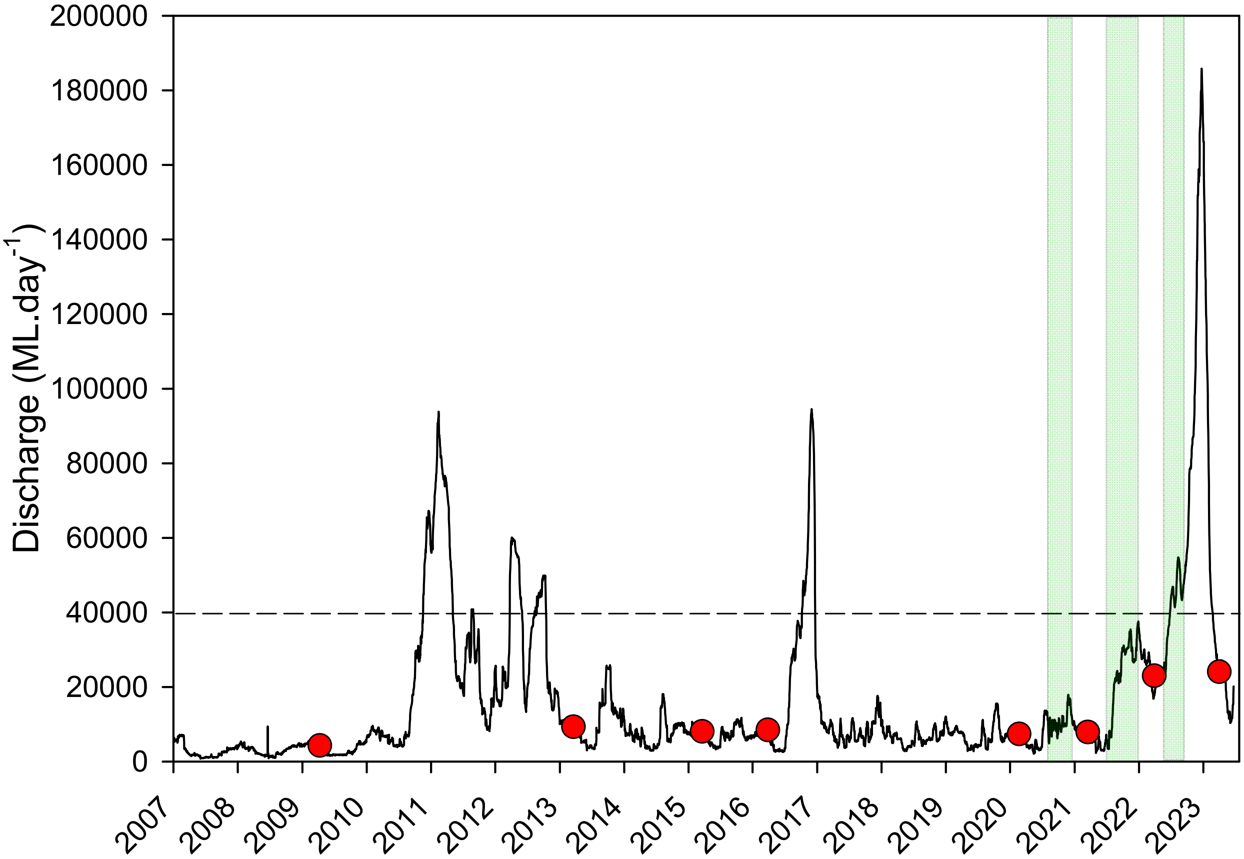

Figure 2. Mean daily discharge (ML.d^{-1}) in the River Murray at the South Australian Border (Site A42610010) January 2009 – July 2023 (https://water.data.sa.gov.au/). Red circles indicate sampling events, the dashed line represents approximate bankfull discharge in the vicinity of the Pike Anabranch (~40,000 ML.d^{-1}) and the green shaded area represents regulator operations within the Pike Anabranch from 2020–2022.

3.2. Catch summary

In 2023, a total of 24,092 fish were captured from 13 species (9 native and 4 non-native; Table 6). The most abundant native species were, bony herring (22.5%), Australian smelt (2.3%) and unspecked hardyhead (1.9%), whilst the remaining native species consisted of 1.2% of the total catch. Non-native common carp (61.9%) were the most abundant species sampled, while non-native goldfish, eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*) collectively comprised 9.9% of the total catch. Three species of conservation significance were sampled, namely: Murray cod (*vulnerable* under the *EPBC Act 1999*); silver perch (*Endangered* under the *EPBC Act 1999*); and freshwater catfish (*protected* under the South Australian *Fisheries Management Act 2007*).

From 2009–2023, a total of 83,818 fish from 16 species (11 native and 5 non-native) were captured over the eight surveys (Table 6). The most abundant species throughout this period were the small- to medium-bodied native species bony herring, unspecked hardyhead, Australian smelt and Murray rainbowfish, whilst common carp and goldfish were the most abundant non-native species.

Table 6. Total (black text) and standardised (fish.site-1) abundances (blue text) of fish captured from condition monitoring sites sampled in the Pike Anabranch system and adjacent River Murray 2009–2023.

Species	2009	2013	2015	2016	2020	2021	2022	2023	Grand Total
Golden perch	47	279	93	66	11	34	37	91	658
(*Macquaria ambigua ambigua*)	3.1	17.4	5.2	3.7	1.1	2.6	2.8	6.5	
Murray cod	-	-	2	2	3	9	13	3	32
(*Maccullochella peelii*)			0.1	0.1	0.3	0.7	1.0	0.2	
Silver perch	5	7	5	2	-	1	9	1	30
(*Bidyanus bidyanus*)	0.3	0.4	0.3	0.1		0.1	0.7	0.1	
Freshwater catfish	8	11	4	4	1	1	1	2	32
(*Tandanus tandanus*)	0.5	0.7	0.2	0.2	0.1	0.1	0.1	0.1	
Bony herring	1524	2,304	6,340	5,506	8,792	2,746	3,073	5,437	35,722
(*Nematalosa erebi*)	101.6	144	352.2	305.9	879.2	211.2	236.4	388.4	
Australian smelt	181	50	1,004	1,819	244	845	1,155	555	5,853
(*Retropinna semoni*)	12.1	3.1	55.8	101.1	24.4	65.0	88.8	39.6	
Murray rainbowfish	81	108	803	540	140	438	184	181	2,475
(*Melantaenia fluviatilis*)	5.4	6.75	44.6	30.0	14.0	33.7	14.2	12.9	
Flat-headed gudgeon	28	1	7	27	12	10	3	-	88
(*Philypnodon grandiceps*)	1.9	0.1	0.4	1.5	1.2	0.8	0.2		
Dwarf flat-headed gudgeon	-	2	2	3	-	-	-	-	7
(*Philynodon macrostomus*)		0.1	0.1	0.2					
Unspecked hardyhead	1,424	144	1,148	4,694	158	1,920	398	480	10,366
(*Craterocephalus fulvus*)	94.9	9	63.8	260.8	15.8	147.7	30.6	34.3	
Carp gudgeon spp.	57	35	141	238	35	54	15	14	589
(*Hypseleotris* spp.)	3.8	2.2	7.8	13.2	3.5	4.2	1.2	1.0	
Common carp*	248	865	326	396	140	404	5,218	14,920	22,517
(*Cyprinus carpio*)	16.5	54.1	18.1	22.0	14.0	31.1	401.4	1,065.7	
Gambusia*	101	12	175	226	14	32	76	82	718
(*Gambusia holbrooki*)	6.7	0.75	9.7	12.6	1.4	2.5	5.8	5.9	
Goldfish*	444	125	616	934	40	27	171	1,368	3,725
(*Carassius auratus*)	29.6	7.8	34.2	51.9	4.0	2.1	13.2	97.7	
Redfin perch*	3	2	2	1	2	5	31	958	1,004
(*Perca fluviatilis*)	0.2	0.1	0.1	0.1	0.2	0.4	2.4	68.4	
Oriental Weatherloach*	-	-	-	2	-	-	-	-	2
(Misgurnus anguillicaudatus)				0.1					
Total species	**13**	**14**	**15**	**16**	**13**	**14**	**14**	**13**	**16**
Total number of sites	**15**	**16**	**18**	**18**	**10**	**13**	**13**	**14**	
Total number of fish	**4,151**	**3,945**	**10,668**	**14,460**	**9,592**	**6,526**	**10,384**	**24,092**	**83,818**
Standardised total abundance	**276.73**	**246.56**	**592.67**	**803.33**	**959.20**	**502.00**	**798.77**	**1720.9**	

3.3. Temporal variation in fish abundance

Between 2009 and 2023, total fish abundance (all species combined) varied significantly among years (Figure 4; $Pseudo\text{-}F_{7,\ 116}$ = 10.962, p < 0.001). Pairwise comparisons (B-Y corrected α = 0.015) indicated abundances in 2009 and 2013 were significantly less than all other years, and abundance in 2023 was significantly greater than all other years. As a proportion of the total catch, native fish numerically dominated non-native fish in most years, except in 2022 and 2023, when non-native fish comprised ~52.9% and ~71.9% of the total catch, respectively (Figure 3).

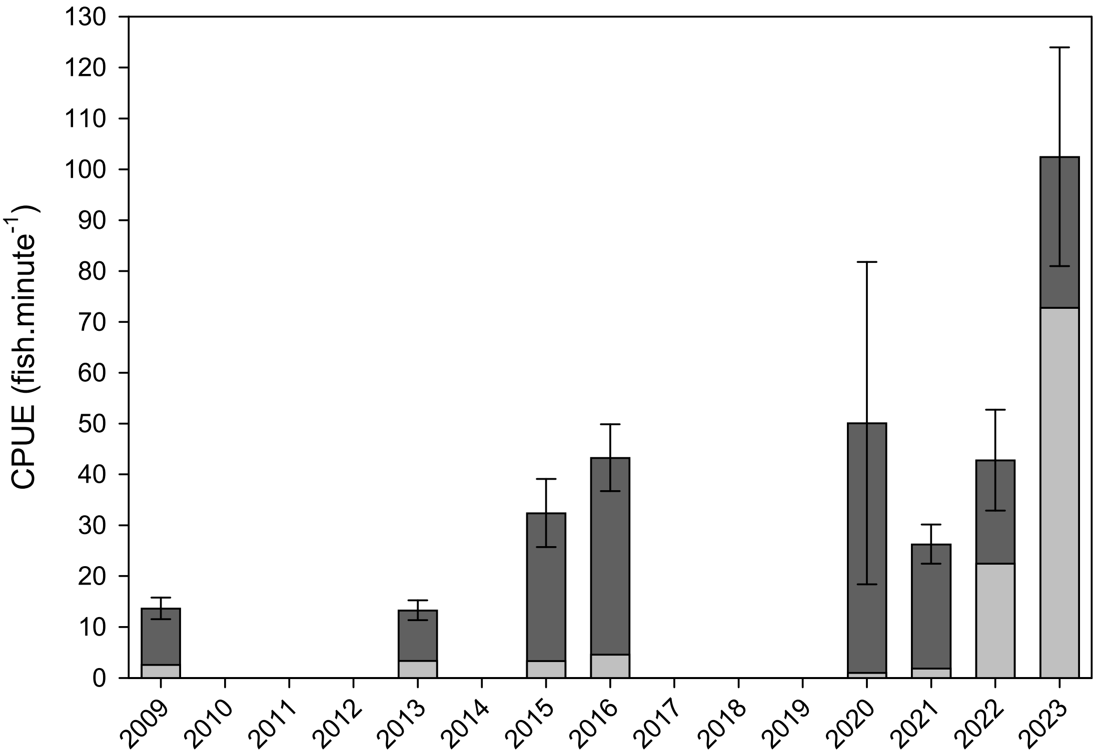

Figure 3. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of fish (all species combined) collected annually during standardised boat electrofishing surveys from 2009–2023 in the Pike Anabranch system and adjacent River Murray (dark grey = proportion native species, light grey = proportion of non-native species). Note: no sampling was conducted in 2010–2012, 2014 or 2017–2019.

3.4. Spatio-temporal differences in fish assemblage structure

Two-factor PERMANOVA detected significant differences in fish assemblages among years and mesohabitats, with no significant interaction (Table 7). This indicated that fish assemblages varied among years and mesohabitats, and that change through time was consistent among mesohabitats.

Table 7. PERMANOVA results comparing the relative abundances of fish between years and mesohabitats from 2009–2023. Significant *P* values are highlighted in bold.

Factor	*df*	*Pseudo-F*	*P*
Year	7, 115	7.6264	**0.001**
Mesohabitat	3, 115	4.7622	**0.001**
Year x mesohabitat	20, 115	0.93066	0.687

Pairwise comparisons revealed significant differences (B-Y corrected α = 0.02) in fish assemblages among mesohabitats for most comparisons, except between fast flowing and river mesohabitats (Table 8). In addition, cluster analysis and MDS indicated six distinct groupings of fish assemblages by sampling years, namely single-year groupings in 2009, 2013, 2020, 2022 and 2023 and a further grouping of assemblages from sampling in 2015, 2016 and 2021 (Figure 4).

Table 8. PERMANOVA pair-wise comparisons between fish assemblages among different mesohabitats in the Pike Anabranch from 2009-2023. (B-Y corrected α = 0.02).

Pairwise comparison		*t*	*p* value
Mesohabitat	Mesohabitat		
Fast	Backwater	2.2984	**0.001**
Fast	Slow	1.7126	**0.01**
Fast	River	1.3741	0.109
Backwater	Slow	2.3911	**0.001**
Backwater	River	2.7159	**0.001**
Slow	River	1.7103	**0.01**

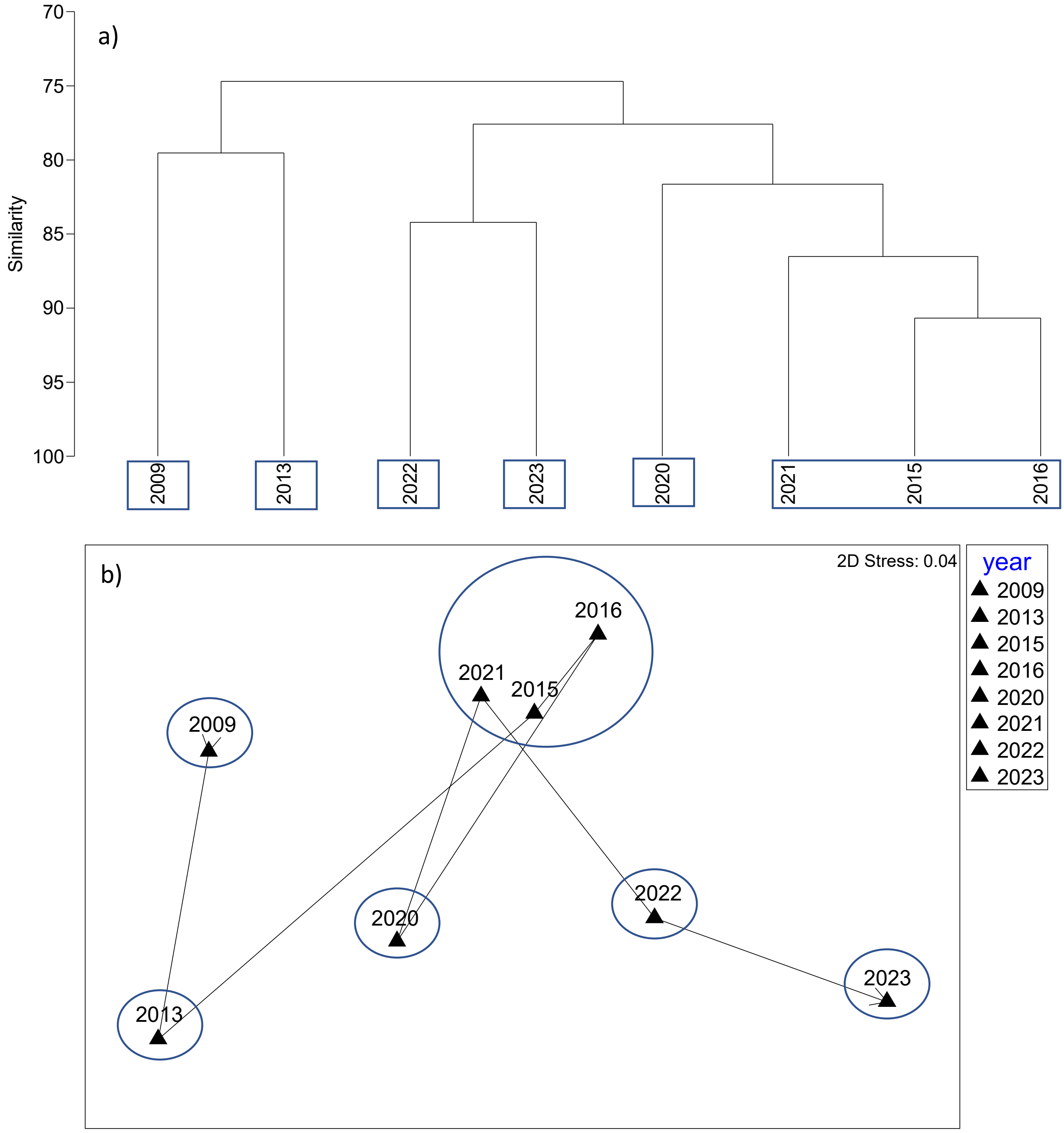

Figure 4. a) Dendrogram indicating fish assemblage clusters throughout all sampling years 2009–2023. b) Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled from all years/sites combined.

SIMPER indicated that differences in fish assemblages among cluster-group comparisons were driven by different species. Yet some consistent differences were evident. Differences between the assemblage grouping of 2015, 2016 and 2021 and other years were typically driven by higher abundances of Australian smelt, unspecked hardyhead, bony herring, goldfish, and Murray rainbowfish in 2015, 2016 and 2021 (Appendix 1). Alternatively, assemblages sampled in 2013 and 2020, typically differed from other years due to higher abundances of golden perch in 2013 and bony herring in 2020. Additionally, in 2022 and 2023, differences among assemblages sampled between all other assemblage groupings were primarily driven by greater abundances of common carp in 2022 and redfin perch and common carp in 2023 (Appendix 1). ISA of the same data suggested the year 2013 was characterised by greater abundances of the large-bodied golden perch and freshwater catfish (Table 9), whilst assemblages from years 2015–2016 and 2021 were characterised by carp gudgeon complex; unspecked hardyhead; and eastern gambusia (Table 9). In 2022, assemblages were characterised by the small-bodied native species Australian smelt, whilst in 2023, assemblages were characterised by the non-native large-bodied species common carp, redfin perch and goldfish (Table 9).

Indicator Species Analysis comparing mesohabitat types suggested that fast-flowing mesohabitats were characterised by Murray cod, bony herring, Australian smelt, and freshwater catfish (Table 10). Main river channel mesohabitats were characterised by Murray rainbowfish, whilst no species were significantly associated with slow-flowing or backwater mesohabitats (Table 10).

Table 9. Indicator species analysis comparing the relative abundance of fish at the Pike Anabranch amongst years from 2009–2023. (Year group 1 = 2009; Year group 2 = 2013; Year group 3 = 2015–2016 and 2021; Year group 4 = 2020; Year group 5= 2022 and Year group 6= 2023). Significant *p*-values (α = 0.05) indicate that a species occurs in a higher relative abundance in a specific year group. Only significant indicators are presented.

Species	**Year Group**	**Indicator value**	***p* value**
Freshwater catfish	2	14.9	0.0340
Golden perch	2	19.2	0.0016
Carp gudgeon spp.	3	22.6	0.0002
Unspecked hardyhead	3	20.3	0.0002
Eastern gambusia	3	17.9	0.0304
Australian smelt	5	16.6	0.0308
Common carp	6	24.5	0.0002
Goldfish	6	21.1	0.0002
Redfin perch	6	61.0	0.0002

Table 10. Indicator species analysis comparing the relative abundance of fish at the Pike Anabranch in the four aquatic mesohabitats from 2009–2023. Significant *p*-values (α = 0.05) indicate that a species occurs in a higher relative abundance in a specific mesohabitat. Only significant indicators are presented.

Species	Mesohabitat	*P* - value
Murray cod	Fast	0.0162
Australian smelt	Fast	0.0008
Bony Herring	Fast	0.0042
Freshwater catfish	Fast	0.0286
Murray rainbowfish	River	0.0194

3.5. Assessment of Ecological targets

Target 1: Maintenance or enhanced species diversity

In all sampling years, species diversity was greater than or equivalent to the reference value across all mesohabitats (Figure 5a). The mean of mesohabitat diversity indices for each year was calculated to provide an overall site diversity score (Figure 5b); in all years, the site diversity score was greater than or equivalent to the reference value.

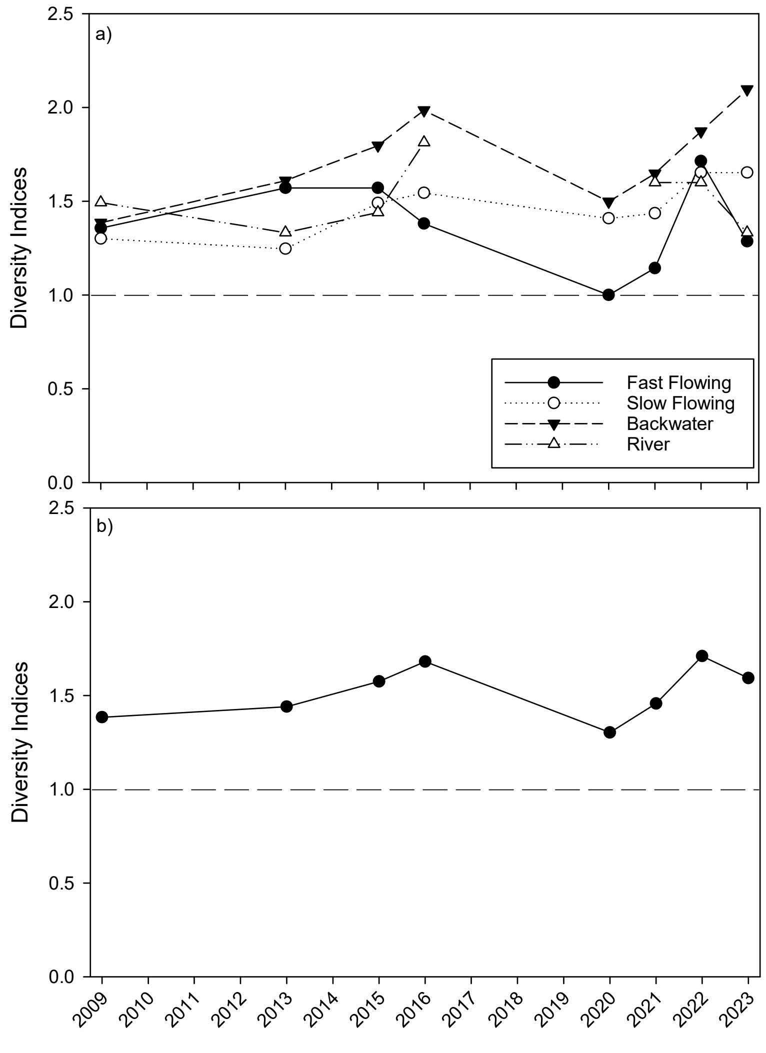

Figure 5. Diversity indices for a) fast-flowing, slow-flowing, backwater and main channel mesohabitats and b) the calculated Site Diversity Index (*DI*), at the Pike Anabranch from 2009–2023.

Target 2: Maintenance or enhanced extent of species across the site

For large-bodied native fishes, the extent index has varied among species (Figure 6a). Golden perch distribution was relatively stable across years, whilst freshwater catfish has exhibited a decline in distribution since a peak in 2013. A slight increase, however, was observed in 2023 but the index remained below the reference value. Silver perch distribution, like that for freshwater catfish, declined from 2013–2021, before a substantial increase in 2022, followed by a decrease again in 2023 (Figure 6a). Murray cod were not sampled from 2009–2013, but distribution has increased in subsequent years, with peak extent recorded in 2022. Distribution decreased slightly in 2023 but remained above the reference value (Figure 6a). The extent index for the majority of small- and medium-bodied species remained stable around or above the reference value in most sampling years, with the exception of flat-headed gudgeon (2013, 2015, 2022 and 2023) and dwarf flat-headed gudgeon (2020–2023), which exhibited extents below reference values in certain years (Figure 6b).

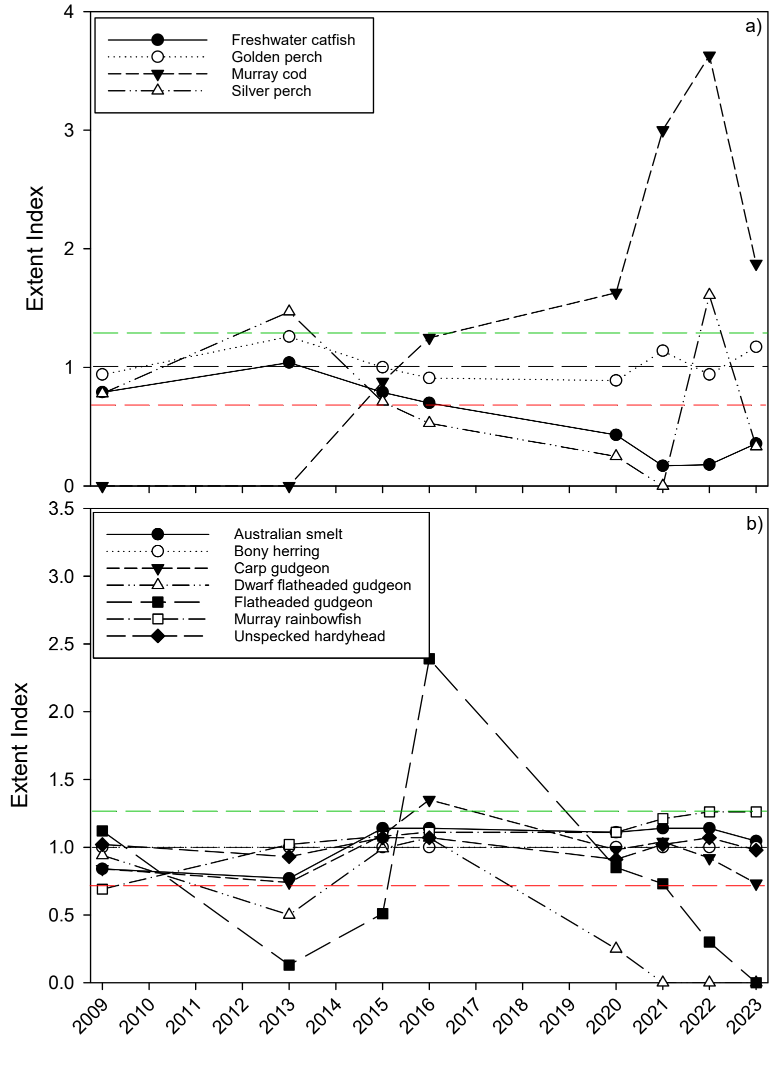

Figure 6. Extent Index (*EI*) scores for a) large-bodied native species and b) small- to medium-bodied native species at the Pike Anabranch from 2009–2023. Black dashed line represents extent equal to the reference, green dashed line extent 25% greater than reference and red dashed line extent 25% lesser than reference.

Target 3: Abundance (CPUE) of large-bodied native fish exhibit positive trajectories over a 5-year period from 2020

The abundance indices for Murray cod, freshwater catfish, golden perch and silver perch have been temporally variable. After being absent from sampling in 2009 and 2013, Murray cod have met or exceeded the reference value since 2013 and exhibited a positive trajectory in 2020–2022, with a slight decrease observed in 2023 (Figure 7a). Abundances of freshwater catfish and golden perch peaked in 2013 but declined to below reference values from 2015–2022. Both species, however, exhibited an increase in abundance in 2023, exceeding the reference value for golden perch, but remaining below the reference value for freshwater catfish (Figure 7b and 7c). Silver perch abundance was above the reference value between 2009–2015 and 2022, but from 2016–2021 and 2023 abundance for this species was below reference (Figure 7d).

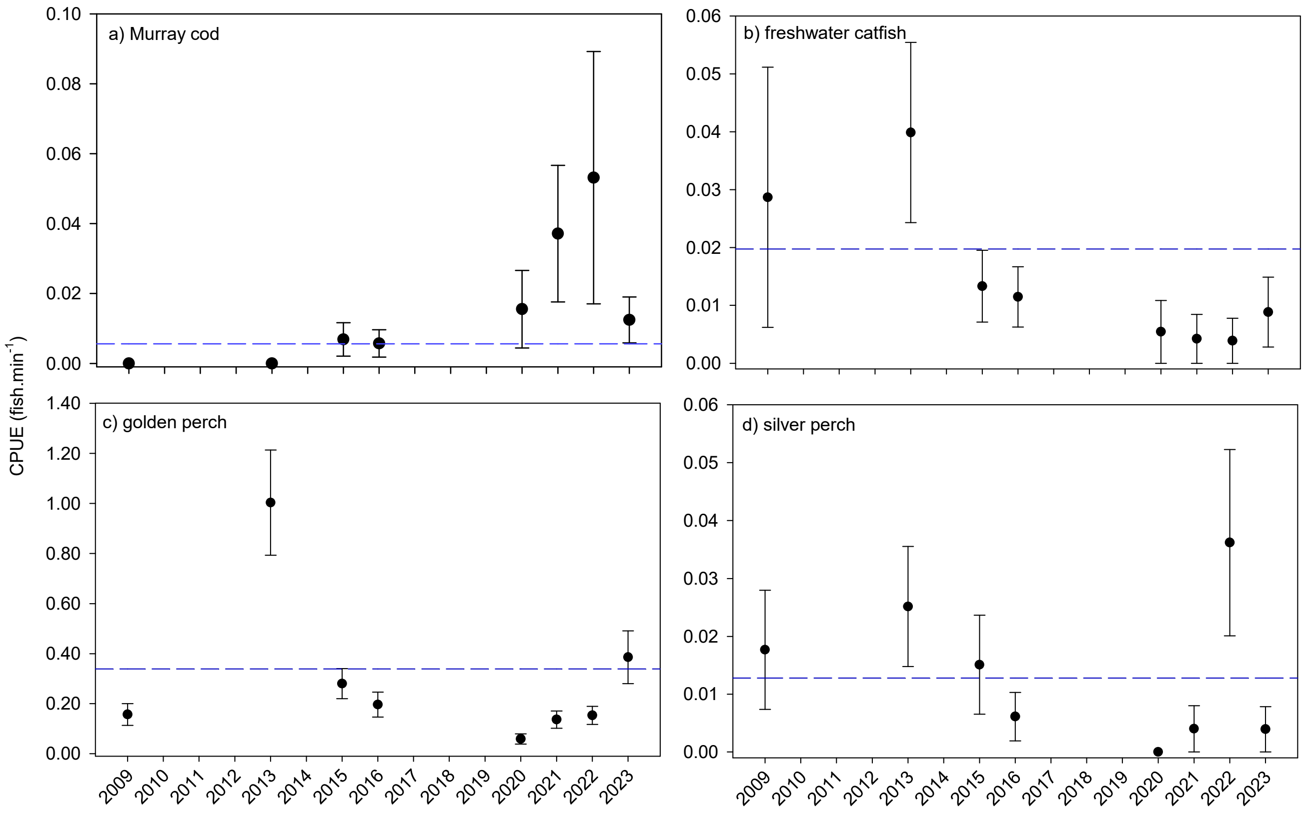

Figure 7. Mean abundance (CPUE; fish.minute electrofishing^{-1}.site^{-1}) ±SE for a) Murray cod, b) freshwater catfish, c) golden perch and d) silver perch at the Pike Anabranch between 2009–2023. The blue dashed line represents mean abundance equal to the reference value.

Target 4: Annual recruitment of foraging generalists is maintained or enhanced

For small- and medium-bodied foraging generalists, recruitment indices have varied among species and sampling years, although recruitment was evident for all species in most years (Figure 8). Common for all species, recruitment was limited after high flow in 2013 and to a lesser extent in 2023. Unspecked hardyhead recruitment was higher than the reference value in 2016 and 2021, but was limited in all other years, including 2023. High levels of recruitment of Murray rainbowfish was evident from 2015–2021 but limited in 2009, 2013, 2022 and 2023. Australian smelt recruitment was variable, with the highest recruitment observed in 2016 and lowest in 2013. Bony herring recruitment was highest in 2020 and above or equivalent to the reference value in 2015 and 2023 but was below the reference value in all other years (Figure 8).

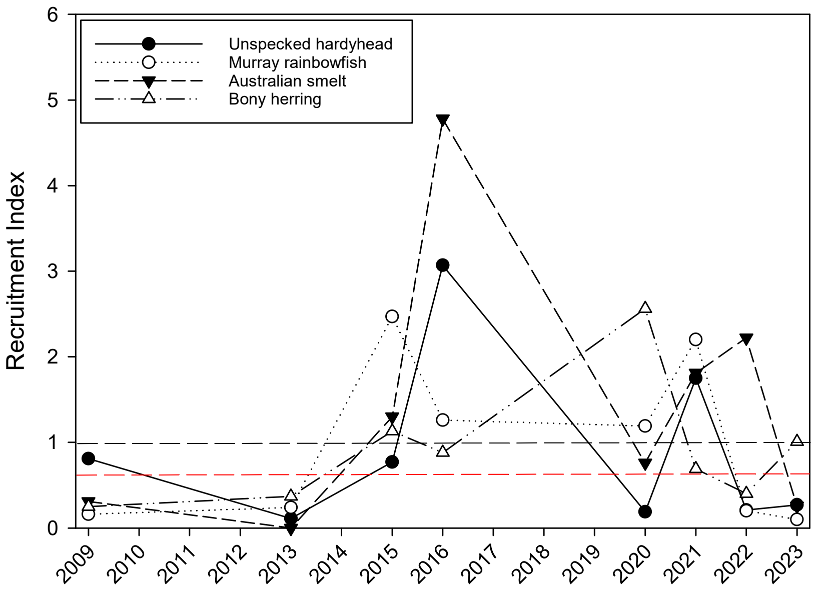

Figure 8. Recruitment Index (*RI*) values for unspecked hardyhead, Murray rainbowfish, Australian smelt and bony herring from 2009–2023. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Target 5: Recent recruitment of Murray Cod to YOY and the adult population is evident as displayed by the presence of individuals <200 and 400–600 mm TL, respectively.

The recruitment index for Murray cod ranging from 400–600 mm TL indicated that no recruitment to the adult population was observed in most sampling years, except in 2022 and 2023 (Figure 9). The index for Murray cod <200 mm TL suggests that recruitment to YOY was greater than the reference value in all years from 2015–2021, but less than the reference value in years 2009, 2013, 2022 and 2023 (Figure 9).

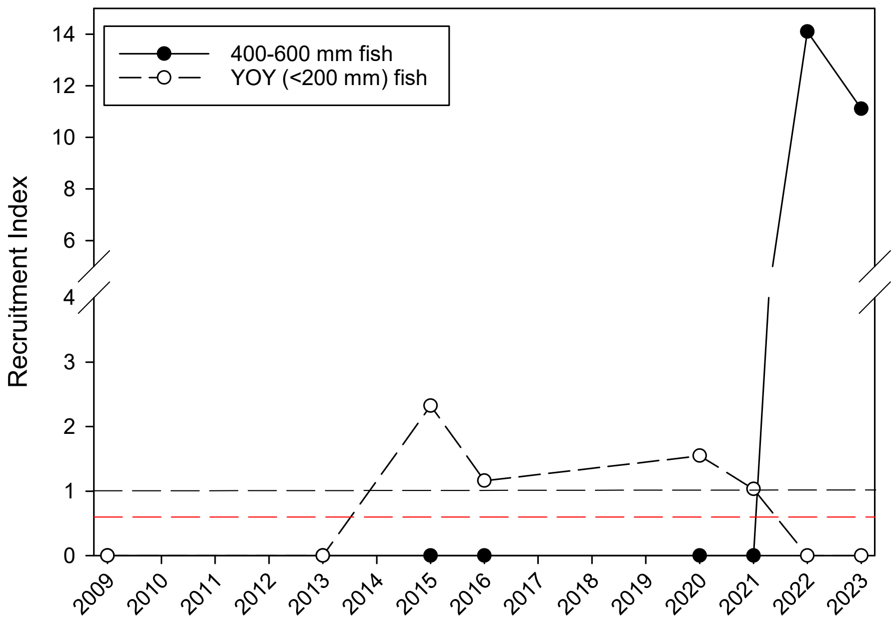

Figure 9. Recruitment Index (*RI*) values for Murray cod ranging 400–600 mm TL and YOY Murray cod (<200 mm TL) from 2009–2023. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Target 6: Recruitment events for common carp and goldfish do not occur in the absence of meeting other key targets under managed inundations (e.g. improved condition of long-lived floodplain vegetation)

Recruitment indices for both common carp and goldfish have been temporally variable, albeit a level of recruitment to YOY was evident in most years (Figure 10). Common carp recruitment was above the reference value in 2016 and 2021–2023 (Figure 10a). Indeed in 2022 and 2023, recruitment of common carp were in orders of magnitude greater than all other years. For goldfish, recruitment was above the reference value in 2009, 2015–2016 and 2023 (Figure 10b).

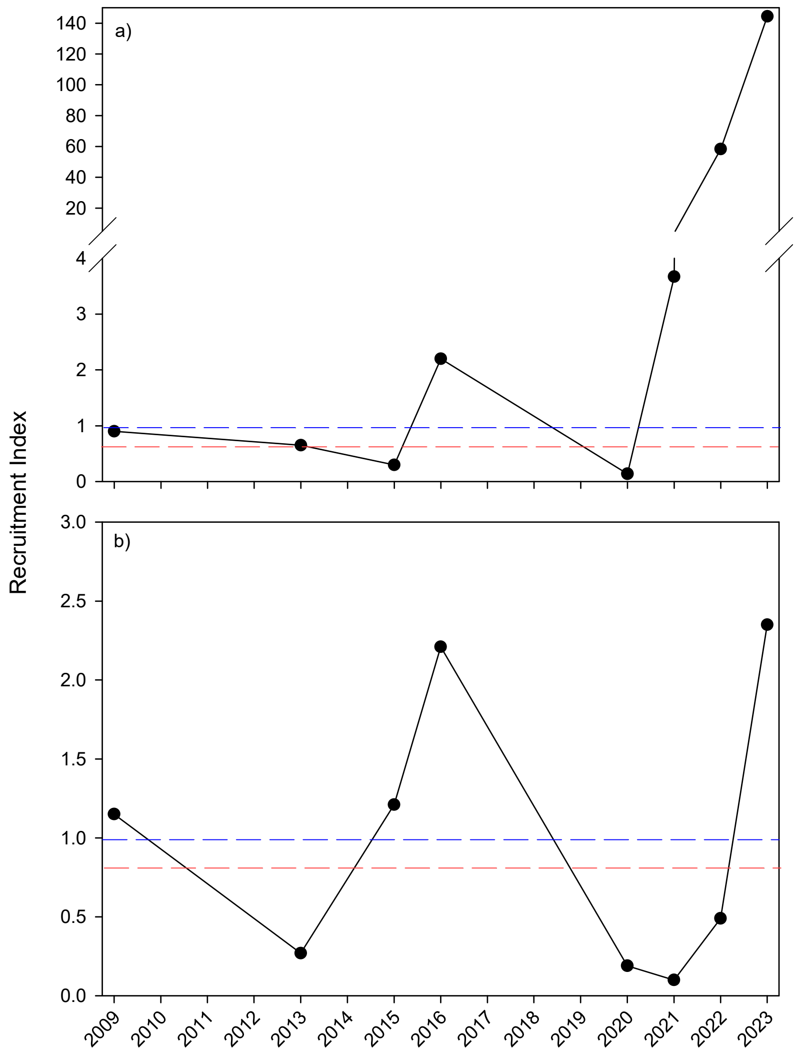

Figure 10. Summary of Recruitment Index (*RI*) values for a) common carp and b) goldfish at the Pike Anabranch from 2009–2023. Dashed blue line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Summary

Sampling data from 2023 suggests that five of the six Ecological Targets were achieved or partially achieved, the decrease in common carp and goldfish abundance, was not (Table 11).

Table 11. Summary of assessment of fish-related Ecological Targets at the Pike Anabranch in 2023.

Primary Ecological Objectives 1, 2 & 3 (see page 5 above)			**Ecological target**	**2023**
Objective 1	Objective 2		Maintenance or enhanced species diversity	Species diversity index greater than reference value
			Maintenance or enhanced extent of species across the site as indicated by species-specific 'extent index'	Extent maintained or enhanced for 6 of 11 target species (see Figure 6)
			Abundance (CPUE) of large-bodied native fish exhibits a positive trajectory over a 5-year period from 2020	Murray cod and golden perch abundance were above reference values. Whilst freshwater catfish and silver perch abundance were not
	Objective 2		Annual recruitment of foraging generalists is maintained or enhanced relative to historical levels, as indicated by species-specific 'recruitment index'	Only one target species (bony herring) exhibited recruitment indices exceeding or equivalent to reference values
Objective 1			Recent recruitment of Murray Cod to YOY and the adult population is evident as displayed by the presence of individuals <200 and 400–600 mm TL, respectively	Strong recruitment of adult population evident, but recruitment to YOY was absent.
		Objective 3	Relative abundance of common carp and goldfish do not increase in the absence of meeting key targets under managed inundations (e.g. improved condition of long-lived floodplain vegetation)	Recruitment of both common carp and goldfish was substantially elevated relative to the reference value but occurred in association with natural flooding.

Not achieved   Partially achieved   Achieved

4. DISCUSSION

The Pike Anabranch system has been the focus of substantial environmental rehabilitation efforts under RRP and SARFIIP (completed 2020). Notably, this has included: the upgrade of inlet regulators at Margaret-Dowling and Deep creeks to enhance capacity to vary inflow volumes; the construction of new regulators at Tanyaca Creek and the Pike River, and associated blocking bank, to facilitate managed inundation of the floodplain; and the construction of fishways on the updated structures. In subsequent years, site management will be guided by an Operations Plan that aims to enhance ecological condition and mitigate risks associated with managed inundations. The plan will be supported by a MERI framework to assess ecological condition through time and inform adaptive management. Fish are a key component of the aquatic ecosystem of the Pike Anabranch and lower River Murray more broadly, and specific Ecological Objectives and Targets have been developed to assess ongoing condition. The current report presents findings from fish assemblage monitoring in 2023 with comparison to data from previous sampling of fish assemblages (2009–2022) and assessment of Ecological Targets.

4.1. General patterns of abundance and assemblage structure

In 2023, 13 fish species were sampled from 13 sites in the Pike Anabranch and adjacent River Murray main channel. The fish assemblage consisted of 9 native and 4 non-native species, with common carp, bony herring, and goldfish the most abundant species. Overall, the assemblage reflected the extensive and prolonged floodplain inundation through spring-summer 2022/23 that preceded sampling. The fish assemblage sampled in 2023 differed from that of preceding sampling years (2009, 2015, 2016, 2020 and 2021) characterised by predominantly low within-channel flows (max annual discharge = 11,000–18,000 ML.day^{-1}), as well as previous sampling years that followed flooding (2013) and high within-channel flows (2022). These differences in assemblage structure in 2023 reflect decreases in abundance of several small- and medium-bodied generalist species and increases in large-bodied species (both native and non-native) whose reproduction is associated with high flows and flooding.

Patterns of elevated abundance of small- and medium-bodied generalist species including bony herring and Australian smelt, are commonly observed in the main channel of the lower River Murray (Zampatti et al. 2011, Bice et al. 2014) and other anabranch habitats (Bice et al. 2015, Fredberg et al. 2021) following prolonged periods of within-channel flow. Causal mechanisms likely relate to the influence of hydraulics on in-stream habitat (e.g., aquatic macrophyte cover) and key life history processes (e.g., survival of early life stages and recruitment). Several of these small-bodied generalist species are typically associated with aquatic macrophytes (Bice *et al.* 2014). Such habitats proliferate in the Pike Anabranch, and in the lower River Murray main channel, during periods of regulated low flow and benign hydraulics (as observed in 2009, 2015, 2016, 2020 and 2021), but are diminished during and immediately following periods of high flow (Bice *et al.* 2014). Within the Pike Anabranch, these patterns were generally consistent following flood and high flow in 2013, 2022 and 2023, whereby decreases in abundance of small-bodied generalist species such as unspecked hardyhead and Murray rainbowfish were observed.

The recruitment of large-bodied fishes, notably common carp, and golden perch, also drove differences among low flow years (2009, 2015, 2016, 2020 and 2021) and those characterised by preceding flood (2013 and 2023) or high within-channel flows (2022). Spawning and recruitment in common carp is positively associated with flooding and inundation of favored shallow, off-channel nursery habitats (Stuart and Jones 2006, Maitzegui et al. 2019), with peak abundances in the Pike anabranch occurring following flooding in 2013 and 2023 or high within-channel flows in 2022. For golden perch in the lower River Murray, spawning and recruitment (from local spawning or immigration) are also associated with elevated flow (Zampatti et al. 2013a, b). In 2013, the population across the lower Murray was abundant and largely comprised of sub-adult fish spawned in 2009/10 and 2010/11 in association with high flow in Darling and Murray rivers (Wilson et al 2014, Zampatti et al 2021). This pattern was also observed across the lower River Murray and associated anabranches (e.g., Katarapko and Chowilla) in 2023 (SARDI unpublished data).

Across sampling years, there were consistent differences in fish assemblages among mesohabitat types and in-turn, associations of certain species with specific mesohabitat types. Specifically, Murray rainbowfish characterised River Murray mesohabitats, and Murray cod, bony herring, Australian smelt and freshwater catfish characterised fast-flowing mesohabitats. Similar associations have been detected at the Chowilla Anabranch (Fredberg et al. 2022). The association of Murray cod and freshwater catfish with fast-flowing mesohabitats indicates the importance of these rare lotic habitats within the Pike system and more broadly within the lower River Murray; where they occur, they support iconic species of conservation concern, as well as generally high abundances of other species.

4.2. Assessment of Ecological Targets

Diversity and extent

The mesohabitat and overall site species diversity indices were stable across years and greater than the reference value, indicating fish species diversity was maintained over the period 2009–2023. The extent of most species has also been maintained, except for flat-headed gudgeon and dwarf flat-headed gudgeon, which exhibited variable extent across sampling years. Nevertheless, variability was likely due to the generally low abundance of these species in most surveys (e.g., dwarf flat-headed gudgeon = 0–3 individuals per year). Electrofishing, whilst efficient in rapidly sampling a diversity of fishes, is not efficient in sampling small, benthic species in turbid waters and as such, caution should be exercised in interpreting fluctuating extent for these species. Surveys in the main channel and connected wetlands of the lower River Murray, using appropriate sampling techniques (e.g., fyke nets), commonly encounter moderate–high abundances of these species (Thwaites and Fredberg 2014, Ye et al. 2021).

The extent index for Murray cod has been above the reference value since 2013 indicating greater prevalence and broader distribution across the system. This is likely due to a combination of natural increases in distribution and the influence of stocking. Broader distribution of this species was also observed at the Katarapko Anabranch over the same period (Fredberg and Bice 2022, SARDI Unpublished data). Different to Katarapko, however, the Pike Anabranch was a stocking site for Murray cod fingerlings in both 2020 and 2021.

The extent index for freshwater catfish has generally decreased across time, however, a slight increase was evident in 2023 but remained below the reference value. Nonetheless, as for dwarf flat-headed gudgeon, freshwater catfish (n = 1–11) are typically only sampled in low numbers and therefore caution should be exercised in interpreting trends in distribution. Silver perch extent was found to be below the reference value from 2015–2021 and in 2023, whilst in 2013 and 2022 was higher than the reference value suggesting a broader distribution in these years.

Abundance of large-bodied native fish

Over the period 2020–2023, similar to the extent index, the 37tandardized abundance of Murray cod has been above the reference value and substantially greater than the period from 2009–2016. Over the same period, increased abundance has also been noted at the Katarapko Anabranch, where similar management interventions have been undertaken (Fredberg and Bice

2022b). For the Pike Anabranch, steadily increasing abundance is likely a result of multiple factors, including: improvements to connectivity (e.g. fishway construction); increased extent of lotic habitats under normal operating conditions; natural recruitment; and stocking events that occurred in 2020 and 2021.

For freshwater catfish, from 2009–2023, total numbers (*n* = 1–11) and 38tandardized abundance have typically been low and variable, with the species being found in low abundance in 2023 (*n* = 2). This species has a life history that operates over meso-scales (1–10's km) (Koehn et al. 2020) and in the lower River Murray, is often associated with lotic habitats (Fredberg et al. 2019; Fredberg et al. 2022). As such, recent interventions at the Pike Anabranch are predicted to promote the abundance of freshwater catfish, but such a pattern is not yet evident.

For golden perch, from 2009–2023, annual abundances have been similar, except for a notable peak in 2013 and to a lesser extent in 2023. 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 2013a, 2013b). High abundance in 2013 and 2023, followed periods of elevated flow and flooding and widespread recruitment in the lower River Murray (Zampatti et al 2021, SARDI unpublished data). In 2023, the population of golden perch sampled at the Pike Anabranch was dominated by individuals 200–300 mm TL (~59%). While no ageing was conducted for fish from Pike, fish of this size in the broader lower River Murray were determined to be predominantly 1+ years of age and derived from spawning in 2021/22 (SARDI Unpublished Data).

Silver perch abundance was above the reference value in 2009, 2013, 2015, 2016 and 2022, but only a single individual was sampled in 2023. This species has a life history that operates over macro-scales (100's–1000's km) (Koehn et al. 2020), yet in the lower River Murray, is often associated local-scale lotic habitats (Fredberg et al. 2019; Fredberg et al. 2022). As such, similar to freshwater catfish, recent interventions at the Pike Anabranch are predicted to promote abundance of silver perch. Such a pattern was suggested from sampling in 2022, but not 2023.

Recruitment of native species

Two approaches were used to assess recruitment of Murray cod: 1) recruitment to YOY (fish <200 mm TL) and 2) recruitment to the reproductively mature population (fish 400–600 mm TL). The YOY recruitment index was variable but exhibited a trend similar to extent and abundance indices, with no recruitment to YOY observed in 2009, 2013 and 2022–2023, but recruitment above the reference value from 2015–2021. Alternatively, recruitment to the adult population has been absent in all sampling years except for 2022 and 2023 when recruitment substantially exceeded the reference value.

Natural recruitment and stocking have likely played a role in the trajectories of recruitment indices, extent, and abundance. Stocking occurred in 2020 and 2021, meaning YOY sampled in 2015 and 2016 were wild recruited individuals. Furthermore, 2020 saw widespread natural recruitment of Murray cod in the lower River Murray (Ye et al. 2021). Nonetheless, it is likely some YOY sampled in 2020 and 2021 were stocked individuals, as ~30,000 fingerlings were collectively released into Pike across these two years. Regardless of origin, the consistent capture of YOY Murray cod from the Pike Anabranch in these years is encouraging and suggests that habitats within the system are suitable for juvenile fish. Limited recruitment of YOY Murray cod between 2022–2023, could be a result of poor natural recruitment, coupled with no stocking events prior to sampling in the region during this period. Nonetheless, individuals spawned/stocked pre-2021 are now likely contributing to increases in the abundance of individuals 400–600 mm TL.

Prior to 2022–2023, the absence of Murray cod 400–600 mm TL from the Pike system was not unexpected. Before completion of SARFIIP works in 2020, the Pike system remained largely fragmented and improvements to lotic habitats were yet to be realised. As a long-lived species, time lags before these mechanisms are reflected in the population abundance index were expected. Encouragingly between 2022–2023, there was a substantial increase in this metric, likely reflecting growth of YOY detected in preceding years and immigration of other sub-adult individuals.

Recruitment indices for the small-bodied Murray rainbowfish, Australian smelt and unspecked hardyhead, and the medium-bodied species bony herring indicate recruitment occurred in all years. Recruitment patterns have varied among species, but all exhibited limited recruitment following periods of high flow in 2013 and 2022–2023, apart from Australian smelt and bony herring. Similar patterns in recruitment have been observed for these species in the Chowilla Anabranch from 2005–2022 (Fredberg et al. 2022). The small and medium-bodied generalist species mentioned above are widespread and abundant throughout the lower River Murray (Baumgartner et al. 2008, Bice et al. 2014) and have flexible spawning and recruitment strategies that are not reliant on elevated flow (Baumgartner et al. 2013).

Recruitment of non-native species

The highest levels of recruitment of YOY common carp and goldfish in the Pike Anabranch have corresponded with increased water levels associated with natural flooding and operation of flow regulating structures. This includes 2016, following weir pool raising at Lock 5 in spring 2015, and 2021, following following the operation of the Pike and Tanyaca Creek regulators. Substantial recruitment of common carp was observed in 2022, which followed regulator operation and elevated within-channel flows in spring summer 2021. Recruitment of common carp and goldfish, however, was greatest in 2023 following widespread flooding of the lower River Murray in the spring/summer of 2022/2023. Throughout the Southern MDB, increased discharge, water levels and floodplain inundation (natural and engineered) typically lead to increases in carp and goldfish recruitment and abundance (King et al. 2003, Stuart and Jones 2006, Bice and Zampatti 2011).

5. CONCLUSION

Monitoring of fish assemblages at the Pike Anabranch in 2023 indicated that five of the six fish-related Ecological Targets were partially or fully achieved. Importantly, metrics related to Murray cod distribution, abundance and recruitment have exhibited positive trajectories. This species is a key target and indicator of success of in-channel management actions at the site (i.e., improved connectivity and hydrodynamics).

The year 2023 represented the third year for application of the recently developed Ecological Targets. The use of these targets for condition assessment provides consistency in the approach adopted at each of Chowilla, Pike and Katarapko. The similarity in management of these anabranches and approaches to monitoring and reporting on fish condition monitoring, presents an opportunity to better integrate understanding and management of these critical habitats across the region.

5.1. Future research needs

Eight years of condition monitoring at the Pike Anabranch across 2009–2023 has provided valuable information on the ecology of freshwater fish at Pike and the lower River Murray. Continued monitoring of fish assemblages post completion of SARFIIP works will be critical to inform responses to changes in management and future adaptive management. Underlying causal mechanisms of observed responses, however, remain speculative and require associated hypothesis-based research. This includes research at the scale of the Pike Anabranch and more broadly.

Specific research questions include:

- Investigating factors influencing recruitment variability of Murray cod at the Pike Anabranch.
- The influence of site management (e.g., regulator operation) on recruitment and abundance of common carp and goldfish at the Pike Anabranch and contribution to broader regional populations.
- The movement and habitat use of native (e.g., Murray cod and golden perch) and non-native fish (e.g. common carp) in the Pike Anabranch and adjacent River Murray in relation to natural flows and engineered floodplain inundation.

- Response of fish assemblages (diversity and abundance) to altered hydrodynamics at the mesohabitat scale.

REFERENCES

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

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

Anderson, M. J. and C. J. F. Ter Braak (2003). Permutation test for multi-factorial analysis of variance. *Journal of Statistical Computation and Simulation* **73**: 85-113.

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

Baumgartner, L. J., I. G. Stuart and B. P. Zampatti (2008). Day and night changes in the structure of fish assemblages on the lower Murray River prior to fishway construction. The Sea to Hume Dam: Restoring Fish Passage in the Murray River. J. Barrett, Murray-Darling Basin Commission, Canberra**:** 12-20.

Benjamini, Y. and D. Yekutieli (2001). The control of false discovery rate under dependency. *Annals of Statistics* **29**: 1165-1188.

Beyer, K., K. B. Marsland, C. Sharpe, T. Wallace, B. P. Zampatti and J. M. Nicol (2010). Fish and Fish Habitats of the Pike River Anabranch and Floodplain Complex, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000090-1. SARDI Research Report Series No. 429. 55 pp.

Bice, C., S. Gehrig and B. Zampatti (2013). Pike Anabranch Fish Intervention Monitoring: Progress Report 2013, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000472-1. SARDI Research Report Series No. 712. 39 pp.

Bice, C. M., S. L. Gehrig and B. P. Zampatti (2015). Pike Anabranch fish intervention monitoring: Progress report 2015, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000472-1. SARDI Research Report Series No. 861. 42pp.

Bice, C. M., S. L. Gehrig, B. P. Zampatti, J. M. Nicol, P. Wilson, S. L. Leigh and K. Marsland (2014). Flow-induced alterations to fish assemblages, habitat and fish–habitat associations in a regulated lowland river. *Hydrobiologia* **722**(1): 205-222.

Bice, C. M., S. L. Genrig and B. P. Zampatti (2016). Pike Anabranch fish intervention monitoring 2013–2016, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000472-3. SARDI Research Report Series No. 926. 50pp.

Bice, C. M., M. S. Gibbs, N. N. Kilsby, M. Mallen-Cooper and B. P. Zampatti (2017). Putting the “river” back into the lower River Murray: quantifying the hydraulic impact of river regulation to guide ecological restoration. *Transactions of the Royal Society of South Australia* **141**: 108-131.

Bice, C. M. and B. P. Zampatti (2011). Engineered water level management facilitates recruitment of non-native common carp, *Cyprinus carpio*, in a regulated lowland river. *Ecological Engineering* **37**: 1901-1904.

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

Bice, C. M. and Fredberg, J. (2021). Assessment of passage efficiency at the Tanyaca and Pike regulator fishways. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2021/000292-1. SARDI Research Report Series No. 1118. 35pp.

Bray, J. and J. Curtis (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27**: 325-349.

DEW (2020). Pike Floodplain Operations Plan, version 1.1, September 2020, Government of South Australia, Department for Environment and Water, Adelaide.

DEWNR (2011). Riverine Recovery Project Implementation Plan - Pike Floodplain Project Element. Version 1.a, Department of Environment Water and Natural Resources.

DEWNR (2016). SARDFIIP - Pike Floodplain Inundation Measures Investment Proposal, Government of South Australia, Department of Enviroment, Water and Natural Resources, Adelaide.

Dufrene, M. and P. Legendre (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs 67: 345-366.

Ellis, I., Whiterod, N., Linklater, D., Bogenhuber, D., Brown, P. and Gilligan, D. (2015), Spangled Perch in the Southern MDB. Austral Ecology, 40: 591-600. https://doi.org/10.1111/aec.12226

Faragher, R. M. and M. Rodgers (1997). Performance of sampling gear types in the new South Wales river surveys. Fish and rivers in stress: The NSW rivers survey. A. H. Harris and P. C. Gehrke, NSW Fisheries Office of Conservation/CRC for Freshwater Ecology, Sydney/Canberra.

Fredberg, J., Zampatti, B.P. and Bice, C.M. (2019). Chowilla Icon Site Fish Assemblage Condition Monitoring 2018. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2008/000907-10. SARDI Research Report Series No. 1005. 62pp.

Fredberg, F. and C. Bice (2021). Refinement of ecological targets for fish Condition Monitoring in the Pike and Katarapko Anabranch systems, South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Fredberg, F., B. P. Zampatti and C. M. Bice (2021). Chowilla Icon Site Fish Assemblage Condition Monitoring 2020, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2008/000907-11. SARDI Research Report Series No. 1088. 63 pp.

Fredberg, J. and C. Bice (2021). Refinement of Ecological Targets for Fish Condition Monitoring in the Pike and Katarapko Anabranch Systems, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2021/000245-1. SARDI Research Report Series No. 1111. 40pp.

Fredberg, J., Leigh, S. J. and Bice, C.M. (2022). Katarapko Fish Assemblage Condition Monitoring 2021. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2021/000517-1. SARDI Research Report Series No. 1124. 38pp.

Fredberg, J. and Bice, C.M. (2022a). Pike Fish Assemblage Condition Monitoring 2022. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2021/000433-2. SARDI Research Report Series No. 1151. 46pp.

Fredberg, J. and Bice, C.M. (2022b). Katarapko Fish Assemblage Condition Monitoring 2022. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2021/000517-2. SARDI Research Report Series No. 1150. 45pp.

Fredberg, J., Bice, C.M. and Zampatti, B. P. (2022). Chowilla Icon Site Fish Assemblage Condition Monitoring 2022. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2008/000907-13. SARDI Research Report Series No. 1139. 66pp.

King, A. J., P. Humphries and P. S. Lake (2003). Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* **60**: 773-786.

J.D. Koehn, S.M. Raymond, I. Stuart, C. R. Todd, S.R. Balcombe, B. P. Zampatti, H. Bamford, B. A. Ingram, C. M. Bice, K. Burndred, G. Butler, L. Baumgartner, P. Clunie, I. Ellis, J. P. Forbes, M. Hutchison, W. M. Koster, M. Lintermans, J. P. Lyon, M. Mallen-Cooper, M. McLellan, L. Pearce, J. Ryall, C. Sharpe, D. J. Stoessel, J. D. Thiem, Z. Tonkin, A. Townsend and Q. Ye (2020). A compendium of ecological knowledge for restoration of freshwater fishes in Australia's Murray–Darling Basin. Marine and Freshwater Research **71**(11): 1391-1463.

Maiztegui T, Baigún CRM, Garcia de Souza JR, Weyl OLF, Colautti DC (2019). Population responses of common carp Cyprinus carpio to floods and droughts in the Pampean wetlands of South America. NeoBiota **48**: 25–44.

Mallen-Cooper, M., J. Koehn, A. King, I. Stuart and B. Zampatti (2008). Risk Assessment of the Proposed Chowilla Regulator and Managed Floodplain Inundations on Fish, Report for the Department of Water, Land and Biodiversity Conservation, South Australia, 94pp.

Mallen-Cooper, M. and I. G. Stuart (2003). Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* **19**: 697-719.

Marsland, K. (2010). Pike Floodplain understorey vegetation condition monitoring: 2010 preliminary report, South Australian Murray Darling Basin Natural Reseources Management Board, Berri.

McCune, B., J. B. Grace and D. L. Urban (2002). Analysis of Ecological Communities, MjM Software Design, Gleneden Beach, Oregon.

McCune, B. and M. Mefford (2006). PC-ORD. Multivariate Analysis of Ecological Data, Version 5.0. MjM Software Design, Glendon Beach, Oregon.

Nicol, J. M., S. L. Gehrig, K. A. Frahn and J. Fredberg (2015). Pike floodplain vegetation condition monitoring 2015 report, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000583-1. SARDI Research Report Series No. 868. 34pp.

Robinson, W. A. (2013). The Living Murray: Towards assessing whole of Icon Site Condition. Report to the Murray-Darling Basin Authority, July 2013.

Rowland, S. J. (1998). Aspects of the reproductive biology of Murray cod, Macullochella peelii peelii. Proceedings of the Linnean Society of New South Wales 120: 147-162.

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

Thwaites, L. A. and J. F. Fredberg (2014). Riverine Recovery Wetland Fish and Water Quality Baseline Surveys: 2013 Data Summary Report, Prepared for the Department of Environment, Water and Natural Resources (DEWNR) by the South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 173 pp.

Wilson, P., Zampatti, B. P., Leigh, S. J. and Bice, C. M. (2014). Chowilla Icon Site Fish Assemblage Condition Monitoring 2013. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2008/000907-5. SARDI Research Report Series No. 785. 50pp.

Ye, Q., L. Bucater, C. M. Bice, D. Fleer, D. A. Short, L. Suitor, I. K. Wegener, P. J. Wilson and B. P. Zampatti (2015). Population dynamics and status of freshwater catfish (*Tandanus tandanus*) in the lower River Murray, South Australia, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. 2014/00000-1. SARDI Research Report Series No. xx.

Ye, Q., G. Giatas, K. Aldridge, B. Busch, M. Gibbs, M. Hipsey, Z. Lorenz, R. Oliver, R. Shiel and B. Zampatti (2016). Long-term intervention monitoring for the ecological responses to environmental water delivered to the Lower Murray River selected area in 2014/15 South Australian Research and Development Institute, Aquatic Sciences.

Ye, Q., G. Giatas, C. Bice, J. Brookes, D. Furst, M. Gibbs, J. Nicol, R. Oliver, R. Shiel, B. Zampatti, L. Bucater, D. Deane, M. Hipsey, P. Huang, Z. Lorenz and S. Zhai (2021). Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Lower Murray 2019-20 Technical Report, A report prepared for the Commonwealth Environmental Water Office by the South Australian Research and Development Institute, Aquatic Sciences.

Zampatti, B. P., C. M. Bice, P. J. Wilson and Q. Ye (2014). Population dynamics of Murray cod (*Maccullochella peelii*) in the South Australian reaches of the River Murray: a synthesis of data from 2002-2013, South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000089-1. SARDI Research Report Series No. 761. 42 pp.

Zampatti, B. P. and S. J. Leigh (2013a). Effects of flooding on recruitment and abundance of golden perch (*Macquaria ambigua ambigua*) in the lower River Murray. *Ecological Management and Restoration* **14**: 135-143.

Zampatti, B. P. and S. J. Leigh (2013b). Within-channel flows promote spawning and recruitment of golden perch, Macquaria ambigua ambigua – implications for environmental flow management in the River Murray, Australia. *Marine and Freshwater Research* **64**(7): 618-630.

Zampatti, B. P., S. J. Leigh, C. M. Bice and P. J. Rogers (2018). Multiscale movements of golden perch (Percichthyidae: *Macquaria ambigua*) in the River Murray, Australia. *Austral Ecology* **43**: 763-774.

Zampatti, B. P., S. J. Leigh and J. M. Nicol (2011). Fish and aquatic macrophyte communities in the Chowilla Anabranch System, South Australia: A report on investigations from 2004 - 2007, South Australia Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000719-1. SARDI Research Report Series No. 525. 180 pp.

APPENDIX

Appendix 1: Results of similarity or percentages analysis (SIMPER) presenting species that cumulatively contributed >50% to dissimilarity between fish assemblages sampled in year groups at the Pike Anabranch, deemed to be significantly different by PERMANOVA. * indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	Year group 1	Year group 2	Year group 3	Year group 4	Year group 5
Year group 2	*C. fulvus** *M. ambigua* *N. erebi* *C. auratus** *M. fluviatilis*	-	-	-	-
Year group 3	*R. semoni* *N. erebi* *M. fluviatilis* *C. fulvus* *C. auratus*	*C. fulvus* *R. semoni* *M. fluviatilis* *C. auratus* *M. ambigua**	-	-	-
Year group 4	*N. erebi* *C. fulvus** *C. auratus** *R. semoni*	*N. erebi* *R. semoni* *M. ambigua* *C. auratus* *C. fulvus**	*N. erebi* *C. fulvus** *C. auratus** *G. holbrooki**	-	-
Year group 5	*C. carpio* *R. semoni* *N. erebi* *M. fluviatilis* *G. holbrooki*	*R. semoni* *C. carpio* *M. ambigua** *C. fulvus* *G. holbrooki*	*C. carpio* *N. erebi** *C. fulvus** *C. auratus** *H. Spp**	*C. carpio* *N. erebi** *G. holbrooki* *C. auratus* *C. fulvus*	-
Year group 6	*C. carpio* *P. fluviatilis* *N. erebi* *R. semoni*	*C. carpio* *P. fluviatilis* *C. auratus* *R. semoni*	*C. carpio* *P. fluviatilis* *N. erebi* *C. auratus*	*C. carpio* *P. fluviatilis* *C. auratus*	*P. fluviatilis* *C. carpio* *N. erebi* *C. auratus*

Appendix 2. Total number of species captured at each site in 2009.

2009	Site Numbers																
Species	1	3	5	6	7	8	9	10	11	12	13	14	15	16	18	19	Total
Golden perch	1	1	8	5		3						7	5	9	1	7	**47**
Silver perch						3									1	1	**5**
Freshwater catfish						1						1			6		**8**
Bony herring	3	8	42	38	322	362	30	3	182	88	22	121	223	40	37	3	**1524**
Australian smelt		1				17	10	2	3	1	7	2	44	1	93		**181**
Murray rainbowfish		4	4	14		1				6		29	6	15		2	**81**
Flatheaded gudgeon	1	2		1			1					3	18	1		1	**28**
Unspecked hardyhead		78	105	151	14	1	65	9	20	8	34	126	311	107	25	370	**1424**
Carp gudgeon		3	1			1	1	4				2		43	1	1	**57**
carp	19	51	15	12	13	12	13	9	9	18	7	15	19	12	12	12	**248**
Gambusia		12	3	3						1		6		3		73	**101**
Goldfish	2	135	16	38	3	3	95	1	36	3	45		5	10		52	**444**
Redfin perch					1			1							1		**3**
Total species	**5**	**10**	**8**	**8**	**5**	**10**	**7**	**7**	**5**	**7**	**5**	**10**	**8**	**10**	**9**	**10**	**13**
Site Total	**26**	**295**	**194**	**262**	**353**	**404**	**215**	**29**	**250**	**125**	**115**	**312**	**631**	**241**	**177**	**522**	**4151**

Appendix 3. Total number of species captured at each site in 2013.

2013	Site Numbers																
Species	**1**	**3**	**2**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Total**
Golden perch	1	49	1	34	42	20	15	27	30	19		3		8	14	13	**276**
Silver perch								2	1	1		2			1		**7**
Freshwater catfish					1			1	1	1				1	2	4	**11**
Bony herring	106	96	109	178	205	149	176	402	71	93	50	62	10	27	399	162	**2295**
Australian smelt		2	1	2			8	1		2	5		7		9	11	**48**
Murray rainbowfish	2	3	1	6		6	27	11	6	5				20	3	15	**105**
Flathead gudgeon									1								**1**
Dwarf flathead gudgeon								1								1	**2**
Unspecked hardyhead	73	3	2		1	7	6	10	2	20	7	4	1	2		6	**144**
Carp gudgeon spp	15	4	1		3		2	6		3				1			**35**
Carp	16	296	55	51	64	81	24	68	49	39	30	47		21	13	9	**863**
Gambusia	1	1			2					2	3				2	1	**12**
Goldfish	1	39	9	9	6	1		14	1	3	22	19		1			**125**
Redfin perch		1					1										**2**
Total species	**8**	**10**	**8**	**6**	**8**	**6**	**8**	**11**	**9**	**11**	**6**	**6**	**3**	**8**	**8**	**9**	**14**
Total fish/site	**215**	**494**	**179**	**280**	**324**	**264**	**259**	**543**	**162**	**188**	**117**	**137**	**18**	**81**	**443**	**222**	**3926**

Appendix 4. Total number of species captured at each site in 2015.

2015	Site Number																		
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**Total**
Golden perch	5		5	8	12	6	2	16	9					9	8	9	1	3	**93**
Murray cod												1						1	**2**
Silver perch								1		2					2				**5**
Freshwater catfish								1							1		1	1	**4**
Bony herring	11	111	54	187	209	298	47	1535	159	495	112	866	77	73	1002	130	599	375	**6340**
Australian smelt	54	8	7	38	4	22	3	127	61	64	71	114	31	2	199	20	124	55	**1004**
Murray rainbowfish	11		18	69	7	19	17	137	69	38	9	42		120	88	48	37	74	**803**
Flatheaded gudgeon	2		1			2				2									**7**
Dwarf flatheaded gudgeon	1							1											**2**
Unspecked hardyhead	41	21	27	159	8	37	58	77	65	108	28	79	34	21	222	85	11	67	**1148**
Carp gudgeon	13	20	19	1		3	1	27	7	27	3	13		1		2	3	1	**141**
Carp	10	28	22	8	7	24	14	23	26	23	6	21	7	22	32	6	34	13	**326**
Gambusia	1	114	7	7	5	2		9	7	4		4		4	2			9	**175**
Goldfish	11	156	73	22	7	36	22	114	53	28	11	1	8	2	7	9	55	1	**616**
Redfin perch							1	1											**2**
Total Species	**11**	**7**	**10**	**9**	**8**	**10**	**9**	**13**	**9**	**10**	**7**	**9**	**5**	**9**	**10**	**8**	**9**	**11**	**15**
Total	**160**	**458**	**233**	**499**	**259**	**449**	**165**	**2069**	**456**	**791**	**240**	**1141**	**157**	**254**	**1563**	**309**	**865**	**600**	**10668**

Appendix 5. Total number of species captured at each site in 2016.

2016	Site Numbers																		
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**Total**
Golden perch			2	8	11	12	7	7						7	4	4	1	3	**66**
Murray cod								1							1				**2**
Silver perch												1			1				**2**
Freshwater catfish									1	1		1			1				**4**
Bony herring	59	212	59	622	969	210	131	821	80	67	65	64	173	11	1509	213	161	80	**5506**
Australian smelt	95	51	22	35	33	41	9	581	24	46	23	66	25	2	237	14	185	330	**1819**
Murray rainbowfish	67		8	31	16	22	38	96	54	23	6	13		50	32	28	31	25	**540**
Unspecked hardyhead	394	324	36	111	280	322	193	372	508	321	231	102	204	261	263	400	118	254	**4694**
Flatheaded gudgeon	15		1	2			1	2			2		1	1	1	1			**27**
Dwarf flatheaded gudgeon	1														2				**3**
Carp gudgeon	56	5	39	6	4	13	3	25	4	28	8	5	3	1	18	8	7	5	**238**
Carp	20	17	127	29	16	20	13	10	8	17	17	7	18	12	21	9	15	20	**396**
Goldfish	1	148	273	42	20	32	38	121	22	32	51	34	60	4	16	35	2	3	**934**
Gambusia		4	5	22	16	37	12	34	5	4	4	17		11	22	13	10	10	**226**
Oriental weatherloach		2																	**2**
Redfin perch									1										**1**
Total Species	**9**	**8**	**10**	**10**	**9**	**9**	**10**	**11**	**10**	**9**	**9**	**10**	**7**	**10**	**14**	**10**	**9**	**9**	**16**
Total	**708**	**763**	**572**	**908**	**1365**	**709**	**445**	**2070**	**707**	**539**	**407**	**310**	**484**	**360**	**2128**	**725**	**530**	**730**	**14460**

Appendix 6. Total number of species captured at each site in 2020.

2020	Site Numbers										
Species	**1**	**3**	**4**	**5**	**6**	**8**	**9**	**12**	**13**	**19**	**Total**
Golden perch		1	4	1	2		1		1	1	**11**
Murray cod						1	2				**3**
Freshwater catfish			1								**1**
Bony herring	3	451	531	598	162	6343	270	153	161	120	**8792**
Australian smelt	23	31	8	7	9	74	38	30	23	1	**244**
Murray rainbowfish	16	12	13	13	8	21	29	3		25	**140**
Unspecked Hardyhead	33	12	9	11	44	2	35			12	**158**
Carp gudgeon	8	19	2		1	1	2			2	**35**
Flatheaded gudgeon		7	2	1	2						**12**
Carp	10	19	10	10	15	5	23	18	10	20	**140**
Gambusia		1	3							10	**14**
Goldfish		18	8	5	4		4			1	**40**
Redfin perch			1							1	**2**
Total Species	**6**	**10**	**12**	**8**	**9**	**7**	**9**	**4**	**4**	**10**	**13**
Total	**93**	**571**	**592**	**646**	**247**	**6447**	**404**	**204**	**195**	**193**	**9592**

Appendix 7. Total number of species captured at each site in 2021.

2021	Site Numbers													
Species	**1**	**3**	**4**	**5**	**6**	**8**	**9**	**12**	**13**	**14**	**15**	**16**	**19**	**Total**
Golden perch	1	1	1	4	4	4				8	3	4	4	**34**
Murray cod						3	4	1				1		**9**
Silver perch	1													**1**
Freshwater catfish												1		**1**
Bony herring	11	266	108	208	5	694	293	416	9	8	604	73	51	**2746**
Australian smelt	152	73	35	41	61	184	34	63	23	4	57	13	105	**845**
Murray rainbowfish	5	35	11	6	20	9	25		2	25	14	150	136	**438**
Unspecked Hardyhead	69	186	32	55	527	3	58		4	159	128	255	444	**1920**
Carp gudgeon	9	9		5	2		1	1	1	1	2	19	4	**54**
Flatheaded gudgeon			1		1						5	2	1	**10**
Carp	21	30	30	23	36	27	108	25	9	13	37	23	22	**404**
Gambusia	2		3	4		2	8	1		1	3	3	5	**32**
Goldfish			4		11		7					3	2	**27**
Redfin perch					3		1				1			**5**
Species Total	**9**	**7**	**9**	**8**	**10**	**8**	**10**	**6**	**6**	**8**	**10**	**12**	**10**	**14**
Total	**271**	**600**	**225**	**346**	**670**	**926**	**539**	**507**	**48**	**219**	**854**	**547**	**774**	**6526**

Appendix 8. Total number of species captured at each site in 2022.

2022	Site Numbers													
Species	**1**	**3**	**4**	**5**	**6**	**8**	**9**	**12**	**13**	**14**	**15**	**16**	**19**	**Total**
Golden perch		4	4	5	2	3	2				4	6	7	**37**
Murray cod			1			9		1			1		1	**13**
Silver perch				3		1	1				3	1		**9**
Freshwater catfish							1							**1**
Bony herring	26	769	190	321	242	62	38	49	81	58	321	717	199	**3073**
Australian smelt	3	257	91	64	232	31	44	63	16	20	190	86	58	**1155**
Murray rainbowfish	5	30	5	7	23	16	12	17	1	14	11	22	21	**184**
Unspecked Hardyhead	7	96	15	21	46	7	29	52	30	37	30	9	19	**398**
Carp gudgeon		1		1		2	3		1	1	1		5	**15**
Flatheaded gudgeon			1							2				**3**
Carp	181	102	129	129	124	296	630	90	100	2357	232	770	78	**5218**
Gambusia		3	3	4	9	12	1	22	1	3	9	4	5	**76**
Goldfish	3	19	7	17	9	5	69	7	2	2	12	6	13	**171**
Redfin perch	3	8	1	4	7	3	4					1		**31**
Species Total	**7**	**10**	**11**	**11**	**9**	**12**	**12**	**8**	**8**	**9**	**11**	**10**	**10**	**14**
Total	**228**	**1289**	**447**	**576**	**694**	**447**	**834**	**301**	**232**	**2494**	**814**	**1622**	**406**	**10384**

Appendix 9. Total number of species captured at each site in 2023.

2023	Site Numbers													
Species	**1**	**3**	**4**	**5**	**6**	**8**	**9**	**12**	**13**	**14**	**15**	**16**	**19**	**Total**
Golden perch	5	5	11	5	7	26	4	6		4	4		14	**91**
Murray cod			1				1						1	**3**
Silver perch												1		**1**
Freshwater catfish					1		1							**2**
Bony herring	8	319	796	741	466	80	76	374	221	27	329	1779	221	**5437**
Australian smelt	3	12	116	48	23	25	12	33	21		179	53	30	**555**
Murray rainbowfish	22	12	8	6	6	22	29	12	10	3	25	18	8	**181**
Unspecked Hardyhead	4	49	12	13	14	27	31	38	31		43	211	7	**480**
Carp gudgeon	2	9	1				1		1					**14**
Flatheaded gudgeon														**0**
Carp	1275	761	562	326	1378	1785	553	349	390	5795	567	795	384	**14920**
Gambusia		3	13	4	3	5	22	1	1	2	6	16	6	**82**
Goldfish	18	270	94	122	380	66	38	27	6	3	37	198	109	**1368**
Redfin perch	37	183	65	106	59	118	114	99	4	14	34	75	50	**958**
Species Total	**9**	**10**	**11**	**9**	**10**	**9**	**12**	**9**	**9**	**7**	**9**	**9**	**10**	**13**
Total	**1374**	**1623**	**1679**	**1371**	**2337**	**2154**	**882**	**939**	**685**	**5848**	**1224**	**3146**	**830**	**24092**