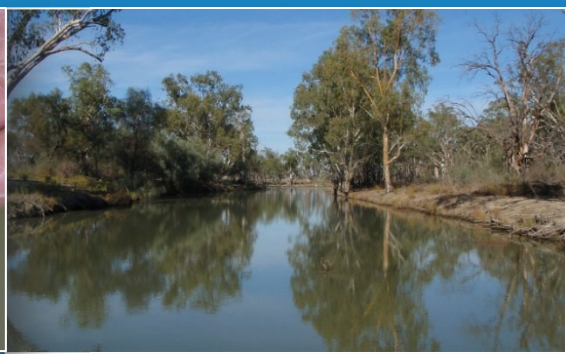
Inland Waters &
Catchment Ecology

Pike
Fish Assemblage Condition Monitoring 2021

J. Fredberg and C. M. Bice

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SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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In 2020/21, this project was funded under the South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP). SARFIIP is a $155 million investment program funded by the Australian Government through the Murray-Darling Basin Authority and implemented by the South Australian Government to improve the watering and management of River Murray floodplains in South Australia's Riverland. The project was managed by Brett Ibbotson and Jan Whittle (South Australian Department for Environment and Water). The authors would like to thank the following SARDI staff for assistance with fieldwork: Arron Strawbridge, Kate Frahn, Leigh Thwaites and Dave Schmarr. All sampling was conducted under an exemption (no. ME9903055) of section 115 of the *Fisheries Management Act 2007*. Finally, we thank Brett Ibbotson (DEW) and Kate Frahn (SARDI Aquatic Sciences) for constructive reviews of a draft of this report. The report was formally approved for release by Dr Mike Steer, Research Director, SARDI Aquatic Sciences.

EXECUTIVE SUMMARY

The Pike Anabranch is one of three large anabranch systems in the Riverland region of the lower River Murray, South Australia. The anabranch consists of a mosaic of aquatic habitats, including permanent lotic (flowing) habitats that are now rare in the main channel of the River Murray. The associated floodplains of the system also support 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 promoting a hydrological regime that includes: improved connectivity and extension of lotic habitats under normal operating conditions; and more frequent floodplain inundation than would occur naturally under current conditions owing to managed inundation events. The operation of this infrastructure will be guided by the Pike Floodplain Operations Plans 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*).

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

In April 2021, 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. 2009–2020) 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 6,526 fish, from 14 species (10 native and 4 non-native) were captured within the Pike Anabranch and the adjacent River Murray main channel. The most abundant native species were bony herring (42.1%), unspecked hardyhead (29.4%), Australian smelt (12.9%) and Murray rainbowfish (6.7%), whilst the remaining native species consisted of 1.7% of the total catch. Non-native common carp, goldfish, eastern gambusia and redfin perch collectively comprised 7.2% 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 2021, the fish assemblage was similar to that sampled during previous years characterised by within-channel flows (2015–2016 and 2020) with generally high abundance of small- to medium-bodied native species (e.g. bony herring) and low abundances of non-native fishes (e.g. common carp and goldfish). 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.

The majority of fish-related Ecological Targets (five of seven) were partially or fully achieved in 2021. Species diversity exceeded the reference value, whilst extent indices were met for eight of eleven target species. The abundance of Murray cod has exhibited a positive trajectory since 2013 and exceeded the reference value in 2021, but the abundance of freshwater catfish was below the reference value. The recruitment target for Murray cod was partially met, with recruitment to YOY evident, but recruitment to the adult population not detected. Recruitment was evident for all common small- and medium-bodied species. The common carp recruitment index was the highest since monitoring began in 2009 and was likely a result of enhanced recruitment associated with the inaugural managed inundation at the Pike Anabranch in spring-early summer 2020.

The results highlight the importance of flowing water habitats within the Pike Anabranch and potential early positive responses (e.g. improvement in Murray cod metrics) to improvements to connectivity and hydrodynamics following RRP and SARFIIP. They also highlight potential

negative outcomes of managed inundations (e.g. carp recruitment). Continued monitoring will provide greater insight and inform adaptive management of the system.

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

1. INTRODUCTION

1.1. Background

The Pike Anabranch and Floodplain is one of three large (~6,700 ha) anabranch systems in the Riverland region of the lower River Murray, South Australia (together with Chowilla and Katarapko). The Pike Anabranch is fed by two inlet creeks (Margaret Dowling Creek and Deep Creek) that flow from the Lock 5 weir pool into Mundic Creek, before flowing through a series of creeks and lagoons, and re-entering the River Murray downstream of Lock 5. As the anabranch system bypasses Lock 5, a head differential (>3 m) is created across the system, creating a mosaic of aquatic habitats, including permanent lotic (flowing) habitats that are now rare in the main channel of the River Murray (Bice et al. 2017). Subsequently, the Pike anabranch 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 systems 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). Due to the declining condition of long-lived floodplain vegetation and a need to meet environmental objectives with limited water, the South Australia 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 will be used to promote a hydrological regime at Pike that includes: 1) improved connectivity and extension of lotic habitats under normal operating conditions; and 2) more frequent floodplain inundation than would occur naturally under current conditions owing to managed inundation events. The operation of this infrastructure will be 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 anabranch system that stand to be influenced by system management. As such, within the Operations Plan, there are three primary ecological objectives for native fish in these systems, 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, a total of seven Ecological Targets were developed (Fredberg and Bice 2021), namely:

1. Maintenance or enhanced species diversity;
2. Maintenance or enhanced extent of species across the site as indicated by species-specific 'extent index';
3. Abundance (CPUE) of Murray cod exhibits a positive trajectory over a 5-year period from 2020;
4. Abundance (CPUE) of freshwater catfish exhibits a positive trajectory over a 5-year period from 2020;
5. Annual recruitment of foraging generalists is maintained or enhanced relative to historical levels, as indicated by species-specific 'recruitment index';
6. 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
7. 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 2021, 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 2009–2021; 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 six occasions, namely: 2009, 2013, 2015, 2016, 2020 and 2021 (Beyer et al. 2010, Bice et al. 2013, 2015, 2016). In total, 13–19 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 in 2020 and 2021. 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 characterization (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 2009–2021.

Site no.	Site name	2009	2013	2015	2016	2020	2021	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

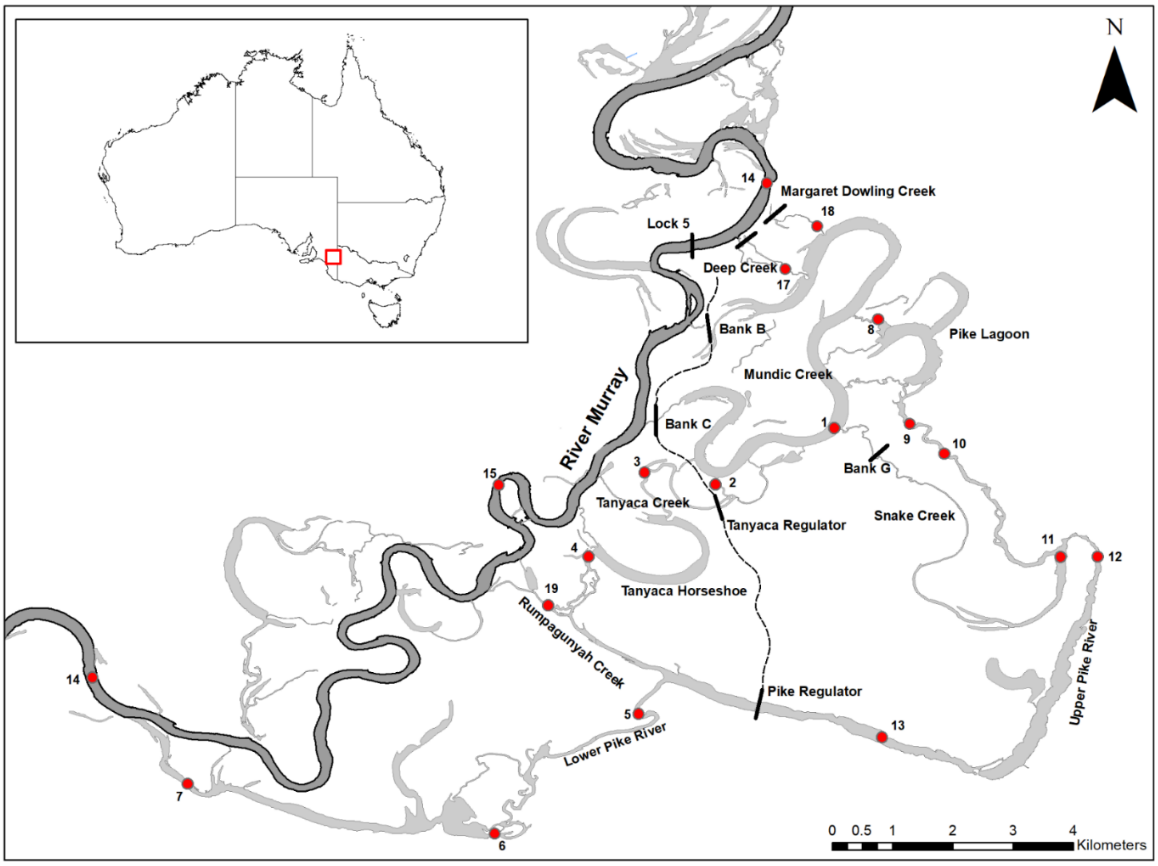

Figure 1. All 18 sites sampled from 2009–2021 as a part of condition monitoring in the Pike anabranch system.

2.2. Data collection

In 2021, fish assemblages were sampled from 21–30 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 (CPUE, fish.min^{-1}) of fish sampled between years were analysed using uni-variate (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 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} for each year), and a cut off score of 83% similarity was used to determine the cluster groups based on species abundance. Indicator Species Analysis was then undertaken with the software package PCOrd v. 5.12 (McCune and Mefford 2006) and used to determine species that characterised assemblages in different clusters (years) and determine species mesohabitat preferences. Indicator species analysis 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 on the basis of 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 against 5000 runs of randomised data (Dufrene and Legendre 1997). A species that is deemed not to be a significant indicator of a particular group is either uncommon or widespread. An uncommon species is found only in one group but in low numbers and a widespread species is found in more than one group in similar numbers (Dufrene and Legendre 1997). A species was classed as a widespread or uncommon non-significant species by examination of the raw data.

2.4. Assessment of Ecological Targets

Fish-related Ecological Objectives and Targets were recently refined 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 2009–2021. 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 (2009–2021).

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

- *MH* = mesohabitat,
- R_{year} = ratio of sites where sampled in given year,
- *ER* = expected ratio for each mesohabitat type,
- *EI* = Icon Site Extent Index,
- $EI = \text{mean}(MH_1(R_{year}/ER_{MH1}) + MH_2(R_{year}/ER_{MH2}) + MH_3(R_{year}/ER_{MH3}) + MH_4(R_{year}/ER_{MH4}))$,
    - *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 (i.e. spangled perch (*Leipotherapon unicolour*) were excluded. Furthermore, Murray cod, silver perch, dwarf flat-headed gudgeon (*Philynodon macrostomus*) and freshwater catfish do not have an expectedness ratio in backwater mesohabitats, as with Murray cod and dwarf flat-headed gudgeons in fast flowing mesohabitats, as they have never been sampled in this mesohabitat type in the Pike Anabranch during sampling events.

Target 3 & 4: Abundance (CPUE) of Murray Cod and freshwater catfish 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 and freshwater catfish. As such, specific targets were developed for both species that propose increasing trajectories of abundance relative to a reference value. For both species, this reference is the mean abundance (CPUE; fish.minute electrofishing^{-1}.site^{-1}) across all previous years of sampling at the Pike anabranch (2009-2020). As such, the reference value for Murray cod = 0.05 fish.minute electrofishing^{-1}.site^{-1} and freshwater catfish = 0.15 fish.minute electrofishing^{-1}.site^{-1}.

Target 5: 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	63%	2.47
Murray rainbowfish	<40 mm FL	25%	0.68
Australian smelt	<40 mm FL	32%	0.74
Bony herring	<100 mm FL	67%	7.92

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 6: 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 7: 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 recruitment indices for the non-native species, common carp and goldfish, followed the same approach for small-bodied native species and incorporates age/size structure 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*) = $mean((X_{2009}*r_{standard}) + (X_{2013}*r_{standard}) + \ldots\ldots (X_{2020}*r_{standard}))$

$r_{standard}$ 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	28%	0.50
Goldfish	<100 mm FL	85%	1.69

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

River Murray discharge to South Australia (QSA) has been highly variable since 2010. Following an extended period of low discharge from 1997–2010. Sampling in 2009, occurred toward the end of this period during low within channel flows of ~3000 $ML.day^{-1}$. This was followed by significant flooding in summer-autumn 2010/11 (peak ~93,000 $ML.day^{-1}$), a subsequent smaller overbank flood in autumn 2012 (peak ~60,000 $ML.day^{-1}$) and generally elevated discharge throughout much of 2012. Sampling in autumn 2013 occurred immediately following these high flow events, but during discharge (mean = 7,432 $ML.day^{-1}$) that approximated summer entitlement flow. Discharge from autumn 2013 to autumn 2015 was generally lower than the preceding years and characterised by within-channel flow events of ~25,000 and 18,000 $ML.day^{-1}$ in September 2013 and August 2014, respectively. Nonetheless, discharge for much of this period was <10,000 $ML.day^{-1}$ and during sampling in autumn 2015, mean daily discharge was 6,427 $ML.day^{-1}$. Similarly, discharge throughout 2015/16 was predominantly <10,000 $ML.day^{-1}$ and during sampling in autumn 2016 mean daily discharge was 5,812 $ML.day^{-1}$. A large overbank flood that peaked at 95,000 $ML.day^{-1}$ occurred in late 2016, but since this time the hydrograph has been characterised by within-channel flow (<12,000 $ML.day^{-1}$), punctuated by pulses in within-channel flow of 15,000–18,000 $ML.day^{-1}$ in December 2017, October 2019 and November 2020. During sampling in autumn 2020, daily mean discharge was 4,450 $ML.day^{-1}$ and in autumn 2021 was 5,346 $ML.day^{-1}$.

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 typically ~300 $ML.day^{-1}$. These upgrades increased capacity for discharge into the system. Following completion of the Tanyaca Creek and Pike Regulators (2020), discharge through the Pike system has ranged 500–1,200 $ML.day^{-1}$. In addition, from 17 September–13 December 2020, newly constructed floodplain infrastructure was operated in the inaugural managed inundation at the Pike system (Pike River Regulator maximum height of 15.25 m AHD and 0.70 m above the normal operating height of 14.55 m AHD).

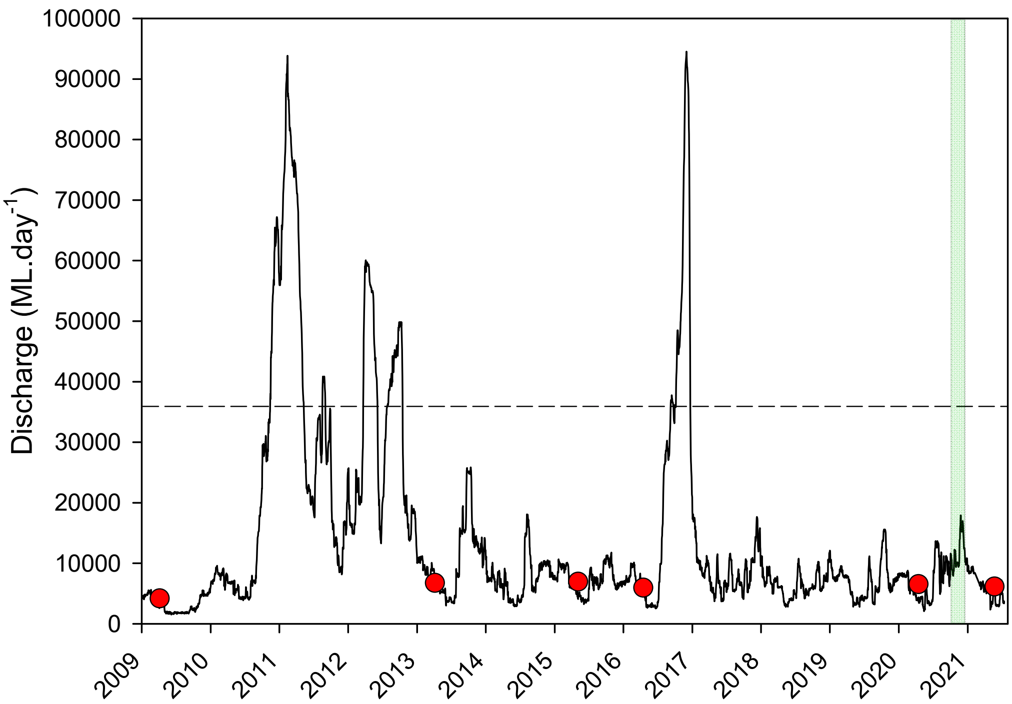

Figure 2. Mean daily flow (ML.d^{-1}) in the River Murray at the South Australian Border (Site A42610010) January 2009 – June 2021 (MDBA, unpublished data). Red circles indicate sampling events, the dashed line represents approximate bankfull discharge at the Pike anabranch (~35,000 ML.d^{-1}) and the green shaded area represents the inaugural regulator inundation within the Pike Anabranch.

3.2. Catch summary

In 2021, a total of 6,526 fish were captured from 14 species (10 native and 4 non-native; Table 6). The most abundant native species were bony herring (42.1%), unspecked hardyhead (29.4%), Australian smelt (12.9%) and Murray rainbowfish (6.7%), whilst the remaining native species consisted of 1.7% of the total catch. Non-native common carp, goldfish, eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*) collectively comprised 7.2% of the total catch. Three species of conservation significance were collected. These were, Murray cod, which is listed as 'vulnerable' under the EPBC Act, silver perch which is listed as "Endangered' under the EPBC Act and freshwater catfish, which is protected under the South Australian *Fisheries Management Act 2007.*

From 2009–2021, a total of 49,342 fish from 16 species (11 native and 5 non-native) were captured over the six 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 and standardised (fish.site-1) abundances of fish captured from condition monitoring sites sampled in the Pike Anabranch system and adjacent River Murray 2009–2021.

Species	**2009**	**2013**	**2015**	**2016**	**2020**	**2021**	Grand Total
Golden perch	47	279	93	66	11	34	530
(*Macquaria ambigua ambigua*)	3.1	17.4	5.2	3.7	1.1	2.6	
Murray cod	-	-	2	2	3	9	16
(*Maccullochella peelii*)			0.1	0.1	0.3	0.7	
Silver perch	5	7	5	2	-	1	20
(*Bidyanus bidyanus*)	0.3	0.4	0.3	0.1		0.1	
Freshwater catfish	8	11	4	4	1	1	29
(*Tandanus tandanus*)	0.5	0.7	0.2	0.2	0.1	0.1	
Bony herring	1524	2304	6340	5506	8792	2746	27212
(*Nematalosa erebi*)	101.6	144	352.2	305.9	879.2	211.2	
Australian smelt	181	50	1004	1819	244	845	4143
(*Retropinna semoni*)	12.1	3.1	55.8	101.1	24.4	65.0	
Murray rainbowfish	81	108	803	540	140	438	2110
(*Melantaenia fluviatilis*)	5.4	6.75	44.6	30.0	14.0	33.7	
Flat-headed gudgeon	28	1	7	27	12	10	85
(*Philypnodon grandicepts*)	1.9	0.1	0.4	1.5	1.2	0.8	
Dwarf flat-headed gudgeon	-	2	2	3	-	-	7
(*Philynodon macrostomus*)		0.1	0.1	0.2			
Unspecked hardyhead	1424	144	1148	4694	158	1920	9488
(*Craterocephalus fulvus*)	94.9	9	63.8	260.8	15.8	147.7	
Carp gudgeon spp.	57	35	141	238	35	54	560
(*Hypseleotris* spp.)	3.8	2.2	7.8	13.2	3.5	4.2	
Common carp*	248	865	326	396	140	404	2379
(*Cyprinus carpio*)	16.5	54.1	18.1	22.0	14.0	31.1	
Gambusia*	101	12	175	226	14	32	560
(*Gambusia holbrooki*)	6.7	0.75	9.7	12.6	1.4	2.5	
Goldfish*	444	125	616	934	40	27	2186
(*Carassius auratus*)	29.6	7.8	34.2	51.9	4.0	2.1	
Redfin perch*	3	2	2	1	2	5	15
(*Perca fluviatilis*)	0.2	0.1	0.1	0.1	0.2	0.4	
Oriental Weatherloach*	-	-	-	2	-	-	2
(Misgurnus anguillicaudatus)				0.1			
Total species	**13**	**14**	**15**	**16**	**13**	**14**	**16**
Total number of sites	**15**	**16**	**18**	**18**	**10**	**13**	
Total number of fish	**4,151**	**3,945**	**10,668**	**14,460**	**9592**	**6526**	**49,342**
Standardised total abundance	**276.73**	**246.56**	**592.67**	**803.33**	**959.20**	**502.00**	

3.3. Temporal variation in fish abundance

Between 2009 and 2021, total fish abundance (all species combined) varied significantly among years (Figure 4; *Pseudo-*$F_{5, 90}$ = 5.66, p < 0.001). Pairwise comparisons (B-Y corrected α = 0.015) indicated abundances in 2009 and 2013 were significantly less than all other years, but that all other comparisons were non-significant. As a proportion of the total catch, native fish numerically dominated that of non-native fish in all years (Figure 4).

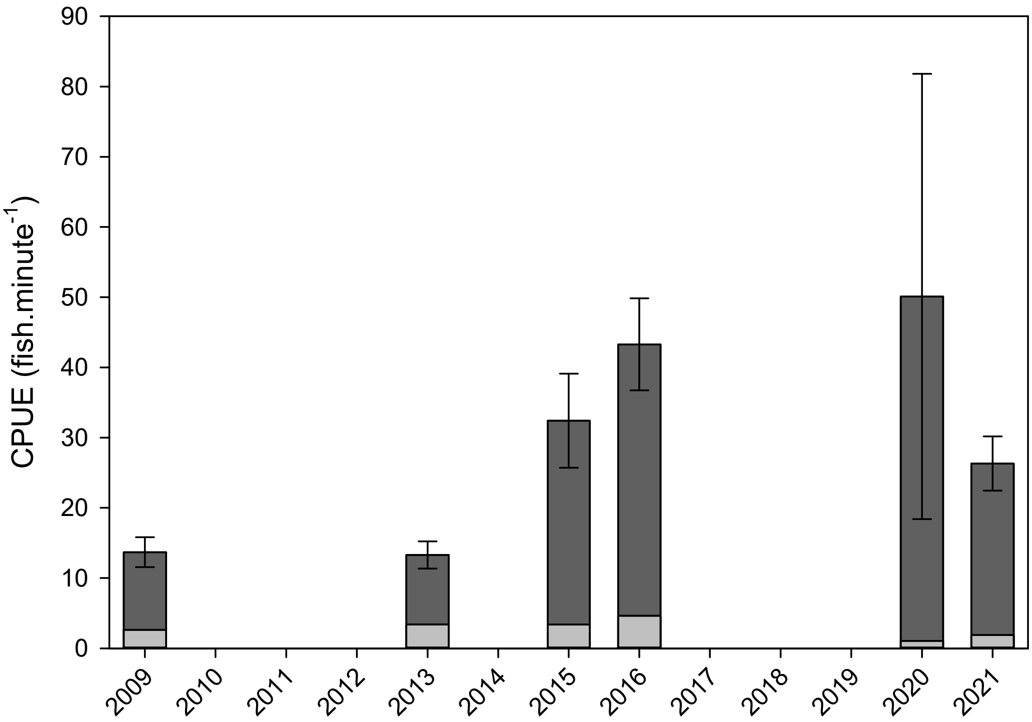

Figure 3. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of fish (all species combined) collected annually during standardised boat electrofishing surveys from 2009–2021 in the Pike anabranch system and adjacent River Murray (dark grey = proportion native species, light grey = proportion of 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, and 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 2009–2021. Significant *P* values are highlighted in bold.

Factor	*df*	*Pseudo-F*	*P*
Year	5, 89	5.7307	**0.001**
Mesohabitat	3, 89	4.9249	**0.001**
Year x mesohabitat	14, 89	0.88698	0.711

Pairwise comparisons revealed significant differences (B-Y corrected α = 0.02) in fish assemblages among mesohabitats for all comparisons, except for fast flowing and river mesohabitats (Table 8). In addition, cluster analysis and MDS indicated two distinct groupings of fish assemblages by sampling years, namely assemblages sampled from 2009–2013 and those sampled from 2015–2021 (Figure 5). A similar general pattern of temporal variability was observed for fish assemblages within most mesohabitats (Figure 6a–6d).

Table 8. PERMANOVA pair-wise comparisons between fish assemblages among different mesohabitats in the Pike anabranch from 2009-2021. Significant values are highlighted in bold (B-Y corrected α = 0.02).

Pairwise comparison		*t*	*p* value
Mesohabitat	**Mesohabitat**		
Fast	Backwater	2.619	**0.001**
Fast	Slow	2.1496	**0.004**
Fast	River	1.704	0.023
Backwater	Slow	2.0286	**0.003**
Backwater	River	2.6657	**0.001**
Slow	River	1.6988	**0.016**

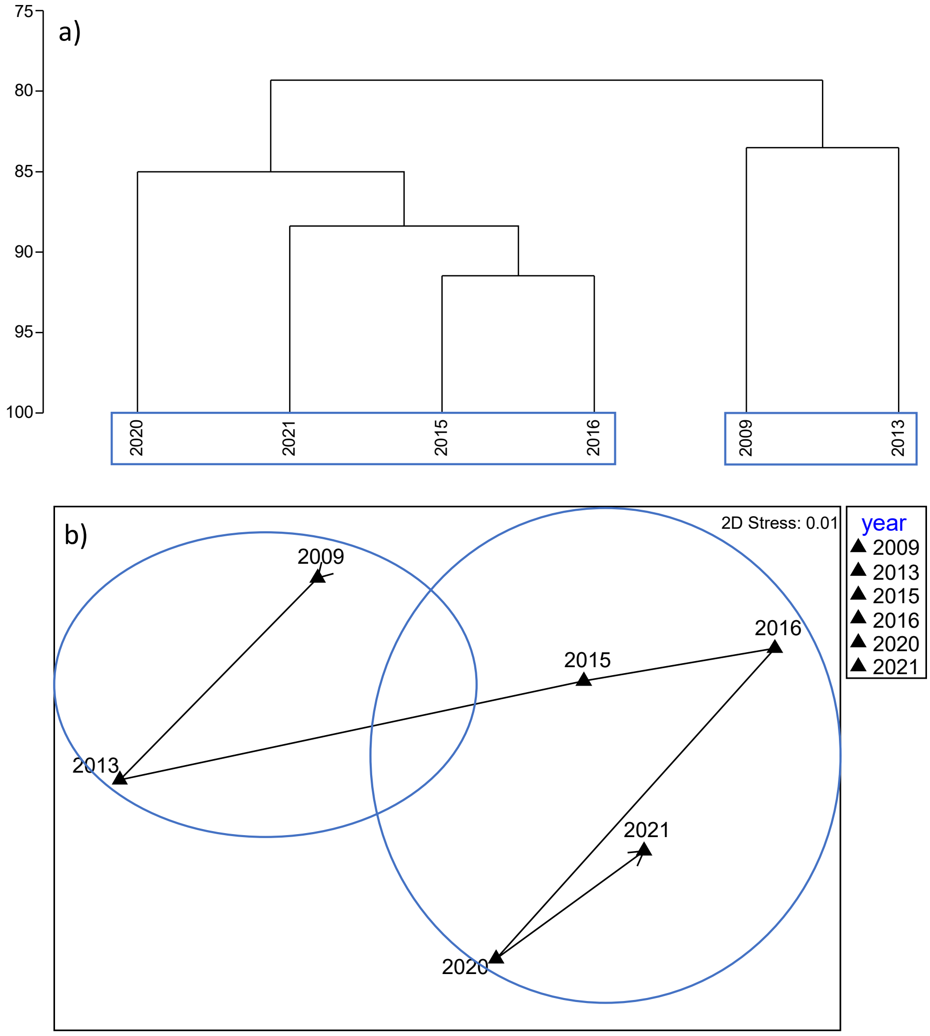

Figure 4. a) Dendrogram indicating fish assemblage clusters throughout all sampling years 2009–2021. b) Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled from all years/sites combined.

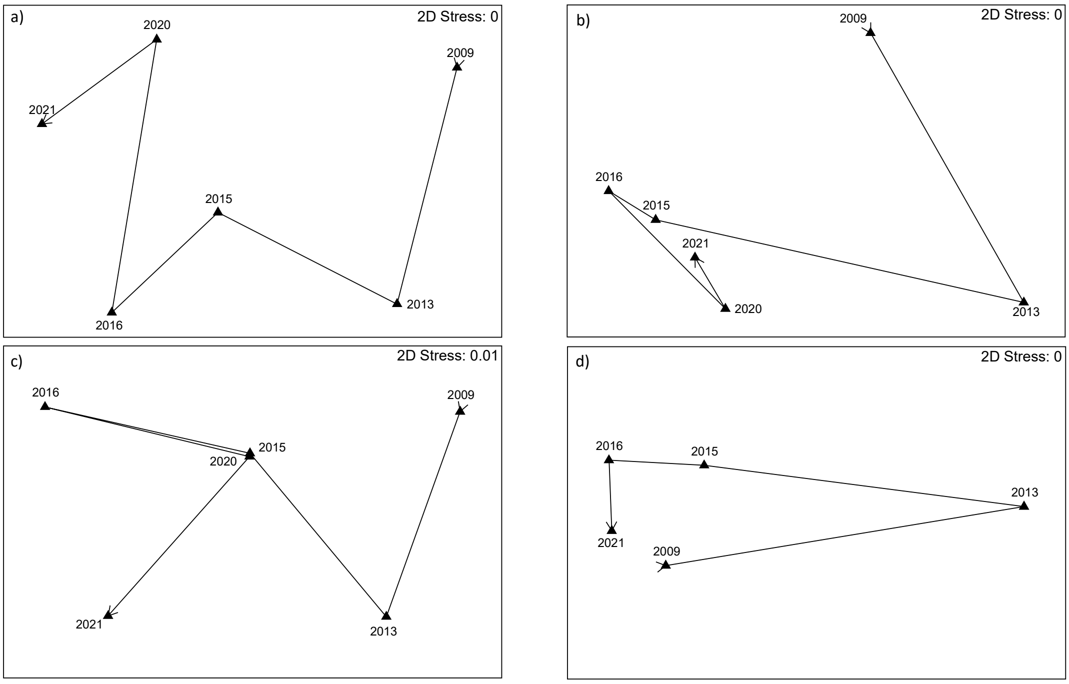

Figure 5. Non-metric multi-dimensional scaling (MDS) plots of a) fast-flowing, b) slow-flowing, c) backwater and d) river mesohabitats sampled from all years/sites combined.

Indicator species analysis comparing mesohabitat types suggested that fast-flowing mesohabitats were characterised by Murray cod, bony herring, Australian smelt and freshwater catfish (Table 9). Main river channel mesohabitats were only characterised by Murray rainbowfish, whilst no species were significantly associated with slow-flowing or backwater mesohabitats (Table 9). Indicator species analysis comparing clusters of sampling years suggested the years 2009–2013 were characterised by greater abundances of the large-bodied golden perch and common carp (Table 10), whilst assemblages from years 2015–2021 were characterised by a suite of large-, medium- and small-bodied species, namely: Murray cod; bony herring; Murray rainbowfish; goldfish; carp gudgeon complex; unspecked hardyhead; and Australian smelt (Table 10).

Table 9. Indicator species analysis comparing the relative abundance of fish at the Pike Anabranch in the four aquatic mesohabitats from 2009–2021. 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	0.0264
Australian smelt	Fast	0.0002
Bony Herring	Fast	0.0034
Freshwater catfish	Fast	0.0216
Murray rainbowfish	River	0.0496

Table 10. Indicator species analysis comparing the relative abundance of fish at the Pike Anabranch amongst years from 2009–2021. (Year group 1 = 2009 and 2013; Year group 2 = 2015–2016 and 2020–2021). 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
Common carp	1	36.7	0.0046
Golden perch	1	51.1	0.0002
Murray cod	2	17.5	0.0394
Bony Herring	2	43.3	0.0402
Murray rainbowfish	2	30.6	0.0218
Goldfish	2	40.1	0.0048
Carp gudgeon spp.	2	38.4	0.0020
Unspecked hardyhead	2	44.8	0.0002
Australian smelt	2	40.3	0.0114

3.5. Assessment of Ecological targets

Target 1: Maintenance or enhanced species diversity

In all sampling years, diversity was greater than or equivalent to the reference value across all mesohabitats (Figure 6a). The mean of mesohabitat diversity indices for each year was calculated to provide an overall site diversity score (Figure 6b). Again, in all years, the site diversity score was greater than or equivalent to the reference value, with 2016 having the highest diversity score out of all sampling years (Figure 6b).

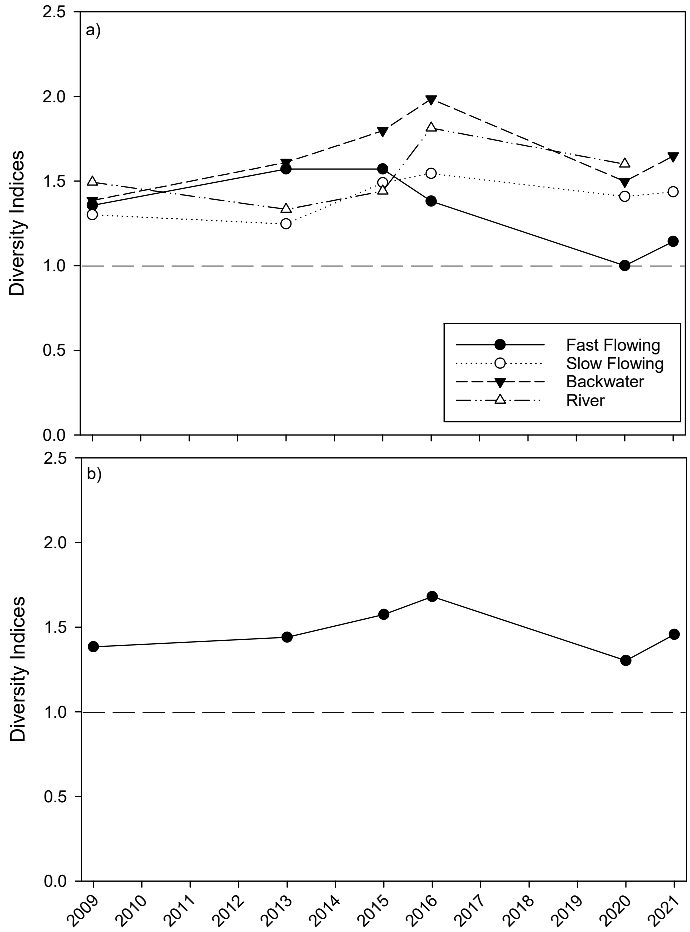

Figure 6. Diversity indices for a) fast-flowing, slow-flowing, backwater and main channel mesohabitats and b) the calculated Site Diversity Index (*DI*), at the Pike anabranch from 2009–2021.

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

For large-bodied native fishes, the extent index has varied among species (Figure 7a). Golden perch distribution was relatively stable across years, but silver perch and catfish have exhibited declines in distribution since peaks in 2013, with extent indices below the reference value in 2021. Murray cod were not sampled from 2009–2013, but distribution has increased thereafter, with peak extent recorded in 2021. The extent index for the majority of small and medium-bodied species remained stable around the reference value in most sampling years, with the exception of flat-headed gudgeon (2013 and 2015) and dwarf flat-headed gudgeon (2020 and 2021), which exhibited extents below the reference value in given years (Figure 7b).

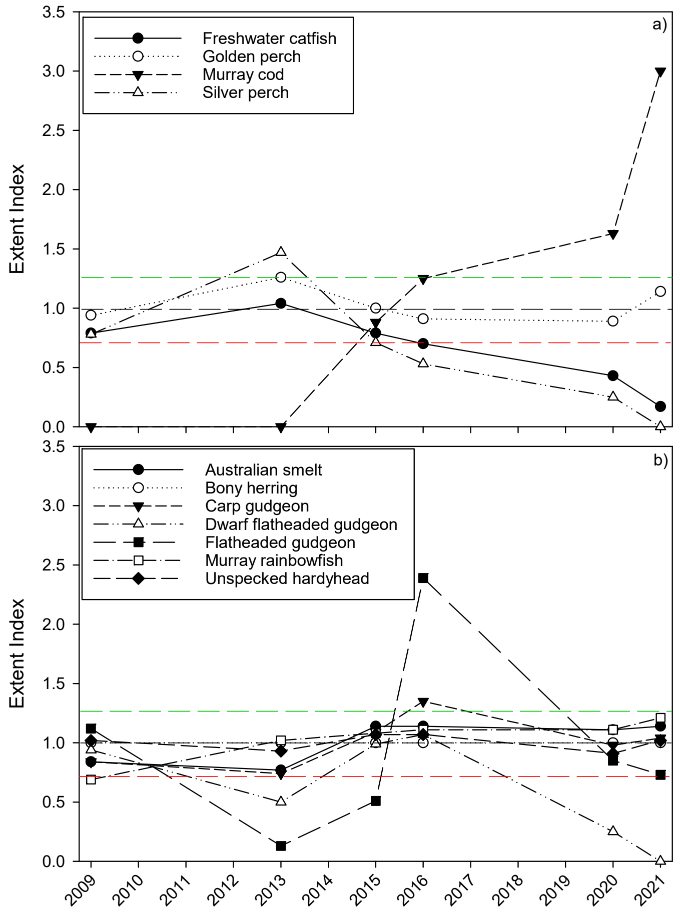

Figure 7. Extent Index (*EI*) scores for a) large-bodied native species and b) small- to medium-bodied native species at the Pike anabranch from 2009–2021. Black dashed line represents extent equal to the reference, green dashed line extent 25% greater than reference and red dashed line extent 25% lesser than reference.

Target 3 & 4: Abundance (CPUE) of Murray Cod and freshwater catfish exhibit positive trajectories over a 5-year period from 2020

The abundance index for Murray cod and freshwater catfish has been temporally variable at the Pike anabranch. 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 and 2021 (Figure 8a). The abundance of freshwater catfish peaked in 2013, however, the species was present in only low abundances, below that of the reference value, in 2020 and 2021 (Figure 8b).

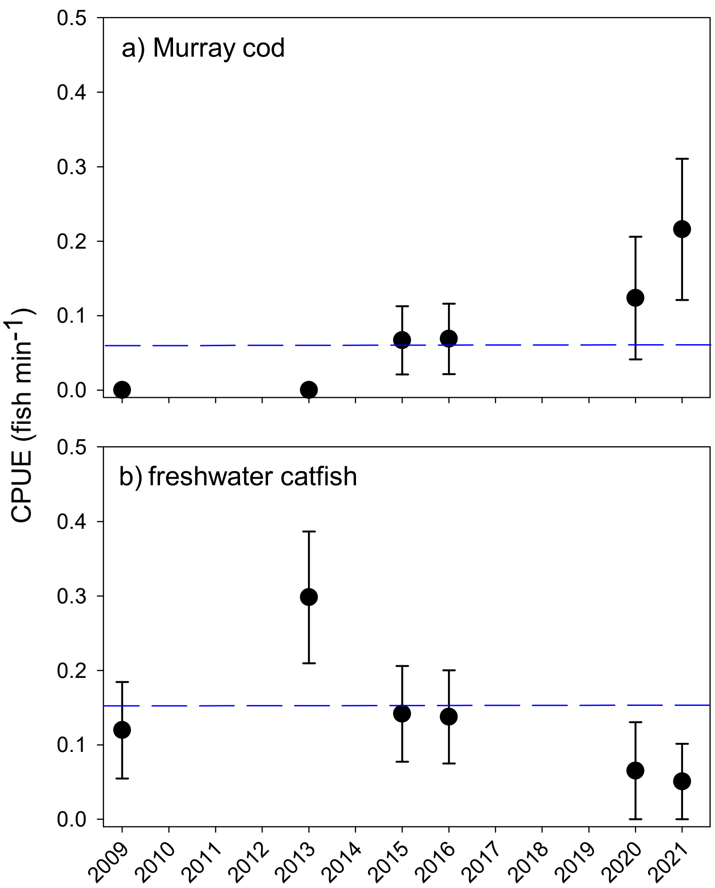

Figure 8. Mean abundance (CPUE; fish.minute electrofishing^{-1}.site^{-1}) ±SE for a) Murray cod and b) freshwater catfish at the Pike anabranch between 2009–2021. The blue dashed line represents mean abundance equal to the reference value.

Target 5: 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 9). Common for all species, recruitment was limited after high flow in 2013. Unspecked hardyhead recruitment was higher than the reference value in 2009, 2016 and 2021, but was limited in 2013 and 2020. High recruitment of Murray rainbowfish was evident from 2015–2021 but limited in 2009 and 2013. Australian smelt recruitment was variable, with the highest recruitment observed in 2016 and lowest in 2013. Bony herring recruitment was highest in 2020 but was below the reference value in all other years.

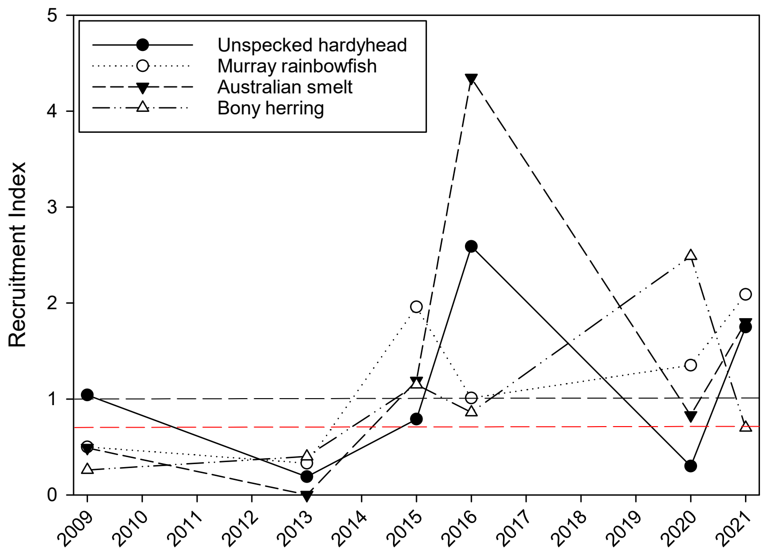

Figure 9. Recruitment Index (*RI*) values for unspecked hardyhead, Murray Rainbowfish, Australian smelt and bony herring from 2009–2021. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Target 6: 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 any sampling year (Figure 10). The index for Murray cod <200 mm TL, however, suggests that recruitment to YOY was greater than the reference value in all years from 2015–2021 (Figure 10).

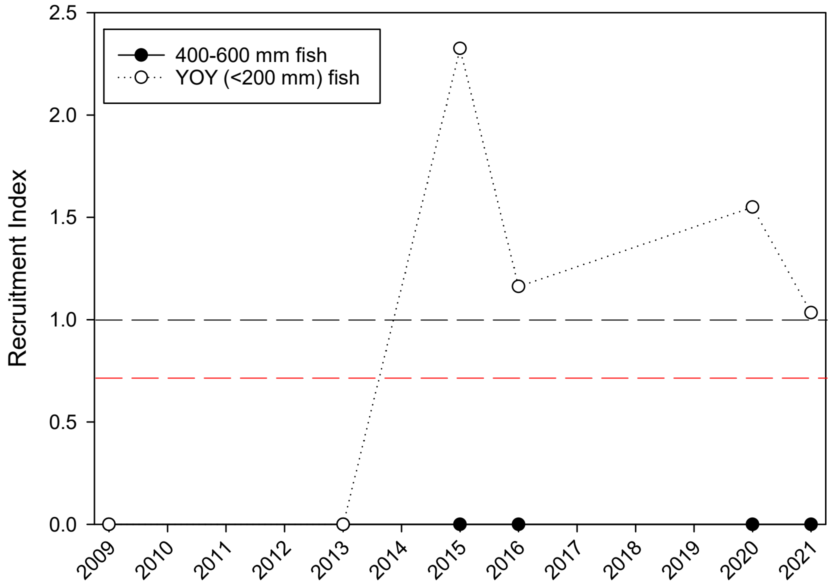

Figure 10. Recruitment Index (*RI*) values for Murray cod ranging 400–600 mm TL and YOY Murray cod (<200 mm TL) from 2009–2021. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Target 7: 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 some recruitment to YOY was evident every year (Figure 11). For common carp recruitment was above the reference in 2013, 2016 and 2021 (Figure 11a) and for goldfish in 2009, 2015 and 2016 (Figure 11b). The sampling year 2021, is the only year that has followed a managed inundation and was also the year of greatest recruitment to YOY for common carp.

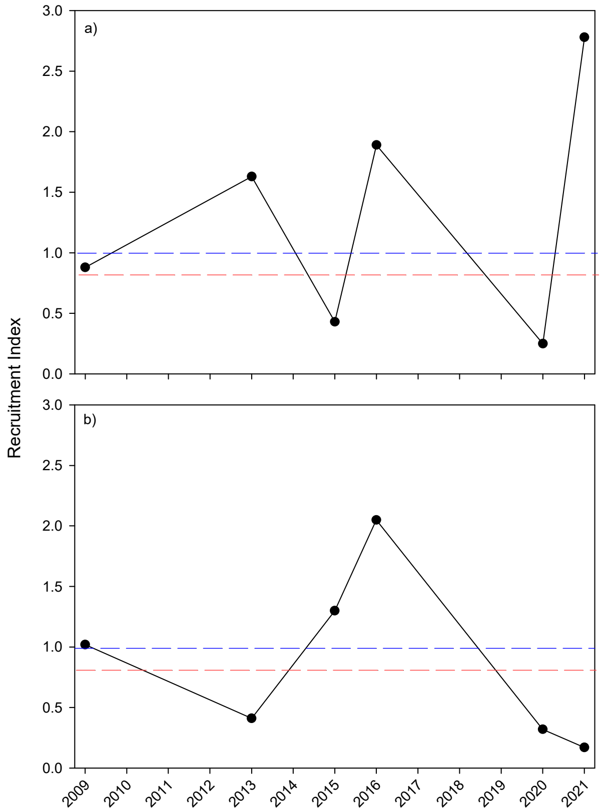

Figure 11. Summary of Recruitment Index (*RI*) values for a) common carp and b) goldfish at the Pike anabranch from 2009–2021. Dashed blue line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Summary

Sampling data from 2021 suggests that five of seven Ecological Targets were achieved or partially achieved (Table 11).

Table 11. Summary of assessment of fish-related Ecological Targets at the Pike Anabranch in 2021.

Primary Ecological Objectives 1, 2 & 3 (see page 5 above)			**Ecological target**	**2021**
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 8 of 11 target species
			Abundance (CPUE) of Murray Cod exhibits a positive trajectory over a 5-year period from 2020	Murray cod abundance currently exhibiting positive trajectory
			Abundance (CPUE) of Freshwater Catfish exhibits a positive trajectory over a 5-year period from 2020	Freshwater catfish abundance not currently exhibiting positive trajectory
	Objective 2		Annual recruitment of foraging generalists is maintained or enhanced relative to historical levels, as indicated by species-specific ‘recruitment index’	All target species exhibited recruitment indices exceeding 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 YOY evident, but recruitment to adult population 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 common carp was elevated relative to the reference value. NOTE: this may be acceptable with achievement of other ecological targets of managed inundation

Not achieved — Partially achieved — Achieved

4. DISCUSSION

The Pike Anabranch system has recently 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 each of the aforementioned 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 2021 with comparison to data from previous sampling of fish assemblages (2009–2020) and applied recently developed indices for assessment of Ecological Targets (Fredberg and Bice 2021).

4.1. General patterns of abundance and assemblage structure

In 2021, 14 fish species were sampled at 13 sites in the Pike Anabranch and adjacent River Murray main channel. The fish assemblage consisted of 10 native and 4 non-native species, with bony herring, unspecked hardyhead, Australian smelt and Murray rainbowfish the most abundant. Overall fish abundance and assemblage structure was similar to that in 2015–2016 and 2020 – all years characterised predominantly by within-channel flows – but, dissimilar from 2013 when sampling followed three consecutive years of elevated flow and flooding. Differences in assemblage structure reflect fluctuations in abundance of several small- and medium-bodied generalist species and peak abundance of golden perch and common carp in 2013.

Patterns of elevated abundance of small- and medium-bodied generalist species including bony herring, unspecked hardyhead, Australian smelt and Murray rainbowfish are commonly observed in the lower River Murray main channel (Bice et al. 2014) and 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, but are diminished during and immediately following periods of high flow (Bice *et al.* 2014). Overall, flow regulation in the form of altered hydrology and hydraulics (i.e. weir pools) favours generalist small-bodied species that historically may have been more characteristic of wetlands than flowing channel habitats.

In 2021, low abundances of golden perch relative to preceding years, are likely unrelated to local-scale factors (e.g. flow-induced habitat alteration), but rather the influence of hydrology on spawning and recruitment. Golden perch are flow-cued spawners, relying on the coincidence of elevated discharge and temperature cues to stimulate spawning (Mallen-Cooper and Stuart 2003, Zampatti and Leigh 2013a, 2013b). Of the golden perch sampled at Pike in 2021, >95% were adults >370 mm TL with likely ages of ≥7 years (based on age structure from the lower River Murray main channel; Ye et al. 2021). This is consistent with sampling in other areas of the lower River Murray that suggest limited recent recruitment of golden perch (Ye et al. 2021; SARDI Unpublished Data). Upstream migration of a proportion of the adult golden perch population appears to occur annually (Zampatti et al. 2018), and when coupled with natural and angling mortality, is likely resulting in a gradual decline in the abundance of this species.

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. 2021). 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, but also 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 2009–2021. The extent of most species has also been maintained or increased, with some notable exceptions. Flat-headed gudgeon and dwarf flat-headed gudgeon 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 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 increased over the past four consecutive years indicating greater prevalence and broader distribution across sites and mesohabitats. This is likely due to a combination of natural increases in distribution and the influence of stocking. The same positive trajectory in extent index was also observed at the Chowilla and Katarapko anabranches over the same period (Fredberg et al. 2021; SARDI Unpublished Data). Different to Chowilla and Katarapko, however, the Pike Anabranch has been a site of stocking with fingerling Murray cod in summer 2020 and 2021, immediately prior to sampling.

Freshwater catfish and silver perch extent has decreased since 2016. Nonetheless, as for dwarf flat-headed gudgeon, freshwater catfish (n = 1–11) and silver perch (n = 0–7) are typically only sampled in low numbers and therefore caution should be exercised in interpreting trends in distribution.

Abundance of Murray cod and freshwater catfish

Similar to the extent indices, the standardised abundance of Murray cod and freshwater catfish exhibited increasing and decreasing trajectories, respectively, particularly relative to pre-2015. The abundance of freshwater catfish peaked in 2013 and this pattern was reflected in other regions of the lower Murray and followed increases in abundance following flooding and high flow in 2010–2013 (Ye et al. 2015). Declines relative to this period or variable abundance have also been noted in other anabranches (SARDI Unpublished Data) in recent years, but again, caution should be exercised in interpreting trends in abundance for this rare species.

During and immediately following the Millennium Drought, Murray cod were absent from sampling in the Pike Anabranch, and were found in only low abundance in the River Murray main channel (Beyer et al. 2010, Bice et al. 2016, Ye et al. 2016). Increased abundance has since been noted at Pike, Katarapko and in the main channel (Ye et al. 2021; SARDI Unpublished Data). For the Pike Anabranch, increased abundance may be the result of multiple factors, including:

improvements to connectivity (e.g. fishway construction); increased extent of lotic habitats under normal operating conditions; stocking; and natural recruitment. A sub-adult Murray cod was detected ascending the Pike Regulator vertical-slot fishway (REF) in December 2020, providing evidence for the first mechanism. Disentangling stocking effects from natural recruitment, however, is more difficult.

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 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 and 2013, but a positive trajectory thereafter. Alternatively, recruitment to the adult population has been absent in all sampling years.

Parallel trajectories for recruitment to YOY, extent and abundance suggest increased prevalence of YOY has driven other metrics for Murray cod. This has likely been due to natural recruitment and stocking. Stocking has only 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 is encouraging and suggests that habitats within the system are suitable for juvenile fish.

The absence of Murray cod 400–600 mm TL is not unexpected. Prior to the completion of SARFIIP works and sampling in 2021, the Pike system remained largely fragmented and improvements to lotic habitats were yet to be realised. As a long-lived species, there may be time lags before these mechanisms are reflected in the population abundance index, but increases in this specific metric are expected in coming years.

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 a prolonged period of high flow in 2013. Indeed, in condition monitoring studies conducted in the Chowilla anabranch between 2005–2020, these same species displayed higher rates of recruitment in low flow years and limited recruitment following periods of high flows (Fredberg *et al* 2021). 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 in the Pike anabranch have generally corresponded with increased discharge and water levels. This includes 2013, which followed high flow and flooding, 2016 following weirpool raising at Lock 5 in spring 2015, and 2021 following the inaugural operation of the Pike and Tanyaca Creek regulators in spring-summer 2020. Throughout the Southern Murray-Darling Basin, increased water levels and floodplain inundation (natural and engineered) typically lead to increases in carp recruitment and abundance (King et al. 2003, Stuart and Jones 2006, Bice and Zampatti 2011).

In 2021, the abundance of common carp increased relative to 2020 as a result of enhanced recruitment to YOY potentially in association with operation of floodplain infrastructure in spring-summer 2020. This is a recognised risk and likely outcome of managed floodplain inundations in the Riverland region of South Australia that occur in spring and early summer (Mallen-Cooper et al. 2008). Managed inundations, however, are undertaken with the aim of supporting a variety of Ecological Objectives, chiefly, improving the condition of floodplain vegetation. While the common carp recruitment target was not met in 2021, promotion in condition of floodplain vegetation may represent an acceptable trade-off in this year.

5. CONCLUSION

Monitoring of fish assemblages at the Pike anabranch in 2021 indicated that the majority of fish-related Ecological Targets (five of seven) were partially or fully achieved. Importantly, metrics related to Murray cod distribution, abundance and recruitment have generally 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 2021, represented the first year for application of the newly developed Ecological Targets. The use of these targets for condition assessment brings Pike in line with the approach adopted at Chowilla and Katarapko. The similarity in management of the Pike, Katarapko and Chowilla anabranches, and approaches to monitoring and reporting on fish condition monitoring, presents an opportunity to better integrate understanding and management of these critical anabranch habitats across the region.

5.1. Future research needs

Six years of condition monitoring at the Pike anabranch across 2009–2021 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 on 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 in:

- 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 at Pike and contribution to broader regional populations.
- The movement and habitat use of native (e.g. Murray cod) 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.

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