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Katarapko Fish Assemblage Condition Monitoring 2021

J. Fredberg, S. J. Leigh and C. M. Bice

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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EXECUTIVE SUMMARY

The Katarapko Anabranch system is one of three large anabranch systems in the Riverland region of the lower River Murray, South Australia. Katarapko comprises hydraulically diverse aquatic habitats including permanent fast-flowing and slow-flowing creeks, as well as backwaters. Flowing water habitats such as these are now largely absent under regulated conditions in the lower River Murray main channel. The associated floodplains of the system also support ecologically significant vegetation communities, including river red gum (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) 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 Katarapko Floodplain Operations Plans and a Monitoring, Evaluation, Reporting and Improvement (MERI) framework.

Fish are a key ecological attribute of the Katarapko 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, a total of 9,186 fish, from 13 species (9 native and 4 non-native) were captured within the Katarapko Anabranch and the adjacent River Murray main channel. The most abundant native species were bony herring (49.8%), Australian smelt (22.1%), unspecked hardyhead (13.1%) and Murray rainbowfish (5%), whilst the remaining native species consisted of 1.1% of the total catch. Non-native species collectively comprised 9.3% of the total catch. Two species of conservation significance were sampled, namely Murray cod (*vulnerable* under the *EPBC Act 1999*) and freshwater catfish (*protected* under the South Australian *Fisheries Management Act 2007*).

The fish assemblage in 2021 was similar to that sampled during previous years characterised by within-channel flows (2009–2010 and 2015), 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, golden perch and Murray rainbowfish were positively associated with river main channel habitats.

The majority of fish-related Ecological Targets (six of seven) were partially or fully achieved in 2021. Species diversity exceeded the reference value, whilst extent indices were met for nine of eleven target species. The abundance of Murray cod exhibited a positive trajectory relative to preceding sampling, and the recruitment target was met for both recruitment to YOY and to the adult population. The abundance of freshwater catfish, however, did not exhibit a positive trajectory relative to preceding sampling. Recruitment was evident for all common small- and medium-bodied species, whilst the recruitment target for common carp and goldfish was also met, with recruitment index below the reference value.

The results highlight potential early positive responses (e.g. improvement in Murray cod metrics) to improvements to connectivity and hydrodynamics in the Katarapko Anabranch following RRP and SARFIIP. Continued monitoring will provide greater insight and inform adaptive management of the system.

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

1. INTRODUCTION

1.1. Background

The Katarapko Anabranch and Floodplain system is one of three large (>9,000 ha) anabranch systems that bypass Lock and Weir structures on the main River channel in the lower River Murray, South Australia (together with Chowilla and Pike). The Katarapko Anabranch bypasses Lock and Weir No. 4 generating a head differential of ~3.5 m between the main inlet through Eckert Creek (Bank J) and the confluence of Katarapko Creek and the River Murray. As such, Katarapko comprises hydraulically diverse aquatic habitats including permanent fast-flowing and slow-flowing creeks, as well as wetlands and backwaters. Permanent lotic (flowing water) habitats are now largely absent under regulated conditions in the lower River Murray main channel (Bice et al. 2017). Subsequently, the Katarapko Anabranch system supports a diversity of native aquatic biota including fishes of conservation concern (e.g. Murray cod (*Maccullochella peelii*), freshwater catfish (*Tandanus tandanus*), silver perch (*Bidyanus bidyanus*)) (Bice et al. 2015). For this reason, the site was considered a *Demonstration Reach* ('Katfish Reach') under the Murray-Darling Basin Authority's *Native Fish Strategy.* 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*) and chenopod shrublands, herblands (incl. flood responsive ephemeral communities).

Whilst the Katarapko Anabranch system supports significant aquatic and floodplain communities it was considered to be in a degraded state due to the impacts of river regulation. 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 Katarapko system with the aim of restoring floodplain condition and function (DEWNR 2017). The program involved a range of on-ground works including: the upgrade, installation and replacement of banks and flow regulating structures, construction of fishways, 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 Katarapko that includes: 1) improved connectivity and extension of lotic habitats under regulated 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

Katarapko Floodplain Operations Plans and a Monitoring, Evaluation, Reporting and Improvement (MERI) framework.

Fish are a key ecological attribute of the Katarapko Anabranch system that are likely to be influenced by system management. As such, within the Operations Plan, three primary Ecological Objectives were developed for native fish, namely to:

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*).

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. Recruitment 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 Katarapko Anabranch system in autumn 2020, 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 2009–2020; 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 Katarapko Anabranch and adjacent River Murray on seven occasions, namely: 2009, 2010, 2011, 2012, 2013, 2015 and 2021 (Leigh *et al.* 2009, 2012, Wilson *et al.* 2012, 2013, Bice *et al.* 2015) (Table 1 and Figure 1). In most years, the number of sites ranged from 13–15, but only four sites were sampled in 2012 and 2013 due to different objectives of monitoring in those years (Wilson *et al.* 2012, 2013) (Table 1 and Figure 1). These years were excluded from statistical analysis of fish assemblage structures and mesohabitat associations. In 2021, a total of 15 sites were sampled from 12–21 April, representing the range of permanent aquatic mesohabitats present within the Katarapko Anabranch (i.e. fast-flowing anabranches, slow-flowing anabranches, backwaters and the River Murray main channel). Fast-flowing habitats were characterised as having mean cross-sectional velocities >0.18 $m.s^{-1}$, slow-flowing habitats 0.05–0.18 $m.s^{-1}$, backwaters <0.05 $m.s^{-1}$ and River Murray main channel <0.1 $m.s^{-1}$ (Zampatti *et al.* 2008). Sites in the River Murray are classified as 'main channel' mesohabitats.

Table 1. Site number, site name, year sampled (indicated by *) and flow type (1 = fast flowing anabranches, 2 = slow flowing anabranches, 3 = backwaters, 4 = River Murray main channel) for sites sampled at Katarapko between 2009–2021 and used to calculate all indices and reference values for future condition monitoring reporting.

Site no.	Site name	2009	2010	2011	2012	2013	2015	2021	Flow type
1	Eckert creek d/s weir	*	*				*	*	1
2	Eckert creek Wide Water	*	*	*			*	*	3
3	Eckert creek u/s log crossing	*	*	*	*	*	*	*	2
4	Eckert creek d/s log crossing	*	*	*	*	*	*	*	1
5	The Splash	*	*	*			*	*	3
6	Katarapko d/s weir	*	*	*			*	*	2
7	Katarapko Creek u/s (Katarapko Isl.)	*	*	*				*	2
9	Katarapko lower	*	*	*			*	*	2
10	Murray 3-4km d/s Lock 4	*	*	*			*	*	4
12	Murray d/s Katarapko junction	*	*	*			*	*	4
13	Eckert Creek below ford	*	*	*			*	*	2
14	Murray u/s Lock 4	*	*	*			*	*	4
20	Eckert widewater u/s^		*		*	*		*	3
22	Eckert Creek d/s Eckert weir^		*		*	*		*	1
24	Eckert Creek Southern arm							*	1

^previous fyke netting sites, however, a part of electrofishing sampling in 2012, 2013 and 2021

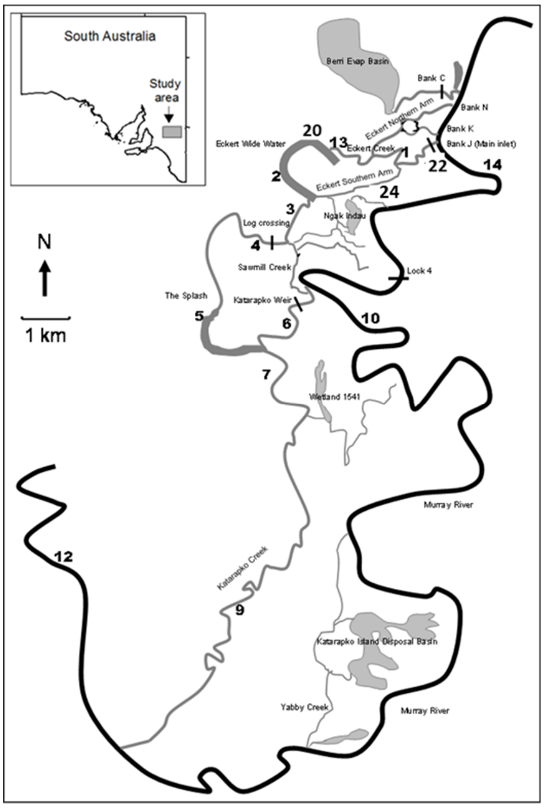

Figure 1. The 15 sites sampled between 2009–2021 as a part of condition monitoring in the Katarapko Anabranch system.

2.2. Data collection

In 2021, fish assemblages were sampled from 12–21 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 (found only in one group but in low numbers) or widespread (found in more than one group in similar numbers).

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 on sampling data from 2009–2015. This time period incorporates a range of hydrological conditions likely to be experienced by fishes within Katarapko, including drought, within channel flow pulses 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 for each mesohabitat 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 Katarapko 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 Katarapko 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	0.71	0.85
Dwarf flat-headed gudgeon	1	0	0
Flat-headed gudgeon	3	0.38	0.45
Freshwater catfish	3	0.50	0.45
Golden perch	5	0.92	0.85
Murray cod	3	0	0
Murray rainbowfish	5	0.92	0.85
Silver perch	3	0.38	0.45
Spangled perch	0	0.08	0.10
Unspecked hardyhead	5	0.92	0.85
	Predicted no. species		10
	Expected no. species		6.55
Slow-flowing			
Australian smelt	5	0.97	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.60	0.45
Dwarf flat-headed gudgeon	1	0.02	0.1
Flat-headed gudgeon	3	0.13	0.1
Freshwater catfish	3	0.41	0.45
Golden perch	5	0.92	0.85
Murray cod	3	0.06	0.1
Murray rainbowfish	5	1	0.85
Silver perch	3	0.31	0.45
Spangled perch	0	0	0
Unspecked hardyhead	5	1	0.85
	Predicted no. species		11
	Expected no. species		5.9
Main channel			
Australian smelt	5	1	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.79	0.85
Dwarf flat-headed gudgeon	1	0.06	0.10
Flat-headed gudgeon	3	0.31	0.45
Freshwater catfish	3	0.31	0.45
Golden perch	5	1	0.85
Murray cod	3	0.48	0.45
Murray rainbowfish	5	1	0.85
Silver perch	3	0.52	0.45
Spangled perch	0	0.13	0.1
Unspecked hardyhead	5	1	0.85
	Predicted no. species		12
	Expected no. species		7.1
Backwater			
Australian smelt	5	0.94	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.44	0.45
Dwarf flat-headed gudgeon	1	0	0
Flat-headed gudgeon	3	0.25	0.45
Freshwater catfish	3	0	0
Golden perch	5	0.36	0.45
Murray cod	3	0.17	0.1
Murray rainbowfish	5	0.53	0.45
Silver perch	3	0	0
Spangled perch	0	0	0
Unspecked hardyhead	5	0.83	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* = Study 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 and freshwater catfish do not have an expectedness ratio in backwater mesohabitats, and dwarf flat-headed gudgeon (*Philypnodon macrostomus*) do not have an expectedness ratio in fast flowing mesohabitats, as they have not been sampled in these mesohabitat types in the Katarapko anabranch during sampling events to date.

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 Katarapko 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 Katarapko anabranch (2009-2015). As such, the reference value for Murray cod = 0.09 fish.minute electrofishing^{-1}.site^{-1} and freshwater catfish = 0.25 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. For these species, fish comprising the young-of-year (YOY) cohort in autumn (generally coinciding with condition monitoring surveys) will contribute to the reproductively mature adult population the following spawning season. Abundance is also 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 more accurate estimates 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 2009–2015, 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 2009–2015.),
- Reference value (RV) = mean((X_{2009}*$r_{standard}$) + (X_{2010}*$r_{standard}$) +…….. (X_{2015}*$r_{standard}$))

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 in two ways: 1) the proportion of YOY individuals; and 2) the proportion of fish that have reached sexual maturity. Recruitment to YOY, as indicated by the proportion of fish <200 mm TL, provides a useful measure of survival of recently spawned fish. The proportion of fish ranging 400–600 mm TL corresponds to individuals approximately 3–6 years of age in the lower River Murray (Zampatti et al. 2014) and the age at sexual maturity (Rowland 1998), thus representing recruitment to the adult population.

The reference value is the mean proportion of the population comprised of fish YOY <200 mm TL and 400–600 mm TL over the period 2009–2015. These values are 17% and 6% for fish <200 mm TL and 400–600 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 an appropriate method for discerning YOY individuals from autumn sampling. Length, however, is not a surrogate for more accurate estimates 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 surveyed from 2009–2015. 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_{2010}*$r_{standard}$) +…….. (X_{2015}*$r_{standard}$))

$r_{standard}$ 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 Katarapko Anabranch from 2009–2015.

Species	Length YOY	$r_{standard}$	*RV*
Common carp	<150 mm FL	40%	5.01
Goldfish	<100 mm FL	62%	3.16

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 2009. Following an extended period of low discharge from 1997–2010. Sampling in 2009 and 2010, occurred toward the end of this period during low within channel flows of ~3000 and ~6700 ML.day^{-1}, respectively. 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}. Discharge from 2015–2021, has been 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 in-channel pulses of 15,000–18,000 ML.day^{-1} in December 2017, October 2019 and November 2020. During sampling in autumn 2021, daily mean discharge was ~5,350 ML.day^{-1}.

Prior to completion of the Bank J Regulator on Eckerts Creek – the primary influent creek to the Katarapko Anabranch – under normal operating conditions and within channel flows in the River Murray (i.e. <15,000 ML.day^{-1}), discharge through Eckerts Creek and the upper part of the Katarapko system was typically ~300 ML.day^{-1}. The upgrade to this structure, and the Log Crossing further downstream, increased capacity for discharge through the system. The Bank J Regulator can now discharge 200–600 ML.day^{-1} under normal upstream pool level, and up to ~1,300 ML.day^{-1} during weir pool raising and managed inundation events. Prior to sampling in 2021, the Bank J Regulator was discharging ~400 ML.day^{-1} when under normal operating conditions, and in addition, from 8 September–24 December 2020, newly constructed floodplain infrastructure was operated in the inaugural managed inundation at the Katarapko system (The Splash Regulator maximum height of 12.84 m AHD and 2.84 m above normal pool level).

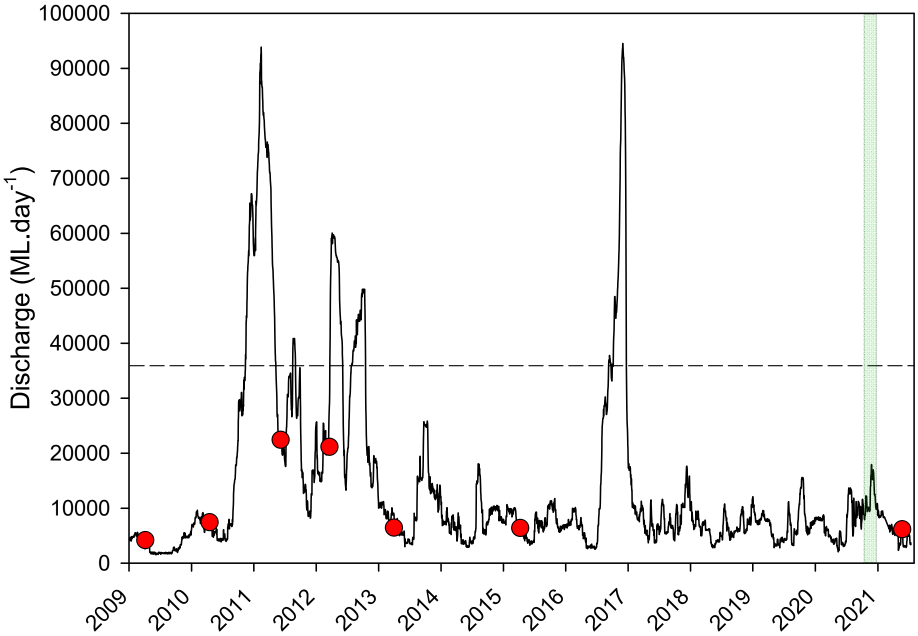

Figure 2. Mean daily flow (ML.d^{-1}) in the River Murray at the South Australian Border (Site A42610010) January 2009–June 2021 (DEW, Water Data SA). Red circles indicate sampling events, the dashed line represents approximate bankfull discharge at the Katarapko anabranch (~35,000 ML.d^{-1}) and the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

3.2. Catch summary

In 2021, a total of 9,186 fish were captured from 13 species (9 native and 4 non-native; Table 6). The most abundant native species were bony herring (49.8%), Australian smelt (22.1%), unspecked hardyhead (13.1%) and Murray rainbowfish (5%), whilst the remaining native species consisted of 1.1% of the total catch (Table 6). Non-native common carp, goldfish, eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*) collectively comprised 9.3% of the total catch (Table 6). Two species of conservation significance were collected. These were, Murray cod, which is listed as 'vulnerable' under the *EPBC Act 1999 and* freshwater catfish, which is protected under the South Australian *Fisheries Management Act 2007.*

In the seven years surveyed from 2009–2021, a total of 63,161 fish from 16 species (12 native and 4 non-native) were captured over the seven 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 Katarapko and the adjacent River Murray from 2009–2021.

Species	2009	2010	2011	2012	2013	2015	2021	Grand Total
Golden perch	69	116	558	157	84	78	39	1101
(Macquaria ambigua)	4.9	6.4	37.2	26.2	14.0	6.5	2.8	
Murray cod	7	2	1	-	-	3	8	21
(Maccullochella peelii)	0.5	0.1	0.1			0.3	0.6	
Silver perch	5	16	26	4	2	5	-	58
(Bidyanus bidyanus)	0.4	0.9	1.7	0.7	0.3	0.4		
Freshwater catfish	2	9	4	12	13	4	2	46
(Tandanus tandanus)	0.1	0.5	0.3	2.0	2.2	0.3	0.1	
Bony herring	1708	8825	1259	78	1292	4470	4582	22214
(Nematalosa erebi)	122.0	490.3	83.9	13.0	215.3	372.5	327.3	
Australian smelt	110	679	412	248	60	394	2029	3932
(Retropinna semoni)	7.9	37.7	27.5	41.3	10.0	32.8	144.9	
Murray rainbowfish	170	244	1935	50	198	536	462	3595
(Melantaenia fluviatilis)	12.1	13.6	129.0	8.3	33.0	44.7	33.0	
Flat-headed gudgeon	23	8	20	5	-	3	10	69
(Philypnodon grandiceps)	1.6	0.4	1.3	0.8		0.3	0.7	
Dwarf flat-headed gudgeon	1	-	1	-	-	-	-	2
(Philynodon macrostomus)	0.1		0.1					
Unspecked hardyhead	876	1421	797	3	91	1828	1201	6217
(Craterocephalus fulvus)	62.6	78.9	53.1	0.5	15.2	152.3	85.8	
Carp gudgeon spp.	45	76	84	-	10	25	41	281
(Hypseleotris spp.)	3.2	4.2	5.6		1.7	2.1	2.9	
Spangled perch	-	-	4	-	-	1	-	5
(Leipotherapon unicolour)			0.3			0.1		
Common carp*	200	287	16365	442	469	371	738	18872
(Cyprinus carpio)	14.3	15.9	1091.0	73.7	78.2	30.9	52.7	
Gambusia*	52	54	278	-	5	61	39	489
(Gambusia holbrooki)	3.7	3.0	18.5		0.8	5.1	2.8	
Goldfish*	319	458	4621	302	272	240	33	6245
(Carassius auratus)	22.8	25.4	308.1	50.3	45.3	20.0	2.4	
Redfin perch*	1	1	1	-	6	3	2	14
(Perca fluviatilis)	0.1	0.1	0.1		1.0	0.3	0.1	
Total species	**15**	**14**	**16**	**10**	**12**	**15**	**13**	**16**
Total number of sites	**14**	**18**	**15**	**6**	**6**	**12**	**15**	
Total number of fish	**3,588**	**12,196**	**26,366**	**1,301**	**2502**	**8022**	**9186**	**63161**
Standardised total abundance	**256.3**	**677.6**	**1757.7**	**216.8**	**417.0**	**668.5**	**656.1**	

3.3. Temporal variation in fish abundance

Between 2009 and 2021, annual relative abundance of fish (all species combined) varied significantly among years (Figure 4; *Pseudo-*$F_{6, 80}$ = 13.735, $p < 0.001$). Pairwise comparisons (B-Y corrected α = 0.014) indicated abundance in 2011 was significantly greater than all other years, whilst abundance in 2009 was significantly less than in 2010, 2011, 2015 and 2021, 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 most years, with the exception of 2011 and 2012 (Figure 4).

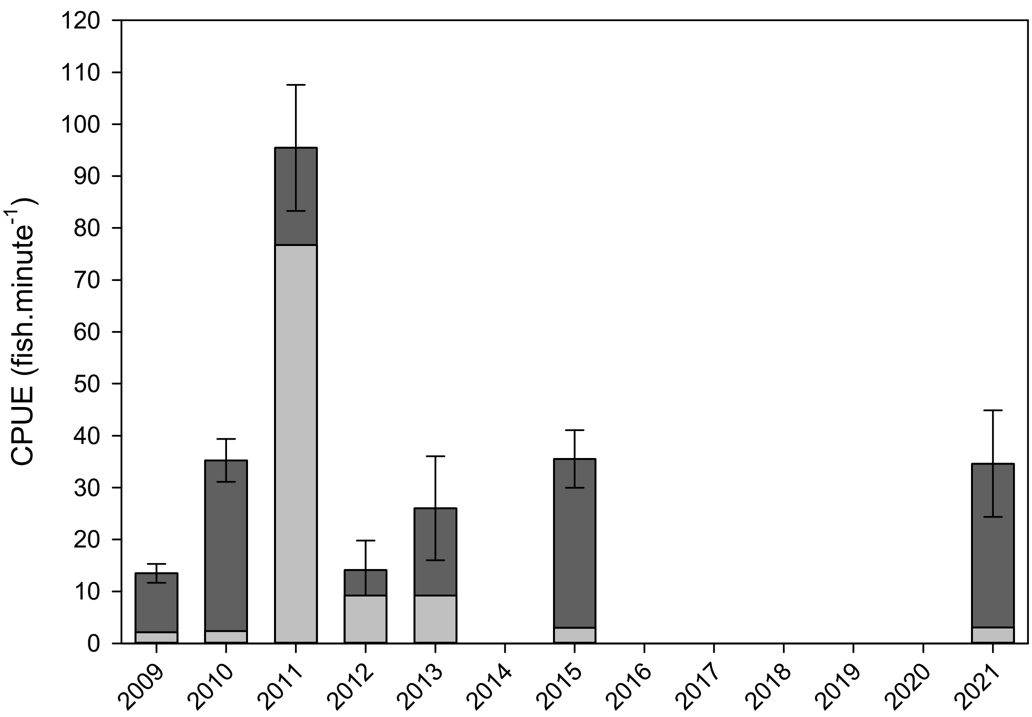

Figure 3. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of fish (all species combined) collected during standardised boat electrofishing surveys from 2009–2021 in the Katarapko anabranch system and adjacent River Murray. Dark grey = proportion native species, light grey = proportion of non-native species.

3.4. Spatio-temporal differences in fish assemblage structure

Two-factor PERMANOVA, performed on data from sampling years 2009, 2010, 2011, 2015 and 2021, 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 for years 2009, 2010, 2011, 2015 and 2021. Significant *P* values are highlighted in bold.

Factor	***df***	***Pseudo-F***	***P***
Year	4, 162	7.3708	**0.001**
Mesohabitat	3, 162	4.7803	**0.001**
Year x mesohabitat	12, 162	1.0572	0.375

Pairwise comparisons revealed significant differences (B-Y corrected α = 0.02) in fish assemblages among mesohabitats for all comparisons (Table 7). In addition, cluster analysis and MDS indicated two distinct groupings of fish assemblages by sampling years (Figure 5). Namely, assemblages sampled in 2009, 2010, 2015 and 2021 and those sampled in 2011 (Figure 5). A similar pattern of temporal variability was observed for fish assemblages among all mesohabitats (Figure 6a –6d).

Table 8. PERMANOVA pair-wise comparisons between fish assemblages among different mesohabitats in the Katarapko anabranch for years 2009, 2010, 2011, 2015 and 2021. Significant values are highlighted in bold (B-Y corrected α = 0.02).

Pairwise comparison		***t***	***p* value**
Mesohabitat	**Mesohabitat**		
Fast	Backwater	2.331	**0.002**
Fast	Slow	2.1999	**0.002**
Fast	River	1.8374	**0.007**
Backwater	Slow	2.1179	**0.002**
Backwater	River	2.9651	**0.001**
Slow	River	1.7968	**0.015**

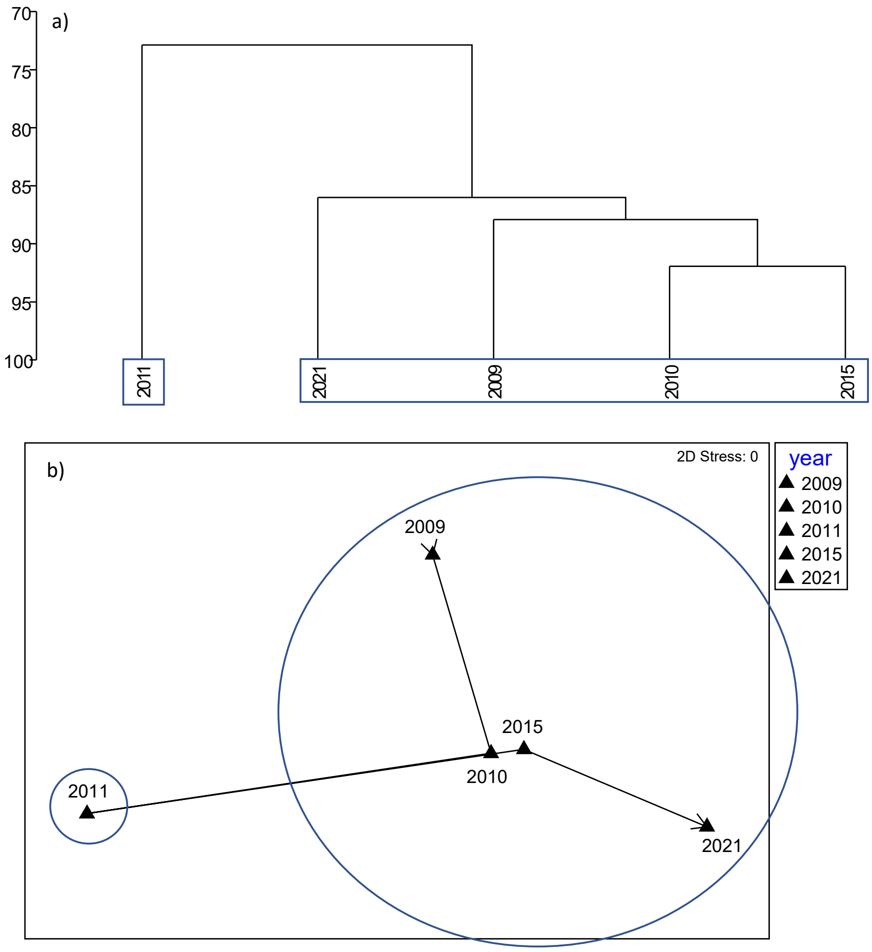

Figure 4. a) Dendrogram indicating fish assemblage clusters for years 2009, 2010, 2011, 2015 and 2021; and b) Non-metric multi-dimensional scaling (MDS) plot of the same data.

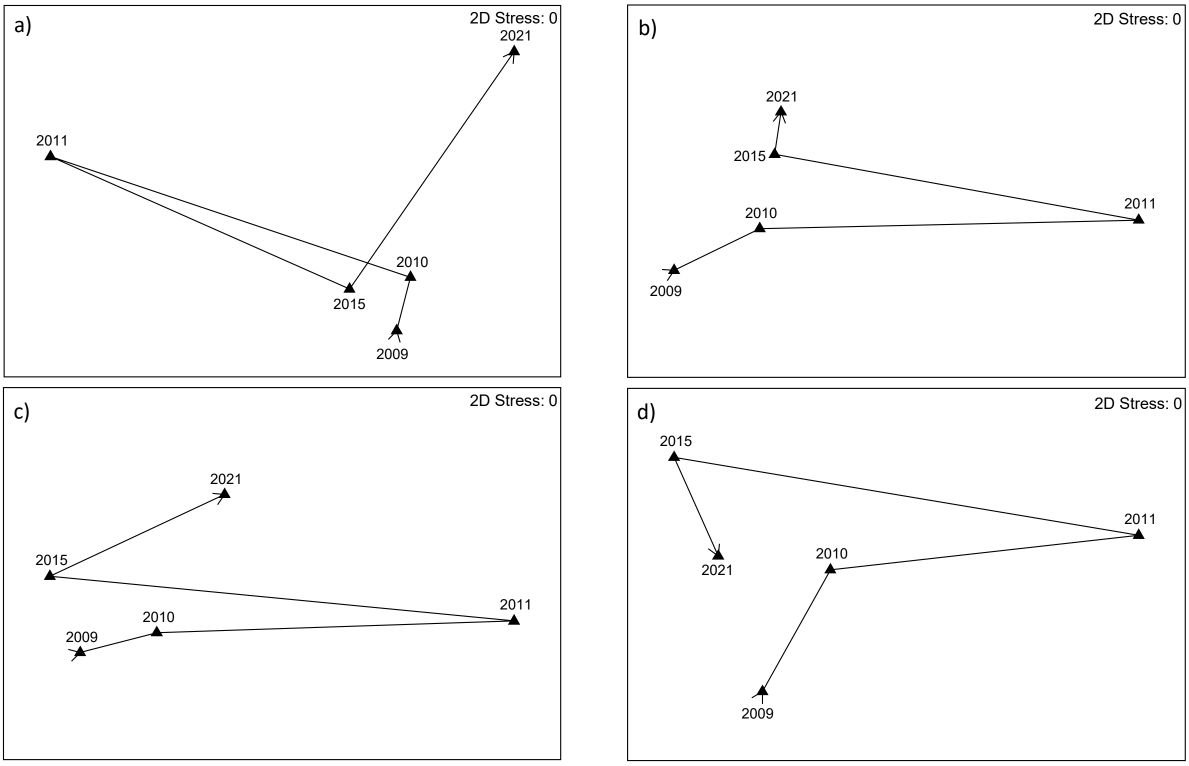

Figure 5. Non-metric multi-dimensional scaling (MDS) plots of a) fast-flowing, b) slow-flowing, c) backwater and d) river mesohabitats sampled in 2009, 2010, 2011, 2015 and 2021 (sites averaged).

Indicator species analysis comparing mesohabitat types suggested fast-flowing mesohabitats were characterised by unspecked hardyhead, eastern gambusia, Australian smelt, redfin perch, bony herring and carp gudgeon complex (*Hypseleotris* spp.) (Table 9). Main river channel mesohabitats were characterised by Murray cod, golden perch and Murray rainbowfish, whilst no species were significantly associated with slow-flowing or backwater mesohabitats. Indicator species analysis comparing groupings of sampling years suggested fish assemblages from 2011 were characterised by common carp, goldfish, gambusia, golden perch and Murray rainbowfish (Table 10), whilst the collective assemblages from sampling in 2009, 2010, 2015 and 2021 were characterised by the small-to-medium-bodied species bony herring and Australian smelt (Table 10).

Table 9. Indicator species analysis comparing the relative abundance of fish in the four aquatic mesohabitats from 2009, 2010, 2011, 2015 and 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**
Unspecked hardyhead	Fast	0.0488
Gambusia	Fast	0.0008
Australian smelt	Fast	0.0082
Redfin perch	Fast	0.0048
Bony Herring	Fast	0.0406
Carp gudgeon spp.	Fast	0.0224
Murray cod	River	0.0260
Murray rainbowfish	River	0.0016
Golden perch	River	0.0024

Table 10. Indicator species analysis comparing the relative abundance of fish amongst sampling years 2009, 2010, 2011, 2015 and 2021. (Year group 1 = 2011; Year group 2 = 2009, 2010, 2015 and 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	40.0	0.0002
Goldfish	1	37.8	0.0002
Gambusia	1	32.4	0.0002
Golden perch	1	33.8	0.0002
Murray rainbowfish	1	31.2	0.0002
Bony Herring	2	24.8	0.0032
Australian smelt	2	26.8	0.0042

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, except for backwater mesohabitats in 2012 (Figure 7a). The mean of mesohabitat diversity indices for each year was calculated to provide an overall site diversity score (Figure 7b). In all years, the site diversity score was greater than or equivalent to the reference value, with 2011 having the highest diversity score out of all sampling years.

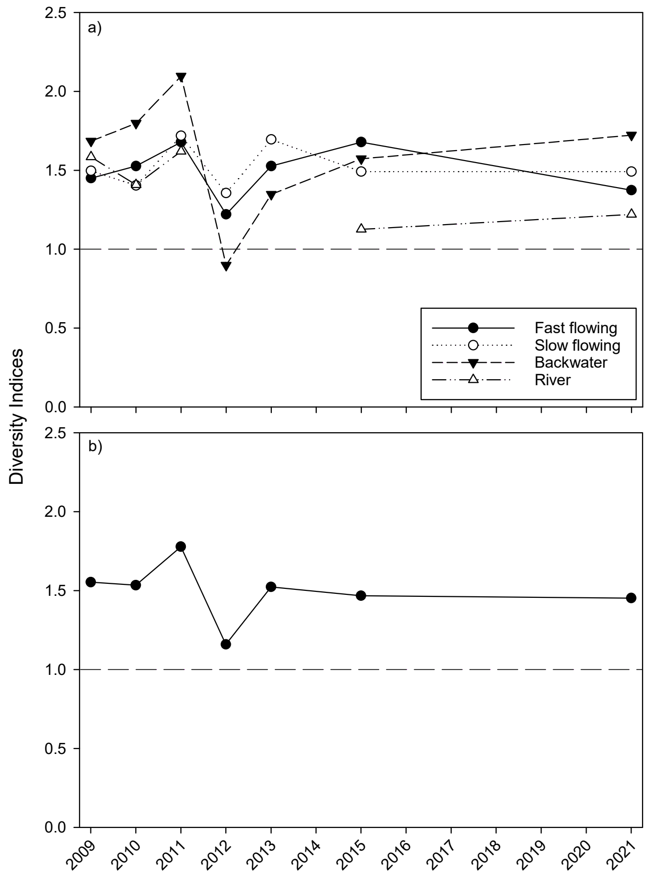

Figure 6. Diversity indices for a) fast-flowing, slow-flowing, backwater and main River channel mesohabitats and b) the calculated Site Diversity Index (*DI*), at the Katarapko anabranch from 2009–2021.

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

For large-bodied native fishes, the extent index varied among species (Figure 7a). Golden perch distribution was relatively stable across years and generally above the reference value. The extent index for Murray cod has been relatively stable, and only below the reference in 2009 and 2010. Silver perch, however, only met the reference value in 2010 and 2011, and were absent in 2021. Similarly, freshwater catfish had the greatest extent in 2009 and 2010, albeit below the reference, and extent was decreased in 2015 and 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 high variability for dwarf flat-headed gudgeon (Figure 7b). Nonetheless, all species met the reference value in 2021, apart from dwarf flat-headed gudgeon which were not sampled in this year (Figure 7b).

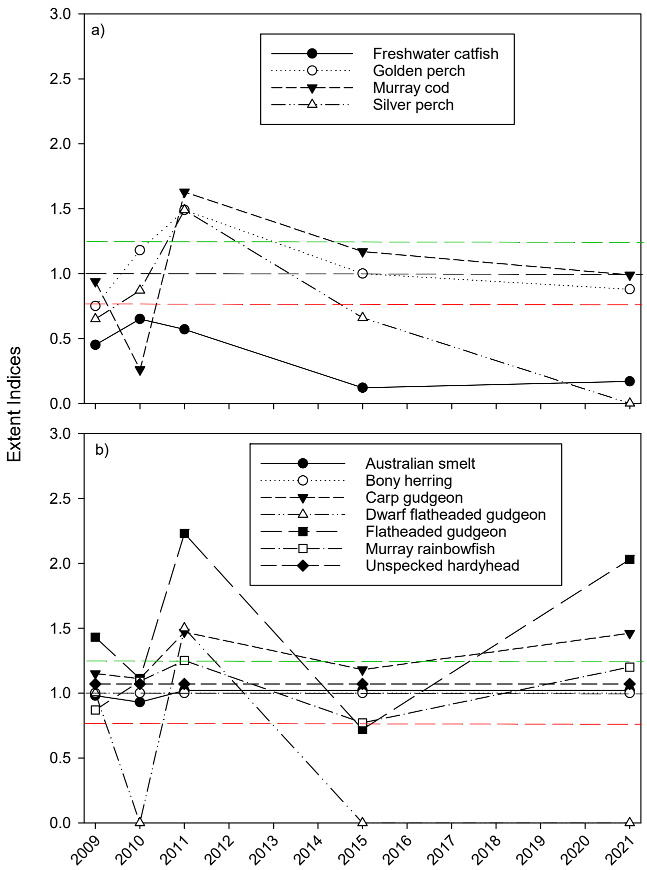

Figure 7. Extent Index (*EI*) scores for a) large-bodied native species and b) small- to medium-bodied native species at the Katarapko anabranch from 2009–2021. Black dashed line represents extent equal to the reference, green dashed line extent 25% greater than reference and red dashed line extent 25% 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 (Figure 8a). For Murray cod, the reference value was exceeded in 2009, 2015 and 2021, and abundance was on a positive trajectory relative to preceding years. Freshwater catfish abundance met the reference value in 2010 and 2011, but abundance has since declined and been below the reference in 2015 and 2021 (Figure 8b).

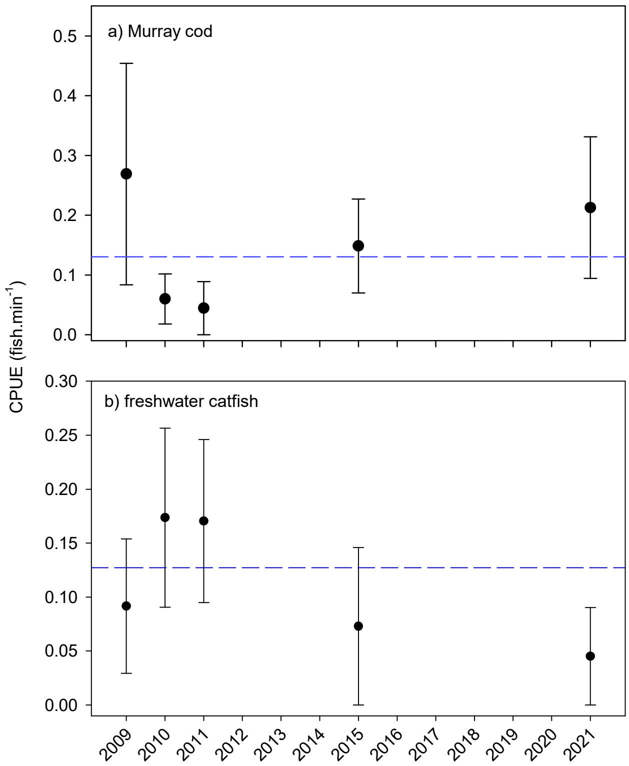

Figure 8. Mean abundance (CPUE; fish.minute electrofishing^{-1}.site^{-1}) ±SE for a) Murray cod and b) freshwater catfish at the Katarapko anabranch between 2009–2021. The blue dashed line represents mean abundance equal to the reference value.

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 most species, recruitment was limited after high flow in 2011. In the past two rounds of monitoring in 2015 and 2021, recruitment indices have well exceeded the reference value for all species.

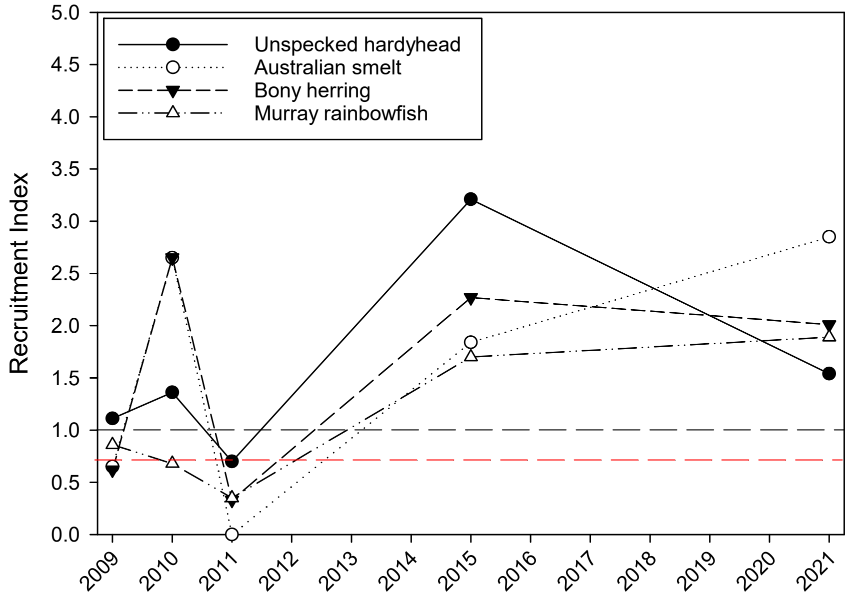

Figure 9. Recruitment Index (*RI*) values for unspecked hardyhead, Murray Rainbowfish, Australian smelt and bony herring from 2009–2021. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

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 recruitment to the reproductive adult population was detected in 2009 and 2021, but not in other years (Figure 10). Alternatively, for YOY Murray cod (<200 mm TL), recruitment was greater than the reference value in 2010, 2015 and 2021 and absent in 2009 and 2011 (Figure 10). The year 2021, is the only year when recruitment to YOY and the adult population have both been detected.

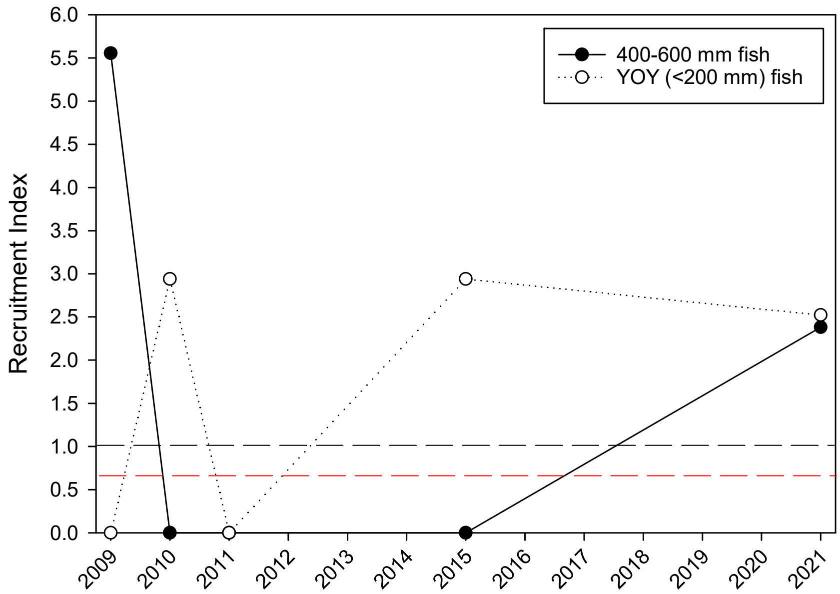

Figure 10. Recruitment Index (*RI*) values for Murray cod ranging 400–600 mm TL (black circles) and YOY (<200 mm TL) Murray cod (open circles) from 2009–2021. Dashed0 black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

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 followed the same patten, characterised by temporal variability, albeit with some recruitment to YOY evident most years (Figure 11). For both species, recruitment was above the reference in 2011, but not in other years. Relative to previous sampling years, 2021 was characterised by moderate recruitment to YOY for common carp, albeit below the reference value, and low recruitment of goldfish.

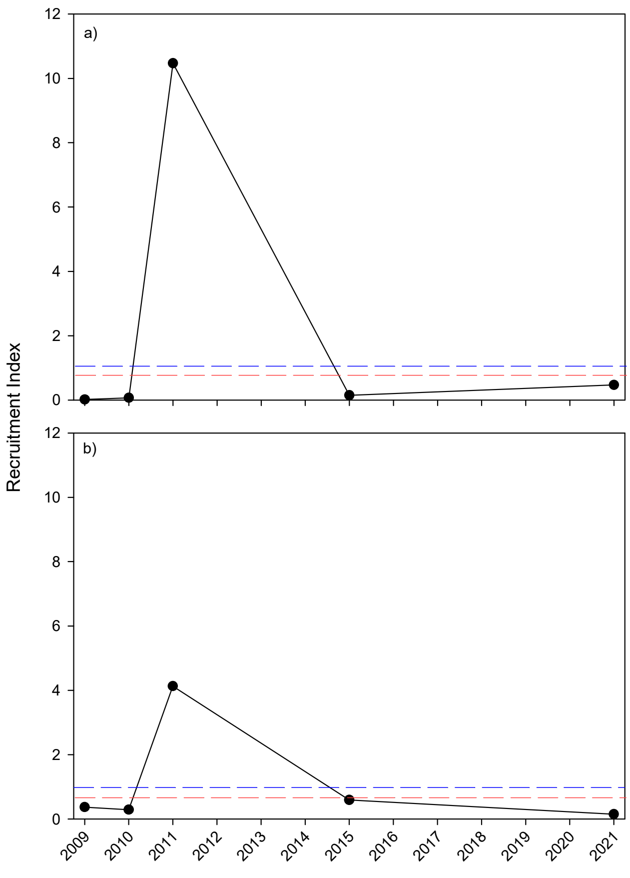

Figure 11. Summary of Recruitment Index (*RI*) values for a) common carp and b) goldfish at the Katarapko anabranch from 2009–2021. Dashed blue line = reference value, dashed red line = 75% of the reference value.

Summary

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

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

Primary Ecological Objects 1, 2 & 3 (see page 4 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 to YOY and the adult population was evident
		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 and goldfish was below the reference

Not achieved Partially achieved Achieved

4. DISCUSSION

The Katarapko 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 Regulators at Bank J and the Log Crossing to enhance capacity to vary inflow/outflow volumes; the construction of new regulators at Sawmill Creek and the Splash, 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 Katarapko 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, 13 fish species were sampled from 15 sites in the Katarapko Anabranch and adjacent River Murray main channel. The fish assemblage consisted of 9 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 2010 and 2015. Each of these years have been characterised by within-channel flows and minor spring flow pulses of varying magnitude (11,000–18,000 $ML.day^{-1}$). Assemblages in 2021 also differed from 2011 when sampling immediately followed elevated flow and flooding from spring 2010–autumn 2011. 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 2011.

Patterns of elevated abundance of small- and medium-bodied generalist species including Australian smelt and bony herring 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 Katarapko 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) favors 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 broad-scale 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 Katarapko in 2021, ~90% were adults >350 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 cod, golden perch and Murray rainbowfish characterised River Murray mesohabitats, while unspecked hardyhead, Australian smelt, carp gudgeon and eastern gambusia characterised fast flowing mesohabitats. Similar associations with river habitats have been found previously at the Katarapko and Pike anabranches (Bice et al. 2015, 2016). The association of several small-bodied species with fast flowing mesohabitats was unexpected. This may result from the fact that changes to system hydrology to promote lotic habitats following interventions under RRP and SARFIIP did not commence till 2020. Furthermore, fast flowing creeks are typically not characterised by uniform high flow velocities, but rather are hydrodynamically diverse, and commonly support high abundances of a range of species, not just iconic large-bodied native fishes (Fredberg et al. 2019).

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. 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 0–1 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 this species.

In 2021 and the preceding sampling event in 2015, the extent index for Murray cod was greater than the reference value, and generally higher than preceding sampling events. This included the first record of an individual within Eckerts Creek since sampling began in 2009. The same positive trajectory in extent index was also observed at the Chowilla over the same period (Fredberg et al. 2021), while increases in abundance and frequency of occurrence were also noted in the lower River Murray main channel (Ye et al. 2021). Positive responses at Katarapko likely reflect broad scale patterns in the lower River Murray and potentially improved hydrology and hydraulics within the Katarapko system.

Freshwater catfish and silver perch extent was below the reference value in 2021. Nonetheless, as for dwarf flat-headed gudgeon, freshwater catfish (n = 2–13) and silver perch (n = 0–26) are typically only sampled in low numbers and therefore caution should be exercised in interpreting trends in distribution. Nonetheless, in time, improved extent is expected following the promotion of lotic habitats at the site since 2020.

Abundance of Murray cod and freshwater catfish

In 2021 at Katarapko, the standardised abundance of Murray cod was above the reference value and on a positive trajectory from the preceding two sampling rounds (2015 and 2011). Similar increases in abundance have been noted at the Pike Anabranch and, to some extent, in the main channel of the lower River Murray (Ye et al. 2021; SARDI Unpublished Data). For the Katarapko 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; and natural recruitment.

In 2021, the abundance of freshwater catfish was below the reference value and exhibited a negative trajectory from 2015. This pattern was also evident at the Chowilla and Pike anabranches (Fredberg et al. 2021; SARDI Unpublished Data).

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 temporally variable but exhibited a trend similar to the extent index, with the reference value being met in the past two sampling rounds in 2015 and 2021. Additionally, the index for recruitment to the adult population also exceeded the reference value in 2021. This is the first evidence of recruitment to the adult population since 2009, and the first time both recruitment indices have been met in the same year. Parallel trajectories for recruitment to YOY and adults, and extent, are positive signs of improved condition of the Murray cod population at Katarapko.

Recruitment indices for the small-bodied Murray rainbowfish, Australian smelt and unspecked hardyhead, and the medium-bodied species bony herring indicate recruitment was variable, but generally present in all years. Limited recruitment was evident in 2011–2013, which coincided with a period of high flow, and two years (2012 and 2013) when sampling was limited. 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), and indeed, appear to be enhanced during years of low flow.

Recruitment of non-native species

The greatest level of recruitment of YOY common carp and goldfish in Katarapko Anabranch was observed in autumn 2011 following extensive and prolonged natural flooding. Recruitment in 2021 was high relative to several previous years of sampling, but was below the reference value, despite the inaugural managed floodplain inundation occurring in spring-summer 2020. These managed inundation events are commonly associated with enhanced recruitment of common carp (Bice and Zampatti 2011). Nonetheless, limited recruitment response to this event resulted in the target being met.

5. CONCLUSION

Monitoring of fish assemblages at the Katarapko Anabranch in 2021 indicated that the majority of fish-related Ecological Targets (six 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 Katarapko in line with the approach at Pike and Chowilla. The similarity in management of the Katarapko, Pike and Chowilla anabranches, and approaches to monitoring and reporting on fish condition monitoring, presents an opportunity better integrate understanding and management of these critical anabranch habitats across the region.

5.1. Future research needs

Monitoring at the Katarapko anabranch across 2009–2021 has provided valuable information on the ecology of freshwater fish at Katarapko 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 Katarapko anabranch and more broadly.

Specific research questions in:

- Investigating factors influencing recruitment variability of Murray cod at the Katarapko anabranch.
- The influence of site management (e.g. regulator operation) on recruitment and abundance of common carp at Katarapko 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 Katarapko 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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