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Chowilla Icon Site
Fish Assemblage Condition Monitoring 2021

J. Fredberg, C. M. Bice and B. P. Zampatti

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

The Chowilla Anabranch and Floodplain system is the largest remaining area of undeveloped floodplain habitat in the lower River Murray. Chowilla consists of a range of aquatic habitats that are now rare in the region, including permanently flowing creeks, and these habitats support a diverse native fish community. The Chowilla Floodplain, however, has become increasingly degraded as a consequence of changes to the natural flow regime, grazing and an extended period (2001–2010) of low flows in the Murray-Darling Basin. To 'enhance and restore' the environmental values of the Chowilla Floodplain, an Asset Environmental Management Plan was developed as part of the Chowilla Integrated Natural Resource Management Project. Subsequently, a Chowilla Floodplain Environmental Water Management Plan (MDBA 2012) has been developed with refined ecological objectives as follows:

- Ecological Objective 10: Maintain or increase the diversity and extent of distribution of native fish species.
- Ecological Objective 11: Maintain successful recruitment of small- and large-bodied native fish.

To assist with monitoring of Ecological Objectives 10 and 11, quantitative fish surveys have been undertaken annually in the Chowilla system since 2005. Sites have been selected to represent all aquatic mesohabitats present within the region (i.e. fast-flowing and slow-flowing creeks, backwaters and the River Murray main channel). Since 2014, additional targeted surveys have been conducted for Murray cod (*Maccullochella peelii*).

In 2021, a total of 27,866 fish from 14 species were sampled from 21 sites within Chowilla and the adjacent River Murray main channel. The fish assemblage consisted of 10 native and 4 non-native species, with bony herring (79.7% of total catch) (*Nematalosa erebi*), Australian smelt (9.8%) (*Retropinna semoni*), unspecked hardyhead (4.2%) (*Craterocephalus fulvus*) and Murray rainbowfish (*Melanotaenia fluviatilis*) (1.3%) the most abundant native species. Of the non-native species, common carp (1.7%) (*Cyprinus carpio*) and eastern gambusia (1.2%) (*Gambusia holbrooki*) were the most abundant, whilst goldfish (*Carassius auratus*) and redfin perch (*Perca fluviatilis*) collectively comprised 0.95% of the total catch.

The fish assemblage in 2021 was similar to those sampled during previous low flow years (2005–2010, 2015–2016 and 2018–2020), with generally high numbers of small- to medium-bodied native species (e.g. Australian smelt and bony herring) and low abundances of non-native fishes (e.g. common carp and goldfish).

Data from 2005–2021 indicate that Objective 10 and 11 of the Icon Site management plan are being met. Over the 17-year sampling period, species diversity in each mesohabitat and for each year was similar, whilst the extent of most species throughout the available aquatic mesohabitats either increased or was maintained. Most species were widespread throughout the available aquatic mesohabitats, although some species were specific to one or more mesohabitats. The native species Murray cod, golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), Australian smelt and freshwater catfish (*Tandanus tandanus*) characterised fast-flowing mesohabitats and the non-native species, goldfish, characterised backwaters.

Recruitment indices indicate that all small- to medium-bodied native species – Murray rainbowfish, Australian smelt, bony herring and unspecked hardyhead – successfully recruited in 2021. In 2015, 2016, 2018, 2019 and 2020, recruitment of Murray cod to reproductive maturity (400–600 mm TL) was less than the reference value, suggesting a decline in Murray cod recruitment in those years. In 2021, however, recruitment exceeded the reference value, suggesting improved recruitment for this size class. In 2021, substantial recruitment to young-of-year (YOY; <200 mm TL) was also observed, similar to previous years (i.e. 2016, 2018 and 2020).

In 2021, golden perch recruitment to YOY was not evident, likely due to the absence of hydrological conditions required to stimulate spawning. Recruitment of the non-native common carp was also low, again reflective of low flows and an absence of floodplain inundation in 2020/21.

Keywords: Chowilla, diversity, recruitment, flow, native, non-native.

1. INTRODUCTION

The Chowilla Anabranch and Floodplain system (hereafter Chowilla) comprises the largest remaining area of undeveloped floodplain habitat in the lower River Murray. It encompasses a series of anabranching creeks, backwaters, wetlands and terminal lakes that bypass Lock and Weir No. 6 (hereafter Lock 6) on the River Murray. Chowilla is part of the Riverland Ramsar site and listed in the directory of important wetlands in Australia as a Wetland of national importance for nationally threatened species, habitats and communities (Environment Australia 2001). Chowilla is also recognised as an *Icon Site* under the Murray-Darling Basin Authority's (MDBA) *The Living Murray Program* (TLM) (MDBA 2016).

The lower River Murray, downstream of the Darling River junction, is regulated by 10 low level (~3 m high) weirs that have substantially altered the hydrology and hydraulics of the river. The combination of short distances (29–86 km) and low gradients (50 $mm.km^{-1}$) between the weirs, and low regulated flows, has produced a shift from hydrodynamically variable lotic habitats to relatively stable lentic habitats more representative of a series of interconnected lakes (Walker 2006, Bice *et al.* 2017). Due to the ~3 m of head differential created by Lock 6, 20–90% of the River Murray main channel flow is diverted through Chowilla under low flow conditions (i.e. main-channel flow to South Australia <10,000 $ML.d^{-1}$) (Stace and Greenwood 2004). Consequently, Chowilla exhibits a range of permanent lotic (flowing water) habitats in what previously would have been a combination of perennial and ephemeral streams. These lotic habitats that characterise Chowilla, are now rare within the lower River Murray (Bice *et al.* 2017, Mallen-Cooper and Zampatti 2018).

Chowilla supports a wide range of aquatic organisms (O'Malley and Sheldon 1990), including a diverse native fish community (Lloyd 1990; Pierce 1990; Zampatti *et al.* 2011). The floodplain, however, has become increasingly degraded as a consequence of changes to the natural flow regime, grazing and drought (MDBC 2006). In response, and to 'enhance and restore' the environmental values of the Chowilla Floodplain system, the Department for Environment and Water (DEW) developed an Asset Environmental Management Plan (AEMP) as part of the Chowilla Integrated Natural Resource Management Project (DWLBC 2006). Four preliminary management targets were developed for fish:

- Target 10. Maintain the diversity and extent of distribution of native fish species.
- Target 11. Reduce barriers to fish passage.
- Target 12. Maintain successful recruitment of small-bodied native fish every year.
- Target 13. Maintain successful recruitment of large-bodied fish at least once every five years.

Subsequently, the Chowilla Floodplain Environmental Water Management Plan (MDBA 2012) was developed with refined ecological objectives:

- Ecological Objective 10. Maintain or increase the diversity and extent of distribution of native fish species.
- Ecological Objective 11. Maintain successful recruitment of small- and large-bodied native fish.

Annual quantitative (standardised electrofishing) fish surveys have been undertaken at Chowilla since 2005. Data from these surveys are used to investigate spatial and temporal variability in the fish assemblage (i.e. species diversity, distribution and abundance) at Chowilla (Ecological Objective 10) and assess evidence for the recruitment of small- and large-bodied fishes (Ecological Objective 11). This report presents the results of fish *condition* monitoring undertaken in 2021 with reference to results from 2005–2020.

2. METHODS

Fish condition monitoring at Chowilla was initially undertaken in 2005 (Zampatti *et al.* 2008). Eighteen sites were selected, representing the range of permanent aquatic mesohabitats present within Chowilla (i.e. fast-flowing anabranches, slow-flowing anabranches, backwaters and the River Murray main channel) as described by Sheldon and Lloyd (1990). These sites were initially assigned to a mesohabitat category based on visual assessments (Table 1) and were later quantified and, if necessary, revised following the measurement of cross-sectional water velocity profiles in March 2007. 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). Four additional sites in the New South Wales section of Chowilla were added to the monitoring program in 2008 and 2009 (Leigh *et al.* 2010), providing the current network of 22 sites (Figure 1).

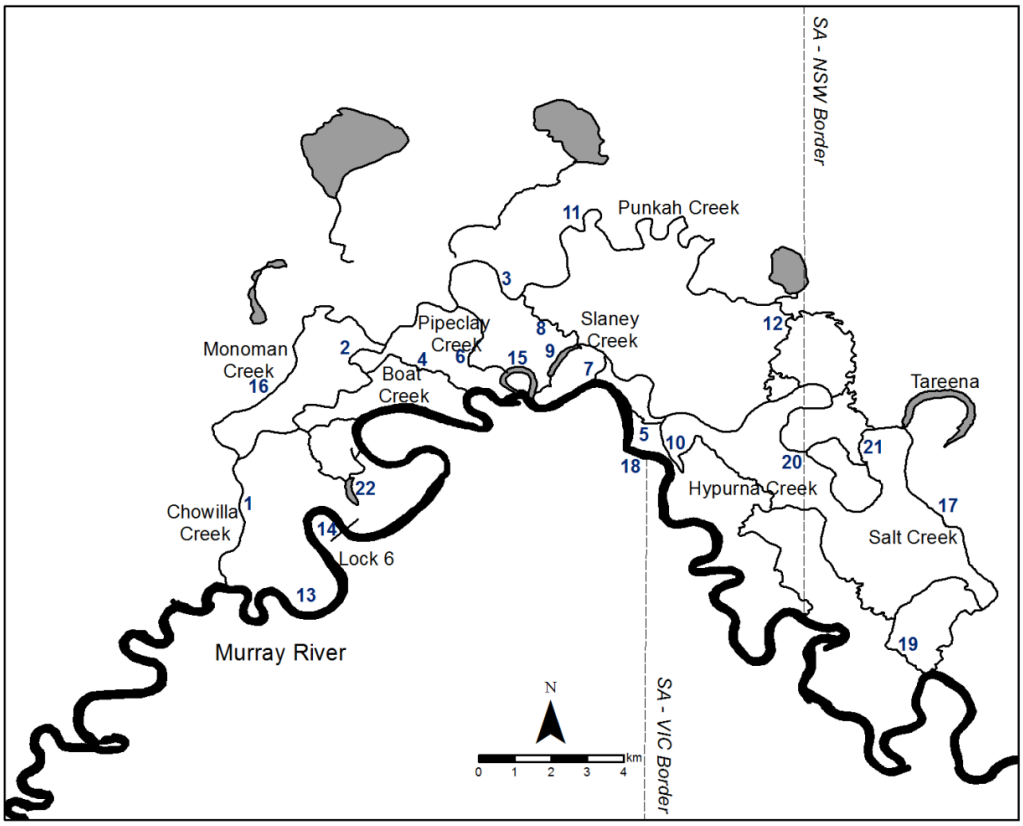

Figure 1. Map of the Chowilla Anabranch and Floodplain system and the adjacent River Murray main channel showing the fish condition monitoring sites 1–22.

Table 1. Site number, location and mesohabitat type of fish condition monitoring sites surveyed within the Chowilla Anabranch system and adjacent River Murray main channel from 2005–2021. Asterisks denote years when sites were surveyed. (d/s = downstream, u/s = upstream).

Site No.	Location	Mesohabitat type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	Chowilla Creek d/s Monoman Creek	Slow-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	Chowilla Creek u/s of Boat Creek	Fast-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	Chowilla Creek d/s Slaney Creek	Fast-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	Boat Creek u/s vehicle bridge	Fast-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	Swiftys Creek d/s Bank I	Fast-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	Pipeclay Creek d/s Pipeclay Weir	Fast-flowing	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*
7	Slaney Creek d/s Slaney Weir	Fast-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	Slaney Creek d/s Salt Creek junction	Fast-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	Slaney Billabong	Backwater	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	Hypurna Creek at Wilkadene	Slow-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	Punkah Creek d/s Punkah Island	Slow-flowing	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	Punkah Creek at Lake Littra	Slow-flowing	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
13	River Murray 5-7 km d/s Lock 6	Main River Channel	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	River Murray d/s Lock 6	Main River Channel	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	Isle of Mann backwater	Backwater	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
16	Monoman Creek at campsite 9	Backwater	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
17	Salt Creek at cliffs (NSW)	Slow-flowing					*	*		*	*	*	*	*	*	*	*	*	*
18	River Murray at Border Cliffs (NSW)	Main River Channel	*				*	*	*	*	*	*	*	*	*	*	*	*	*
19	Salt Creek d/s Bank K (NSW)	Fast-flowing				*	*	*	*	*	*	*	*	*	*	*	*		*
20	Salt Creek at NSW border (NSW)	Slow-flowing					*	*	*	*	*	*	*	*	*	*	*	*	*
21	Salt Creek near Tareena Billabong	Slow-flowing					*	*	*	*	*	*	*	*	*	*	*	*	*
22	Pilby Billabong	Backwater	*					*	*	*	*	*	*		*		*	*	
		Total number of sites	**18**	**16**	**15**	**14**	**21**	**22**	**21**	**22**	**22**	**21**	**22**	**21**	**22**	**21**	**22**	**21**	**21**

In 2021, 21 sites were sampled from 1–19 March (Figure 1, Table 1). Pilby Billabong was not sampled in 2021, due to low water levels precluding access for an electrofishing boat. Annual condition monitoring from 2005–2021 (except for 2011) was conducted in March–April to maximise the likelihood that young-of-year (YOY) individuals from the preceding spring/summer spawning season were represented in the catch, enabling the recruitment of individual species to be assessed. Fish surveys were undertaken following low (i.e. below entitlement) flows (<7,500 $ML.d^{-1}$, QSA – flow at the South Australian border) in 2004/05, 2006/07, 2007/08, 2008/09, 2015/16 and 2017–20, small to medium within-channel increases in flow (~15,000 $ML.d^{-1}$ in 2005/06, ~10,000 $ML.d^{-1}$ in 2009/10, ~20,000 $ML.d^{-1}$ in 2013/14, and ~18,000 $ML.d^{-1}$ in 2014/15) and bankfull to overbank flows (~93,000 $ML.d^{-1}$ in 2010/11, ~60,000 $ML.d^{-1}$ in 2011/12, ~50,000 $ML.d^{-1}$ in 2012/13 and ~95,000 $ML.d^{-1}$ in 2016/17). Due to high river levels and extensive floodplain inundation in 2011 (Figure 3), surveys were delayed until May when flow had decreased substantially (~45,000 $ML.d^{-1}$), in an effort to ensure that the area sampled at each site was comparable to previous surveys (2005–2010). Nevertheless, at the time of the survey, flow was still bankfull and water levels remained ~1.5 m higher than levels experienced during previous surveys, therefore, the data from 2011 were treated independently. In March 2021, condition monitoring at Chowilla was undertaken during low flows, with QSA varying from 5,666 – 7,690 $ML.d^{-1}$, whilst discharge in Chowilla Creek varied from 3,304 – 3,929 $ML.d^{-1}$.

Fish surveys were conducted using a vessel mounted 5 kW Smith Root Model GPP electrofishing system. At each site, 12 (6 on each bank) x 90 second (power on time) electrofishing shots were undertaken during daylight hours. All fish were dip-netted and placed in holding tanks. Any positively identified fish unable to be dip netted were recorded as “observed” and included in the total catch. 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.

In addition to March sampling, in May 2021 targeted sampling was conducted for Murray cod (*Maccullochella peelii*) to provide additional data to assess Objective 11 (maintain successful recruitment of small- and large-bodied native fish). Spatio-temporally specific sampling for Murray cod was adopted in 2014 following collection of juvenile Murray cod (i.e. <200 mm TL) in targeted sampling in May 2013 that were not detected through standard condition monitoring in March 2013 (Wilson *et al.* 2014). From 17–21 May 2021, four regions were sampled: Chowilla Creek downstream of bridge, Chowilla Creek upstream of bridge, Slaney Creek and River Murray main channel (Figure 2) using the methods described above. At each site, effort (power-on time) was increased, compared to standardised condition monitoring, and only specific habitats were targeted (e.g. large wood and flowing water).

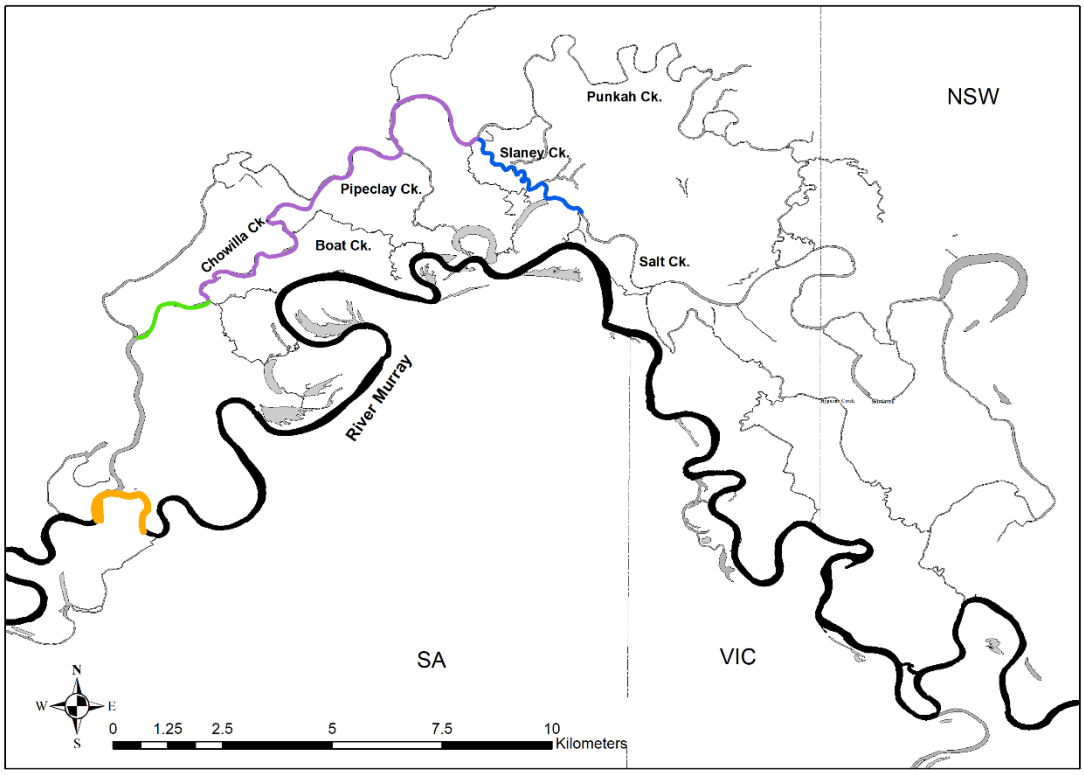

Figure 2. Regions sampled to target Murray cod in May 2021: Slaney Creek (blue), Chowilla Creek downstream bridge (green), Chowilla Creek upstream bridge (purple) and River Murray main channel (orange).

Abundance

Fish abundance is not a specific target in the Environmental Water Management Plan; nevertheless, changes in abundance may reflect environmental conditions. The abundance of individual fish species was investigated over the seventeen sampling years. Total and standardised abundances are presented for each species in each year. Total abundances for each fish species were calculated as the number of fish captured in addition to the number of fish observed. Standardised abundances were calculated by dividing the total number calculated for each species by the number of sites sampled in that year (i.e. fish.site^{-1}).

Data analysis

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).

Differences in fish assemblages from 2005–2021 (excluding 2011) and among mesohabitats (fast-flowing, slow-flowing, backwater and River Murray main channel) were analysed using two-factor permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001; Anderson and Ter Braak 2003), Non-Metric Multi-Dimensional Scaling (MDS), cluster analysis (McCune *et al.* 2002) and indicator species analysis (Dufrene and Legendre 1997). Bray-Curtis (1957) similarities were used to construct the similarity matrices for all multi-variate PERMANOVA analyses and MDS ordinations. For these analyses a significance level of $\alpha = 0.05$, and the B-Y significance correction was used for all subsequent pairwise comparisons (Benjamini and Yekutieli 2001).

Group average clustering was then 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 2005) and used to determine species that characterised assemblages in different clusters 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.

Diversity and extent of fish species (Ecological Objective 10)

In 2021, sites were grouped into aquatic mesohabitat categories (Table 1) with the diversity and extent of native fish species calculated using the methodology defined by Robinson (2013) and outlined below.

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 2005–2021. Sampling conducted from 2005–2014 was used to calculate all reference values, as no suitable 'baseline' data on fish diversity and extent are available for the icon site prior to the TLM program. This 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 Chowilla Icon Site.

RS	Interpretation (expectedness ratio, *ER*)	Expectedness weight
1	Either rare or cryptic species. Expected to be collected in up to 20% of sites in the Chowilla region.	0.10
3	Locally abundant species. Expected to be collected in 20 to 70 % of sites in the Chowilla region.	0.45
5	Common and abundant species. Expected to be collected in 70 to 100% of sites in the Chowilla region.	0.85
0	Native species not historically recorded in the Chowilla region. 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 at the icon site are presented below in Tables 3a–d. These metrics are presented separately for each mesohabitat type. Non-native species are not included in diversity calculations.

Table 3a. Rarity scores, expectedness ratio and expectedness weight for all native species sampled at the icon site within 'fast-flowing' mesohabitats.

Species	Rarity score	Expectedness ratio	Expectedness weight
Australian smelt	5	0.96	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.66	0.45
Dwarf flat-headed gudgeon	1	0.04	0.1
Flat-headed gudgeon	3	0.43	0.45
Freshwater catfish	3	0.23	0.45
Golden perch	5	1	0.85
Murray cod	3	0.57	0.45
Murray rainbowfish	5	0.90	0.85
Silver perch	3	0.39	0.45
Spangled perch	0	0	0
Unspecked hardyhead	5	0.77	0.85
	Predicted no. species		**11**
	Expected no. species		**6.6**

Table 3b. Rarity scores, expectedness ratio and expectedness weight for all native species sampled at the icon site within 'slow-flowing' mesohabitats.

Species	Rarity score	Expectedness ratio	Expectedness weight
Australian smelt	5	0.83	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.64	0.45
Dwarf flat-headed gudgeon	1	0.05	0.1
Flat-headed gudgeon	3	0.61	0.45
Freshwater catfish	3	0.06	0.1
Golden perch	5	0.94	0.85
Murray cod	3	0.06	0.1
Murray rainbowfish	5	0.79	0.85
Silver perch	3	0.20	0.1
Spangled perch	0	0.02	0
Unspecked hardyhead	5	0.75	0.85
	Predicted no. species		**11**
	Expected no. species		**5.55**

Table 3c. Rarity scores, expectedness ratio and expectedness weight for all native species sampled at the icon site within 'river main channel' mesohabitats.

Species	Rarity score	Expectedness ratio	Expectedness weight
Australian smelt	5	0.9667	0.85
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.7	0.45
Dwarf flat-headed gudgeon	1	0.1667	0.10
Flat-headed gudgeon	3	0.65	0.45
Freshwater catfish	3	0.267	0.45
Golden perch	5	0.96667	0.85
Murray cod	3	0.1833	0.10
Murray rainbowfish	5	1	0.85
Silver perch	3	0.283	0.45
Spangled perch	0	0.033	0
Unspecked hardyhead	5	0.9667	0.85
	Predicted no. species		**11**
	Expected no. species		**6.25**

Table 3d. Rarity scores, expectedness ratio and expectedness weight for all native species sampled at the icon site within 'backwater' mesohabitats.

Species	Rarity score	Expectedness ratio	Expectedness weight
Australian smelt	5	0.66	0.45
Bony herring	5	1	0.85
Carp gudgeon complex	3	0.70	0.45
Dwarf flat-headed gudgeon	1	0.08	0.10
Flat-headed gudgeon	3	0.483	0.45
Freshwater catfish	3	0.1	0.10
Golden perch	5	0.7083	0.45
Murray cod	3	0	0
Murray rainbowfish	5	0.7	0.45
Silver perch	3	0.125	0.10
Spangled perch	0	0	0
Unspecked hardyhead	5	0.9	0.85
	Predicted no. species		**10**
	Expected no. species		**4.25**

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 9) is the mean of these site specific indices from all sites within a particular mesohabitat. In turn, the icon 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.

Extent

An Extent Index (*EI*) was developed using the expectedness ratios calculated above (Tables 3a–d) 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 (2005–2021).

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*)) or 1 (i.e. dwarf flat-headed gudgeon (*Philynodon macrostomus*)) were excluded. Furthermore, Murray cod do not have an expectedness ratio in backwater mesohabitats, as they have never been sampled in this mesohabitat type in Chowilla.

Recruitment of fish species (Ecological Objective 11)

Recruitment indices were developed for six native species representative of the varying life history strategies exhibited by fish of the region (see Winemiller and Rose 1992). These life history groupings are based on longevity, biology/ecology and spatial scale of life history, and thus, the potential to be influenced by icon site-scale management. Reference and index values were calculated as per Robinson (2013) for: 1) four small- to medium-bodied generalist species, 2)

Murray cod (an equilibrium strategist) and 3) golden perch (*Macquaria ambigua*, a periodic strategist). Recruitment indices were not developed for non-native species such as common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*), but length frequency distributions are presented.

Small- and medium-bodied species

References and indices were developed for the following generalist species,

- Unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*);
- Murray rainbowfish (*Melantaenia fluviatilis*);
- Australian smelt (*Retropinna semoni*); and
- Bony herring (*Nematalosa erebi*).

The index for small-bodied fish 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 2005–2014, and is calculated as:

- X = icon 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 2005–2014.),
- Reference value (RV) = mean((X_{2005}*$r_{standard}$) + (X_{2006}*$r_{standard}$) + (X_{2007}*$r_{standard}$) +…….. (X_{2014}*$r_{standard}$))

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	65%	2.36
Murray rainbowfish	<40 mm FL	25%	0.20
Australian smelt	<40 mm FL	40%	0.57
Bony herring	<100 mm FL	65%	12.64

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

Murray cod

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 2005–2014. These values are 20% and 7% for fish 400–600 mm TL and <200 mm TL, respectively.

Golden perch

Golden perch length-at-age is highly variable (Anderson *et al.* 1992), therefore the recruitment index for golden perch incorporates abundance and age-structure data (as derived from otolith microstructure analyses). Recruitment of golden perch is measured as the abundance of

individuals classified at age 0+ (i.e. YOY) and age 1+. Detectability of 1+ fish is likely greater than for 0+ fish and provides a more reliable estimate of recruitment. The reference value is calculated as the mean abundance of the age 0+/1+ cohorts from baseline data collected from 2005–2014, where:

- X = icon site abundance (fish.minute electrofishing^{-1}.site^{-1}),
- $r_{standard}$ = set proportion of the combined 0+/1+ cohort* (*Values of $r_{standard}$ were calculated as the mean proportion of the population comprised of 0+ and 1+ individuals from 2005–2014.)
- Reference value (RV) = mean((X_{2005}*$r_{standard}$) + (X_{2006}*$r_{standard}$) + (X_{2007}*$r_{standard}$) +…….. (X_{2014}*$r_{standard}$)) $\boldsymbol{r_{standard}}$ = 19%, RV = 10.46

The recruitment index for golden perch is then calculated as:

- X_{year} = year specific abundance (fish.minute electrofishing^{-1}.site^{-1}),
- r_{year} = year specific 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

Hydrology during study period

From 2001 to 2010, the MDB experienced one of the most severe droughts in recorded history (van Dijk *et al.* 2013) (Figure 3). The 2005–2010 fish condition monitoring surveys were undertaken when flows in the River Murray system were approximately 40% below average and insufficient to inundate floodplains (MDBA 2011). Small within-channel increases in discharge, however, occurred during this period, notably in spring/early summer 2005. From June 2010 to May 2011, total inflows to the River Murray increased and were among the highest on record (MDBA 2011). The dramatic increase in inflows resulted in widespread flooding, with flow in the River Murray at the South Australian border (QSA) peaking at 93,000 ML.d^{-1} in February 2011 and an atypical flood duration of ~11 months (large flows of ~100,000 ML.d^{-1} typically last for ~3 months) (Sharley and Huggan 1995).

Widespread, persistent flooding in the lower River Murray in 2010/11 prompted a shift from disconnected lentic weir pool environments to connected lotic environments. Discharge remained relatively high in 2012 but decreased from 2013 to early 2016. In October–December 2016, another overbank flow event occurred (QSA peak: ~95,000 ML.d^{-1}; Figure 3), but with a relatively short duration of ~3 months (Figure 3). From 2017–2021, flow in the River Murray (QSA) remained below bankfull, with peak discharges occurring in early December 2017 (~17,600 ML.d^{-1}), late December 2018 (~12,060 ML.d^{-1}), mid-October 2019 (~15,734 ML.d^{-1}) and late November 2020 (~17,917 ML.d^{-1}). During the March 2021 condition monitoring survey, flow in the River Murray (QSA) ranged 5,666 – 7,690 ML.d^{-1} (Figure 3).

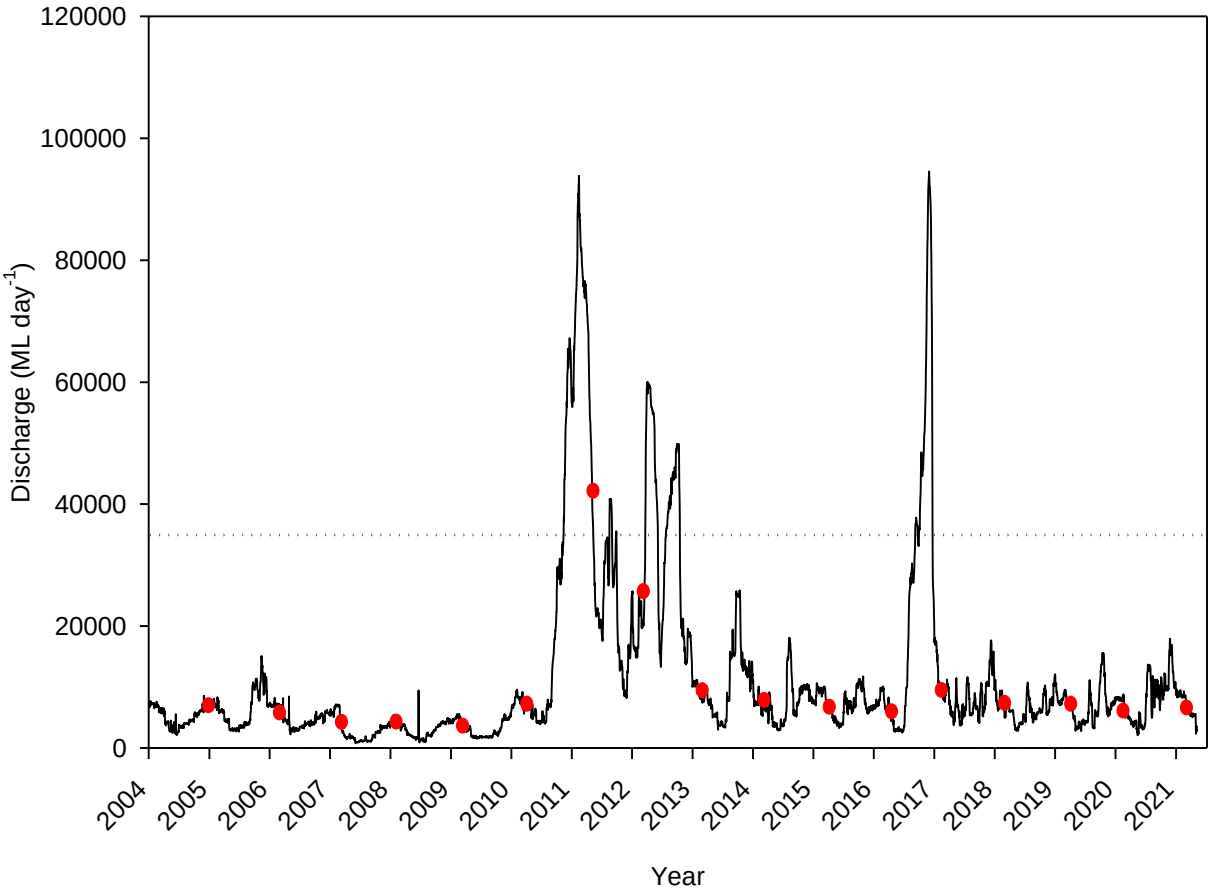

Figure 3. Mean daily flow (ML.d^{-1}) in the River Murray at the South Australian Border (Site A42610010) January 2004–June 2021 (MDBA, unpublished data). Closed red circles indicate sampling events and the dotted line represents approximate bankfull discharge at Chowilla (~35,000 ML.d^{-1}).

Catch Summary

In 2021, a total of 27,866 fish, from 14 species (10 native and 4 non-native) were captured (Table 5). The most abundant native species were bony herring (79.7%), Australian smelt (9.8%), unspecked hardyhead (4.2%) and Murray rainbowfish (1.3%), whilst the remaining species collectively consisted of 1.1% of the total catch (Table 5). Non-native common carp, goldfish, eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*) collectively comprised 3.9% of the total catch (Table 5). Three species of conservation significance were collected. Two of these, Murray cod and silver perch (*Bidyanus bidyanus*) are listed as 'vulnerable' and 'critically

endangered' respectively, under the *EPBC Act*. The third, freshwater catfish, is protected under the South Australian *Fisheries Management Act 2007.*

From 2005–2021, a total of 270,266 fish from 16 species (12 native and 4 non-native) were captured over seventeen surveys (Table 5, Appendix 1–17). The most abundant species from 2005–2010 were the small- to medium-bodied native species, bony herring, unspecked hardyhead and Australian smelt (Table 5). From 2011–2014, the most abundant species were bony herring, common carp, goldfish and golden perch. Total catch and standardised total abundance generally increased from 2005–2011 due mostly to increases in the number of bony herring, although in 2011 increases in abundance were primarily due to common carp and goldfish (Table 5). Total catch and standardised total abundances decreased following 2011, due primarily to reduced numbers of common carp and goldfish. In 2015, total catch and standardised total abundances increased due to increased catches of common carp and goldfish, whilst in 2016, total catch and standardised total abundances increased further with increased catches of bony herring, unspecked hardyhead, carp gudgeon (*Hypseleotris* spp.), eastern gambusia and goldfish. From 2017–2018, total catch and standardised total abundance decreased, due primarily to lower catches of bony herring compared to 2016 (Table 5). From 2019–2020, however, total catch and standardised total abundance increased, due to increased abundances of bony herring (Table 5). Again, in 2021, total catch and standardised total abundance increased, to be the highest recorded since monitoring commenced in 2005 (Table 5). This increase was driven predominantly by Australian smelt, unspecked hardyhead, eastern gambusia and goldfish.

Abundance of native fish

Golden perch was the most abundant large-bodied native species sampled in all years, with standardised abundance highest following significant overbank flooding in 2010/11 and lowest in low flow years (Table 5). In 2021, golden perch abundance was low when compared to previous years (2006–2019), however, abundance had increased from sampling conducted in 2020 (Table 5). Low abundances of Murray cod and silver perch were captured each year, although in 2021, Murray cod abundances were the highest recorded in all sampling years, whilst only five silver perch were collected (Table 5). Freshwater catfish were captured in low abundances in most years except for 2012 and 2013 when numbers increased, and spangled perch were only captured in 2011, 2014 and 2015.

Bony herring were most abundant in 2016, 2020 and 2021, whilst the abundance of Murray rainbowfish was highest in 2011 and carp gudgeon, unspecked hardyhead and flat-headed

gudgeon (*Philypnodon grandiceps*) were most abundant in 2005 (Table 5). Australian smelt was most abundant in 2021, whilst dwarf flat-headed gudgeon were not captured each year and when present, were sampled in low numbers (Table 5).

Abundance of non-native fish

Common carp and goldfish were the most abundant non-native species in most years, except in 2010, when higher numbers of eastern gambusia were sampled (Table 5). Standardised abundances of common carp and goldfish were greatest in 2011 and 2017 (Table 5). Redfin perch were not captured each year and when present, were sampled in low numbers. In 2021, the abundance of redfin perch was the highest recorded since monitoring commenced in 2005 (Table 5).

Table 5. Total and standardised (fish.site^{-1}) abundances of fish captured from condition monitoring sites sampled in the Chowilla Anabranch system and adjacent River Murray 2005–2021.

Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Grand Total
Golden perch (*Macquaria ambigua*)	69 (3.8)	75 (4.7)	112 (7.5)	94 (6.7)	174 (8.3)	114 (5.2)	802 (38.2)	286 (13.0)	230 (10.5)	148 (7.0)	143 (6.5)	99 (4.7)	139 (6.3)	112 (5.3)	68 (3.1)	46 (2.2)	61 (2.9)	**2772**
Murray cod (*Maccullochella peelii*)	13 (0.7)	11 (0.7)	14 (0.97)	15 (1.1)	21 (1.0)	15 (0.7)	7 (0.3)	9 (0.4)	7 (0.3)	7 (0.3)	14 (0.6)	13 (0.6)	5 (0.2)	18 (0.9)	13 (0.6)	33 (1.6)	38 (1.8)	**253**
Silver perch (*Bidyanus bidyanus*)	5 (0.3)	5 (0.3)	1 (0.1)	14 (1.0)	8 (0.4)	20 (0.9)	30 (1.4)	6 (0.3)	7 (0.3)	5 (0.2)	14 (0.6)	7 (0.3)	4 (0.2)	9 (0.4)	5 (0.2)	0 (0)	5 (0.2)	**145**
Freshwater catfish (*Tandanus tandanus*)	-	-	1 (0.1)	-	3 (0.1)	2 (0.1)	8 (0.4)	20 (0.9)	15 (0.7)	6 (0.3)	4 (0.2)	1 (0.1)	2 (0.1)	5 (0.2)	2 (0.1)	3 (0.1)	2 (0.1)	**74**
Bony herring (*Nematalosa erebi*)	3849 (213.8)	6229 (389.3)	6251 (416.7)	7782 (555.9)	10,629 (506.1)	17,948 (815.8)	2521 (114.6)	4433 (201.5)	5508 (250.4)	5225 (248.8)	10,314 (468.8)	19,221 (915.3)	11,045 (502)	11,151 (531)	15,530 (705.9)	22,611 (1076.7)	22,229 (1058.5)	**182,475**
Australian smelt (*Retropinna semoni*)	526 (29.2)	189 (11.8)	740 (49.3)	803 (57.4)	1067 (50.8)	589 (26.8)	484 (22.0)	132 (6.0)	215 (9.8)	151 (7.2)	1029 (46.8)	916 (43.6)	2169 (98.6)	2377 (113.2)	680 (30.9)	1164 (55.4)	2720 (129.5)	**15,951**
Murray rainbowfish (*Melantaenia fluviatilis*)	458 (25.4)	378 (23.6)	123 (8.2)	213 (15.2)	231 (11.0)	240 (10.9)	686 (31.2)	50 (2.3)	200 (9.1)	235 (11.2)	652 (29.6)	490 (23.3)	195 (8.9)	557 (26.5)	204 (9.3)	293 (13.9)	372 (17.7)	**5,577**
Flat-headed gudgeon (*Philypnodon grandicepts*)	93 (5.2)	6 (0.4)	20 (1.3)	18 (1.3)	70 (3.3)	21 (1.0)	11 (0.5)	20 (0.9)	69 (3.1)	35 (1.7)	65 (3.0)	14 (0.7)	4 (0.2)	33 (1.6)	6 (0.3)	102 (4.9)	88 (4.2)	**675**
Dwarf flat-headed gudgeon (*Philynodon macrostomus*)	2 (0.1)	-	-	11 (0.8)	2 (0.1)	6 (0.3)	-	-	-	-	3 (0.1)	4 (0.2)	-	-	1 (0.0)	1 (0.1)	-	**30**
Unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*)	2659 (147.7)	1602 (100.1)	1574 (104.9)	1786 (127.6)	2145 (102.1)	1687 (76.7)	455 (20.7)	26 (1.2)	84 (3.8)	89 (4.2)	656 (29.8)	2441 (116.2)	1687 (76.7)	1494 (71.1)	525 (23.9)	922 (43.9)	1168 (55.6)	**21,000**
Carp gudgeon spp. (*Hypseleotris* spp.)	398 (22.1)	113 (7.1)	104 (6.9)	73 (5.2)	84 (4.0)	153 (7)	92 (4.2)	2 (0.1)	28 (1.3)	222 (10.6)	137 (6.2)	251 (12.0)	181 (8.2)	68 (3.2)	93 (4.2)	109 (5.2)	102 (4.9)	**2,210**
Common carp* (*Cyprinus carpio*)	234 (13.0)	466 (29.1)	277 (18.5)	185 (13.2)	400 (19.1)	357 (16.2)	11602 (527.4)	2023 (92.0)	1218 (55.4)	590 (28.1)	730 (33.2)	339 (16.1)	5164 (234.7)	539 (25.7)	700 (31.8)	412 (19.6)	484 (23)	**25,720**
Gambusia* (*Gambusia holbrooki*)	200 (11.1)	61 (3.8)	125 (8.3)	60 (4.3)	107 (5.1)	490 (22.3)	647 (29.4)	12 (0.5)	40 (1.8)	65 (3.1)	126 (5.7)	300 (14.3)	398 (18.1)	160 (7.6)	27 (1.2)	103 (4.9)	331 (15.8)	**3,252**
Goldfish* (*Carassius auratus*)	202 (11.2)	296 (18.5)	177 (11.8)	156 (11.1)	551 (26.2)	217 (9.9)	3945 (179.3)	385 (17.5)	55 (2.5)	171 (8.1)	299 (13.6)	331 (15.8)	2517 (114.4)	188 (9.0)	146 (6.6)	90 (4.3)	200 (9.5)	**9,926**
Redfin perch* (*Perca fluviatilis*)	-	-	9 (0.6)	3 (0.2)	7 (0.3)	8 (0.4)	5 (0.2)	3 (0.1)	-	-	3 (0.1)	1 (0.1)	27 (1.2)	13 (0.6)	21 (1.0)	36 (1.7)	66 (3.1)	**202**
Spangled perch^ (*Leipotherapon unicolour*)	-	-	-	-	-	-	1 (0.05)	-	-	1 (0.05)	1 (0.05)	-	-	-	-	-	-	**3**
Total species	**13**	**12**	**14**	**14**	**15**	**15**	**15**	**14**	**13**	**14**	**16**	**15**	**14**	**14**	**15**	**14**	**14**	**16**
Total number of sites	**18**	**16**	**15**	**14**	**21**	**22**	**21**	**22**	**22**	**21**	**22**	**21**	**22**	**21**	**22**	**21**	**21**	
Total number of fish	**8,708**	**9,431**	**9,528**	**11,213**	**15,499**	**21,867**	**21,296**	**7,407**	**7,676**	**6,950**	**14,190**	**24,428**	**23,537**	**16,724**	**18,021**	**25,925**	**27,866**	**270,266**
Standardised total abundance (fish.site^{-1})	**483.7**	**589.4**	**635.2**	**800.9**	**738.0**	**934.0**	**969.7**	**336.7**	**348.9**	**330.9**	**644.9**	**1163.2**	**1069.9**	**796.4**	**858.1**	**1234.5**	**1326.9**	

Temporal variation in fish abundance

Between 2005 and 2021, annual relative abundance of fish (all species combined) varied significantly among years (Figure 4; *Pseudo-*$F_{16,\ 341}$ = 6.6421, p < 0.001). Between 2005 and 2011, relative abundance gradually increased before decreasing substantially in 2012–2014 (Figure 4). Abundance again increased from 2015–2017, before slightly decreasing in 2018 and 2019, but increased again in 2020 and 2021, with 2021 having the highest fish abundance recorded since monitoring commenced in 2005 (Figure 4). As a proportion of the total catch, native fish dominated in all years except for the high flow year of 2011, when common carp and goldfish comprised the majority of catch (Figure 4).

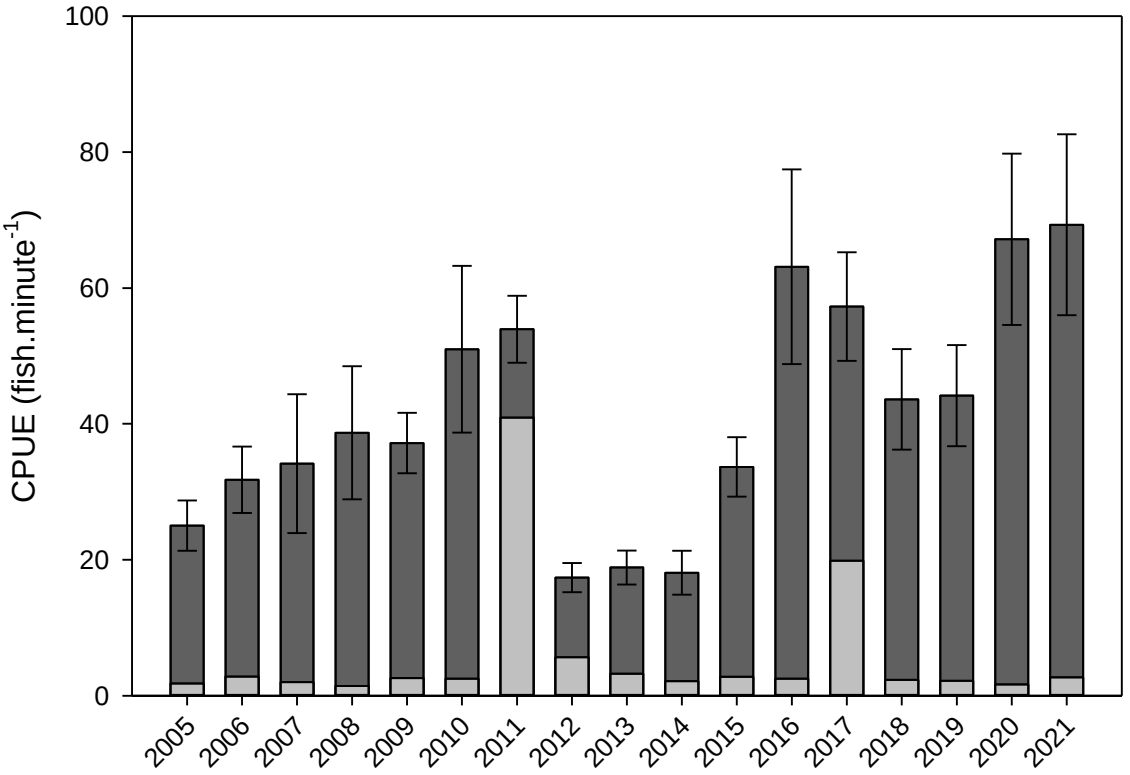

Figure 4. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of fish (all species combined) collected annually during standardised boat electrofishing surveys from 2005–2021 at 22 sites in the Chowilla Anabranch system and adjacent River Murray (dark grey = proportion native species, light grey = proportion of non-native species).

Spatio-temporal differences in fish assemblage structure

Two-factor PERAMNOVA showed significant differences among years and mesohabitats, and no significant interaction (Table 6). This indicated that fish assemblages varied among years and mesohabitats, and that change through time was consistent among mesohabitats.

Pairwise comparisons revealed significant differences (B-Y corrected α = 0.02) in fish assemblages among mesohabitats for all comparisons (Table 7). In addition, MDS and cluster analysis indicated four distinct groupings of fish assemblages by sampling years (Figure 5a). Namely, assemblages sampled in 2005–2010, 2015–2016 and 2018–2021 were similar, but distinctly different, from assemblages sampled in 2011, 2012–2014 and 2017 (Figure 5b). A similar pattern of temporal variability was observed for fish assemblages among all mesohabitats (Figure 6a **–**6d).

Table 6. PERMANOVA results comparing the relative abundances of fish between years and mesohabitats from 2005–2021, excluding 2011. Significant *P* values are highlighted in bold.

Factor	***df***	***Pseudo-F***	***P***
Year	15, 320	9.6387	**0.001**
Mesohabitat	3, 320	20.829	**0.001**
Year x mesohabitat	45, 320	0.91222	0.797

Table 7. PERMANOVA pair-wise comparisons between fish assemblages among different mesohabitats in Chowilla from 2005-2021, excluding 2011. Significant values are highlighted in bold (B-Y corrected α = 0.02).

Pairwise comparison		***t***	***p* value**
Mesohabitat	**Mesohabitat**		
Fast	Slow	6.0958	**0.001**
Fast	Backwater	5.354	**0.001**
Fast	River	3.6475	**0.001**
Slow	Backwater	2.9027	**0.001**
Slow	River	4.3998	**0.001**
Backwater	River	2.7166	**0.001**

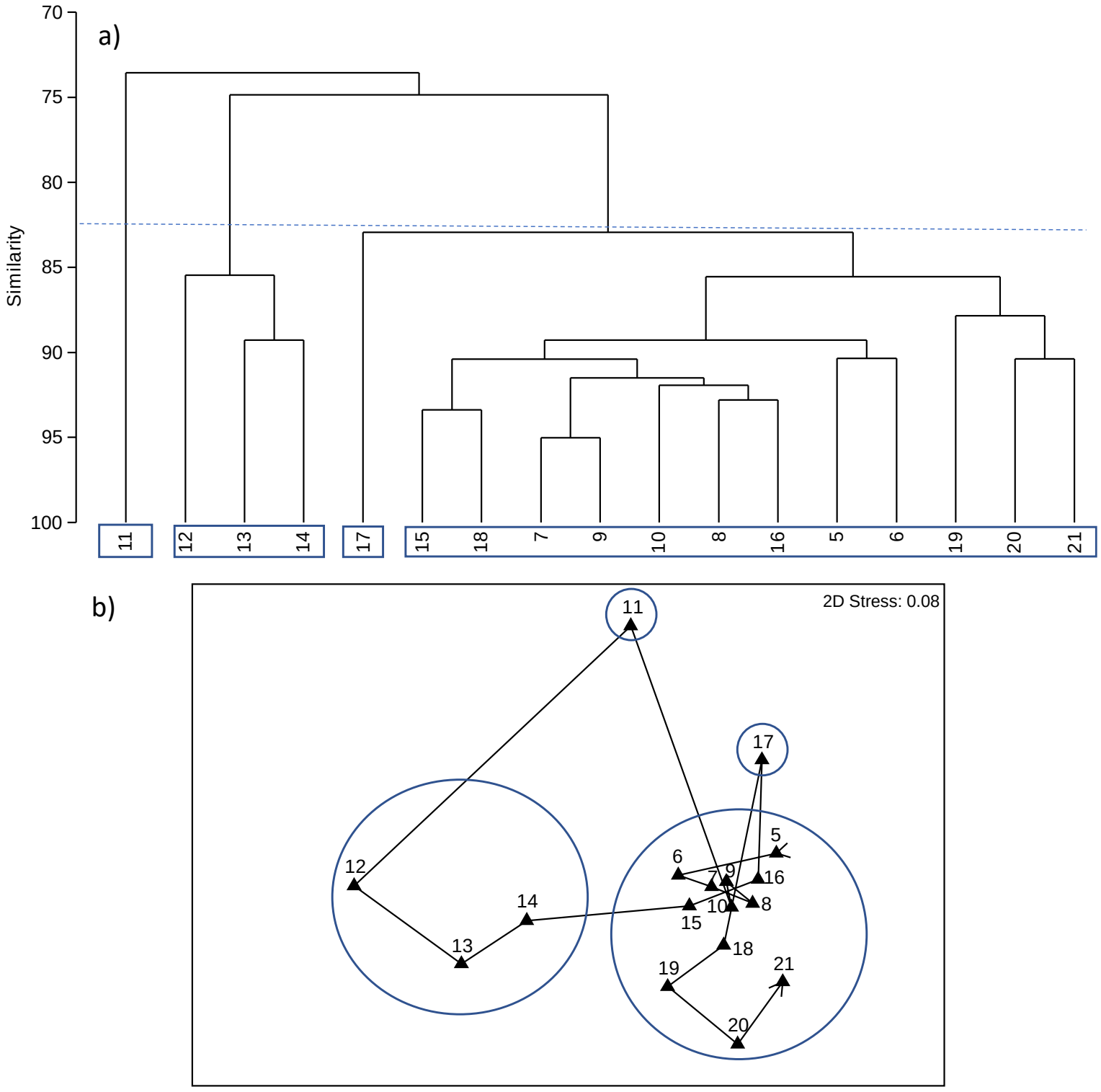

Figure 5. a) Dendrogram indicating fish assemblage clusters across sampling years from 2005–2021. b) Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled from all years/sites combined.

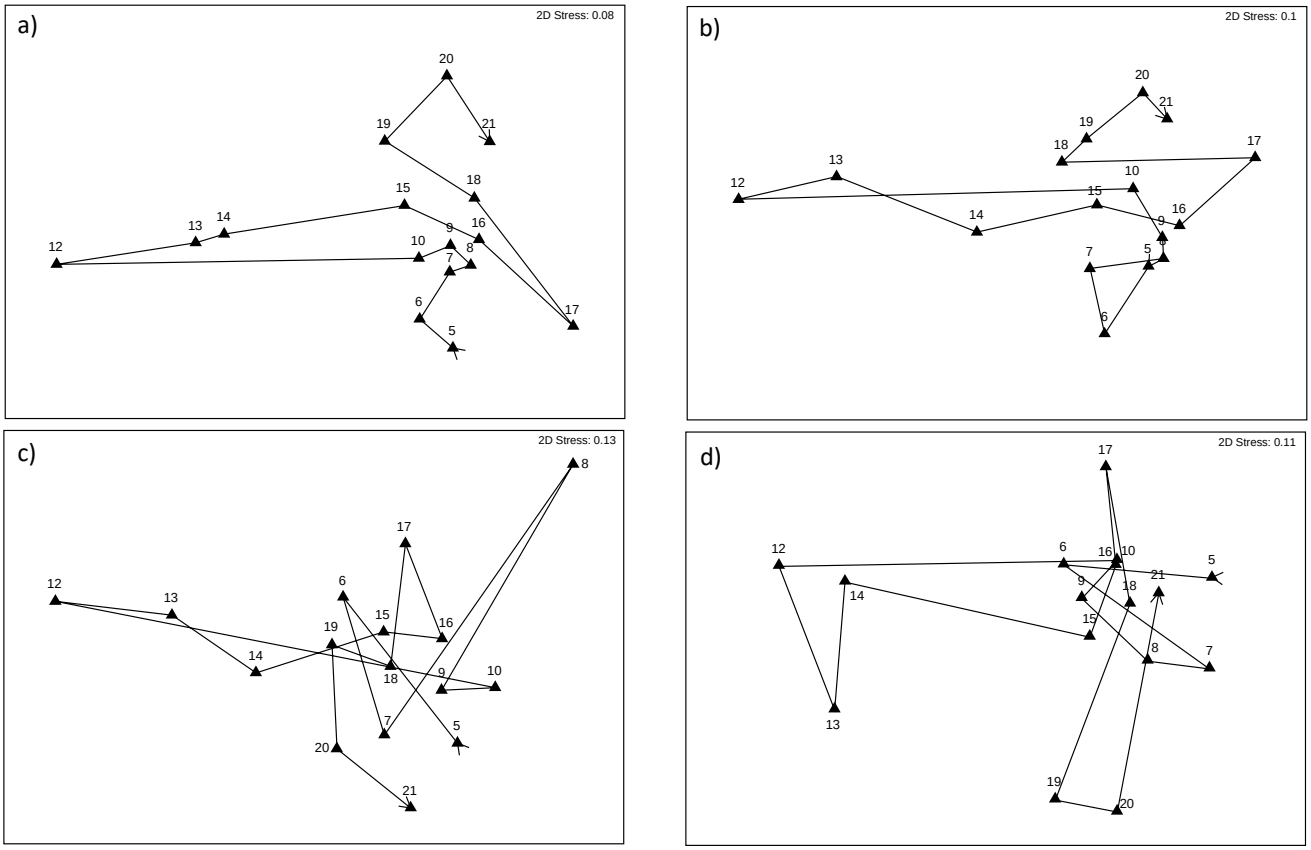

Figure 6. Non-metric multi-dimensional scaling (MDS) plots of a) fast-flowing, b) slow-flowing, c) backwater and d) river mesohabitats sampled from all years/sites combined (excluding 2011).

Indicator species analysis demonstrated that, in low flow years (Group 1: 2005–2010, 2015–2016, 2019–2021), fish assemblages were characterised by the medium-bodied native fishes bony herring. Conversely, for two high flow groupings (Group 2: 2012–2014; and Group 3: 2011), fish assemblages were dominated by large-bodied native fishes (silver perch, golden perch and freshwater catfish) and non-native (common carp and goldfish) (Table 8), and in 2011 were also characterised by the small-bodied species, Murray rainbowfish and eastern gambusia (Group 3: 2011) (Table 8). Group 4 (2017) was characterised by the small-bodied carp gudgeon spp., unspecked hardyhead, Australian smelt.

Table 8. Indicator species analysis comparing the relative abundance of fish amongst years from 2005–2021, including 2011. (Year group 1 = 2005–2010, 2015–2016 and 2019–2021; Year group 2 = 2012–2014; Year Group 3 = 2011; and Year Group 4 = 2017). Significant indicators (α = 0.05) signifies that a species occurs in a higher relative abundance in a specific year group. Indicators that are not significant signify that a species was either sampled in similar numbers in more than one year (widespread across years) or captured in low abundances (uncommon).

Species	Year Group	Indicator value	*p* value
Flat-headed gudgeon	1	18.9	0.1748
Dwarf flat-headed gudgeon	1	9.0	0.0610
Bony Herring	1	29.1	**0.0010**
Murray cod	1	14.8	0.1796
Freshwater catfish	2	16.7	**0.0146**
Silver perch	3	26.3	**0.0012**
Gambusia	3	37.2	**0.0002**
Golden perch	3	35.4	**0.0002**
Spangled perch	3	3.4	0.2362
Murray rainbowfish	3	35.1	**0.0002**
Goldfish	3	36.5	**0.0002**
Common carp	3	35.6	**0.0002**
Carp gudgeon spp.	4	30.1	**0.0086**
Unspecked hardyhead	4	34.9	**0.0002**
Redfin perch	4	34.6	**0.0002**
Australian smelt	4	32.6	**0.0006**

From 2005–2021, fast-flowing mesohabitats were characterised by golden perch, Murray cod, silver perch, Australian smelt and freshwater catfish (Table 9). Main river channel mesohabitats were characterised by Murray rainbowfish, unspecked hardyhead and redfin perch, and backwater mesohabitats were characterised by goldfish. No species were significant indicators associated with slow-flowing mesohabitats (Table 9).

Table 9. Indicator species analysis comparing the relative abundance of fish in three of the four aquatic mesohabitats from 2005–2021, excluding 2011 (no species were found to be associated with slow-flowing mesohabitats). A significant difference (α = 0.05) indicates that a species occurs in a higher relative abundance in a specific mesohabitat. Values that are not significant indicate that a species was either sampled in similar numbers in more than one mesohabitat (widespread) or captured in low abundances (uncommon).

Species	Mesohabitat	*P* - value
Golden perch	Fast	**0.0004**
Murray cod	Fast	**0.0002**
Silver perch	Fast	**0.0020**
Australian smelt	Fast	**0.0002**
Bony Herring	Fast	**0.0262**
Freshwater catfish	Fast	**0.0350**
Flat-headed gudgeon	River	0.0730
Murray rainbowfish	River	**0.0002**
Spangled perch	River	0.5135
Dwarf flat-headed gudgeon	River	0.3445
Unspecked hardyhead	River	**0.0002**
Redfin perch	River	**0.0106**
Carp gudgeon spp.	River	0.1122
Common carp	Backwater	0.1332
Goldfish	Backwater	**0.0190**
Gambusia	Backwater	0.1412

Targeted Murray cod sampling

In 2021, a total of 90 Murray cod were collected, with a catch-per-unit-effort of 0.14 fish.min^{-1}, which is the highest total abundance and second highest relative abundance recorded since targeted Murray cod sampling commenced in 2014 (Table 10; Figure 7). Thirty-eight Murray cod were captured during standard condition monitoring in March 2021 and the remaining 52 were captured during targeted sampling in May 2021. Relative abundances of Murray cod were highest at Bank K, Slaney Creek, Salt Creek and Swifty's Creek (Table 10).

Table 10. Total and standardised catch-per-unit-effort (CPUE) (fish.min^{-1}) of Murray cod from targeted sampling and condition monitoring in the Chowilla Anabranch system and adjacent River Murray in 2021.

	Targeted cod surveys									
Species	Chowilla Creek d/s bridge	Chowilla Creek u/s bridge	River Murray Main channel	Slaney Creek	Pipeclay Creek	Bank K	Swifty's Creek	Salt Creek	Standard condition monitoring (*n* = 21 sites)	Total
Murray cod (*Maccullochella peelii*)	1 (0.03)	4 (0.13)	4 (0.14)	25 (0.34)	4 (0.17)	7 (0.49)	2 (0.21)	5 (0.34)	38 (0.09)	90 (0.14)

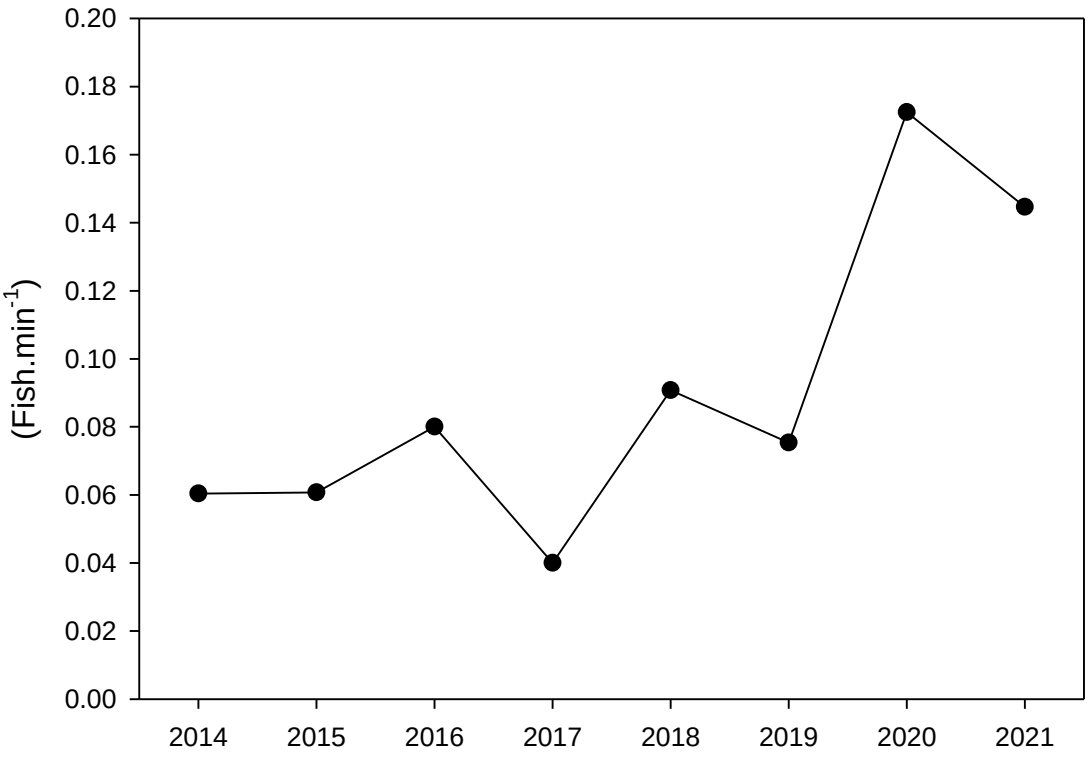

Figure 7. Relative abundance (fish.min^{-1}) of Murray cod from targeted Murray cod surveys and condition monitoring combined since 2014.

Diversity and extent of fish species (Ecological Objective 10)

Diversity

In the years 2005–2007, 2009, 2011 and 2015–2021 diversity was greater than or equivalent to the reference value across all mesohabitats (Figure 8a). In years 2008, 2010 and 2012–2014 diversity was less than the reference value across one or more mesohabitat (Figure 8a).

The mean of mesohabitat diversity indices for each year was calculated to provide an overall icon site diversity score (Figure 8b). In most years, except 2012–2014, the icon site diversity score was greater than or equivalent to the reference value, with 2021 having the highest diversity score out of all sampling years (Figure 8b).

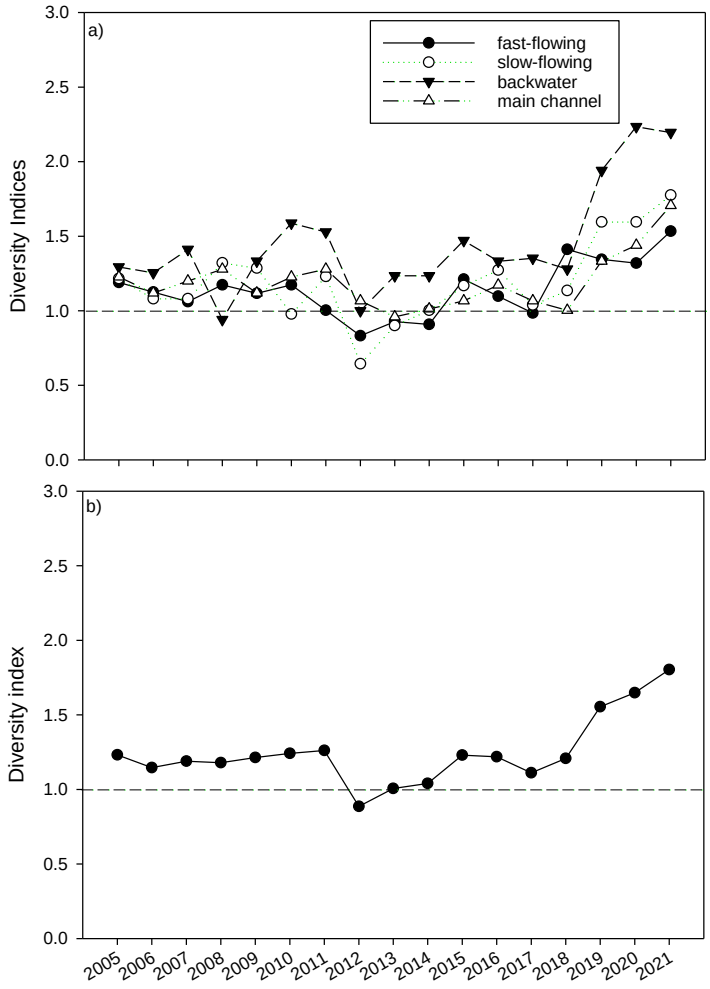

Figure 8. Diversity indices for a) fast-flowing, slow-flowing, backwater and main channel mesohabitats and b) the calculated Icon Site Diversity Index (DI), at the Chowilla Icon Site from 2005–2021.

Extent

For the large-bodied species golden perch and silver perch, distribution among mesohabitats was relatively stable across all years (Figure 10a). For silver perch, however, distribution was higher during years of increased discharge. Freshwater catfish had limited distribution from 2005–2010, 2016–2017, 2019 and 2021, whilst from 2011–2015 and in 2018 and 2020, distribution either increased or remained stable (Figure 10a). Murray cod distribution varied greatly from year to year, however, increased distribution was observed from 2018–2021 (Figure 10a).

The distribution of the majority of small- to medium-bodied species among mesohabitats remained stable or increased slightly over sampling years associated with low flows (2005–2011, 2014–2016 and 2018–2021) (Figure 10b). Decreases in distribution for carp gudgeon (2012–2013), flat-headed gudgeon (2014–2017) and unspecked hardyhead (2012–2014) were associated with periods of high flow that occurred post flooding in 2011–2013 and 2016/17.

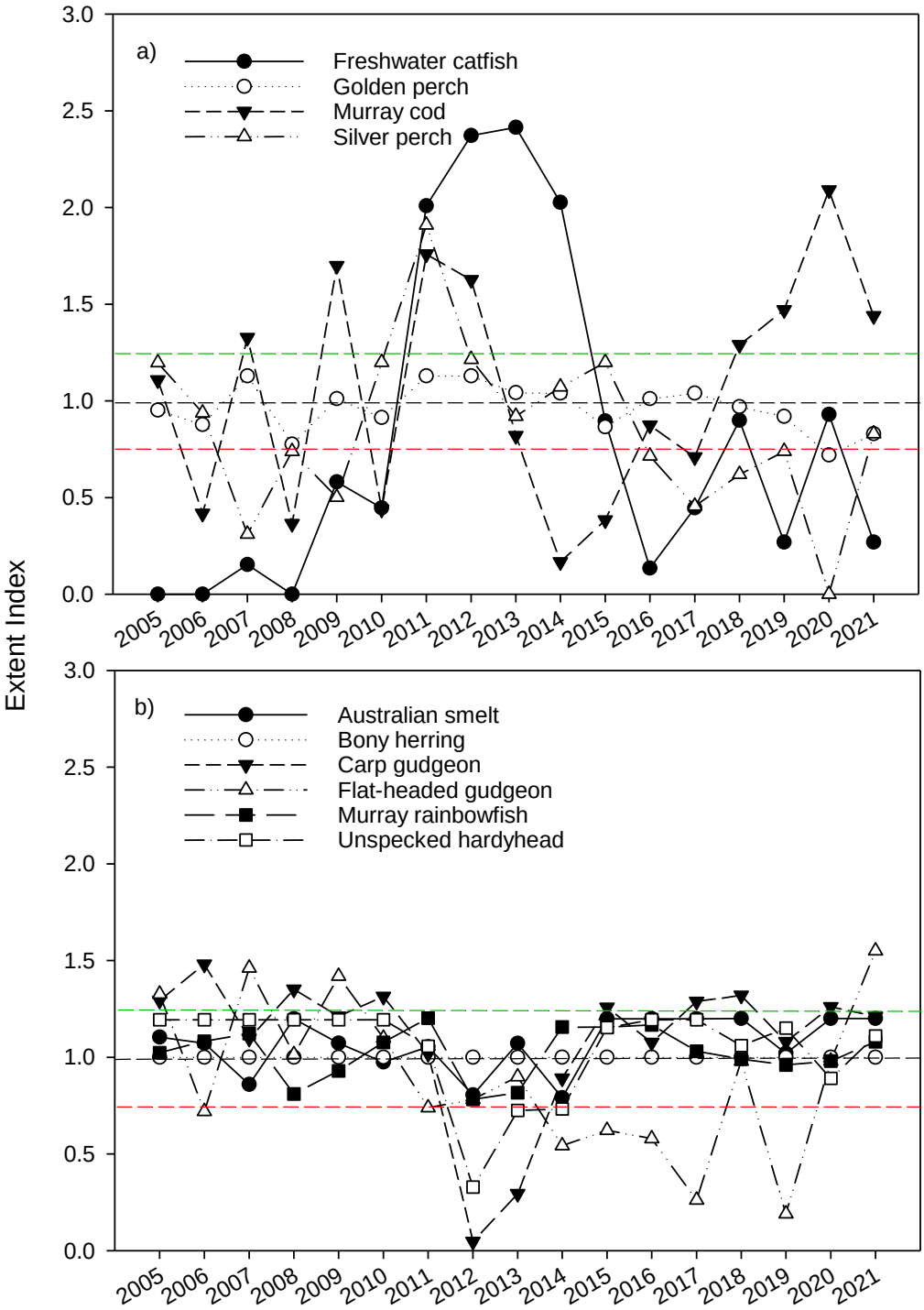

Figure 9. Extent Index (EI) scores for a) large-bodied native species and b) small- to medium-bodied native species at the Chowilla Icon Site from 2005–2021. Black dashed line represents extent equal to the reference, green dashed line extent 25% greater than reference and red dashed line extent 25% lesser than reference.

Recruitment of small- to medium-bodied native species

For most small- to medium-bodied species, recruitment was evident in most years but recruitment indices varied among sampling years (Figure 11). Unspecked hardyhead recruitment was highest from 2005–2010, 2016, 2018 and 2021, but reduced in 2012–2015, 2017 and 2019–2020 (Figure 11). High recruitment of Murray rainbowfish was evident in 2005–2006, 2014–2015 and 2019–2021, but limited in 2017–2018 (Figure 11). Australian smelt recruitment was variable, with high recruitment in 2005, 2007–2010 and 2015–2021 and low recruitment observed in 2006 and 2012–2014 (Figure 11). Bony herring recruitment was highest in 2007–2010 and 2015–2021 but limited from 2012–2014 (Figure 11).

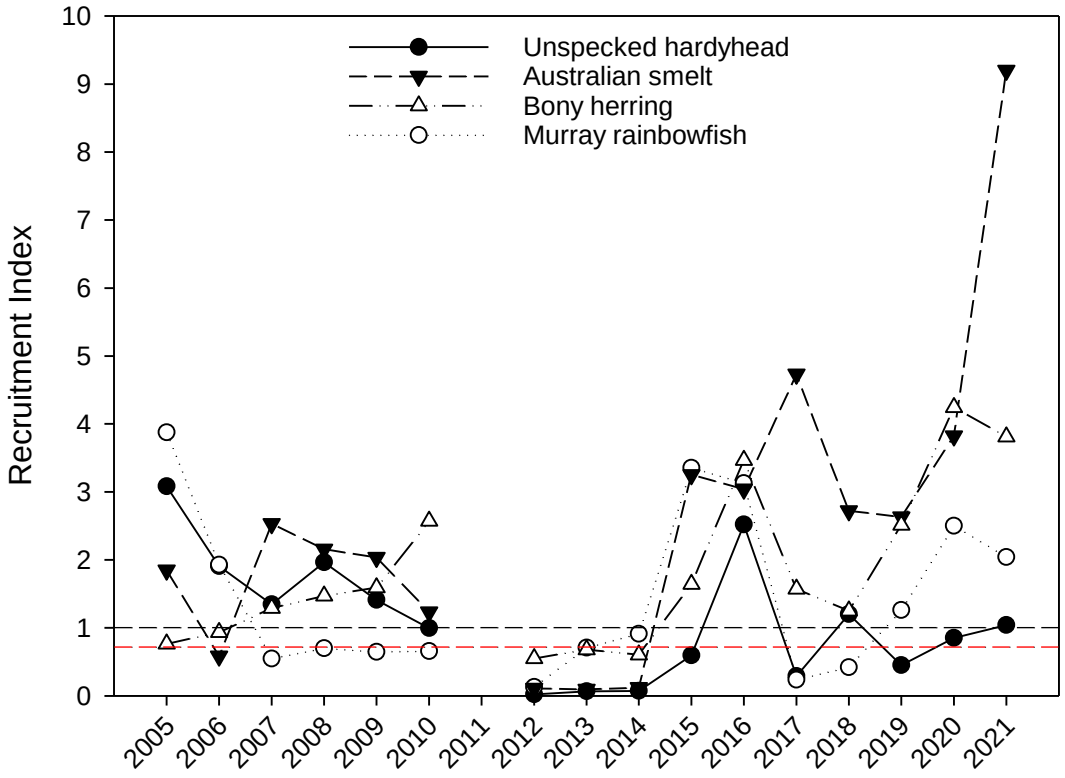

Figure 10. Recruitment Index (*RI*) values for unspecked hardyhead, Murray Rainbowfish, Australian smelt and bony herring from 2005–2021. Values for 2011 are not presented as sampling occurred at atypical time of year due to flooding. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Recruitment of large-bodied native species

Murray cod

Recruitment indices for Murray cod ranging from 400–600 mm TL were greater than reference in 2005–2006, 2012–2014, 2017 and 2021, similar to reference in 2008–2009 and lower than reference in 2007, 2010, 2015–2016 and 2018–2020 (Figure 12a). For YOY Murray cod (<200 mm TL), recruitment was greater than reference in 2009–2010, 2013–2014, 2016 and 2018–2021, similar to reference in 2006, 2008 and 2015 and less than reference in 2005, 2012 and 2017 (Figure 12b).

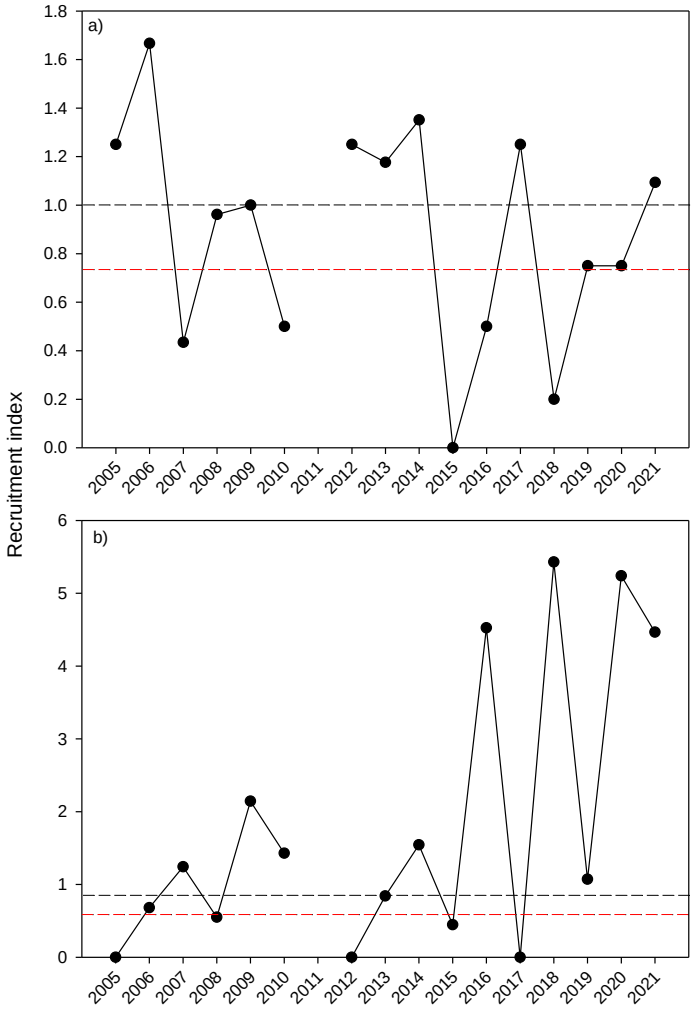

Figure 11. Recruitment Index (*RI*) values for a) Murray cod ranging 400–600 mm TL and b) YOY Murray cod (<200 mm TL) from 2005–2021. Values for 2011 are not presented as sampling occurred at an atypical time of year due to flooding. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Golden perch

Golden perch recruitment was highest in the 2007, 2011 and 2012, when recruitment index values exceeded the reference value (Figure 12). In the remaining years, including 2021, YOY were absent and therefore recruitment was negligible (Figure 12).

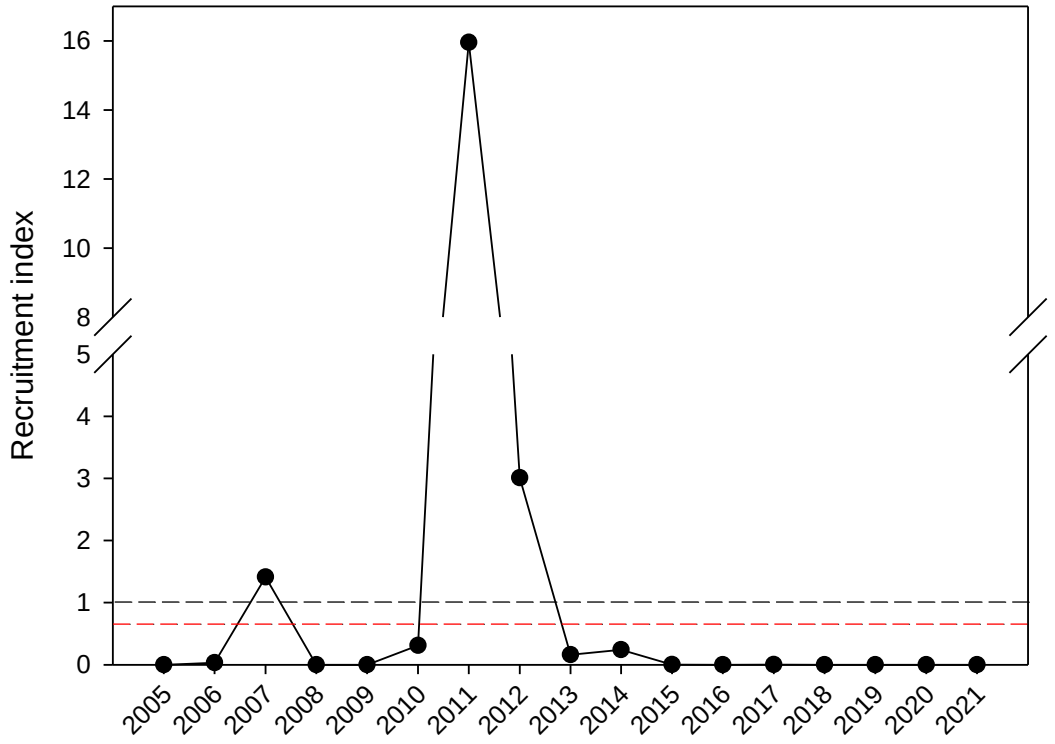

Figure 12. Recruitment Index (RI) values for golden perch from 2005–2021. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Recruitment of non-native species

Length frequency distributions for common carp and goldfish indicate annual recruitment of age 0+ fish for both species (i.e. common carp and goldfish ~100 mm in length) (Figure 13 and 14). Nevertheless, for common carp, recruitment of age 0+ fish was temporally variable and strong cohorts were evident in 2006, 2009–2012, 2014–2017 and 2019, whilst for goldfish, strong cohorts of 0+ fish were evident in 2006, 2008–2009, 2014–2017 and 2019. In 2021, both common carp and goldfish exhibited broad size ranges, similar to those seen in 2020 (Figure 13 & 14).

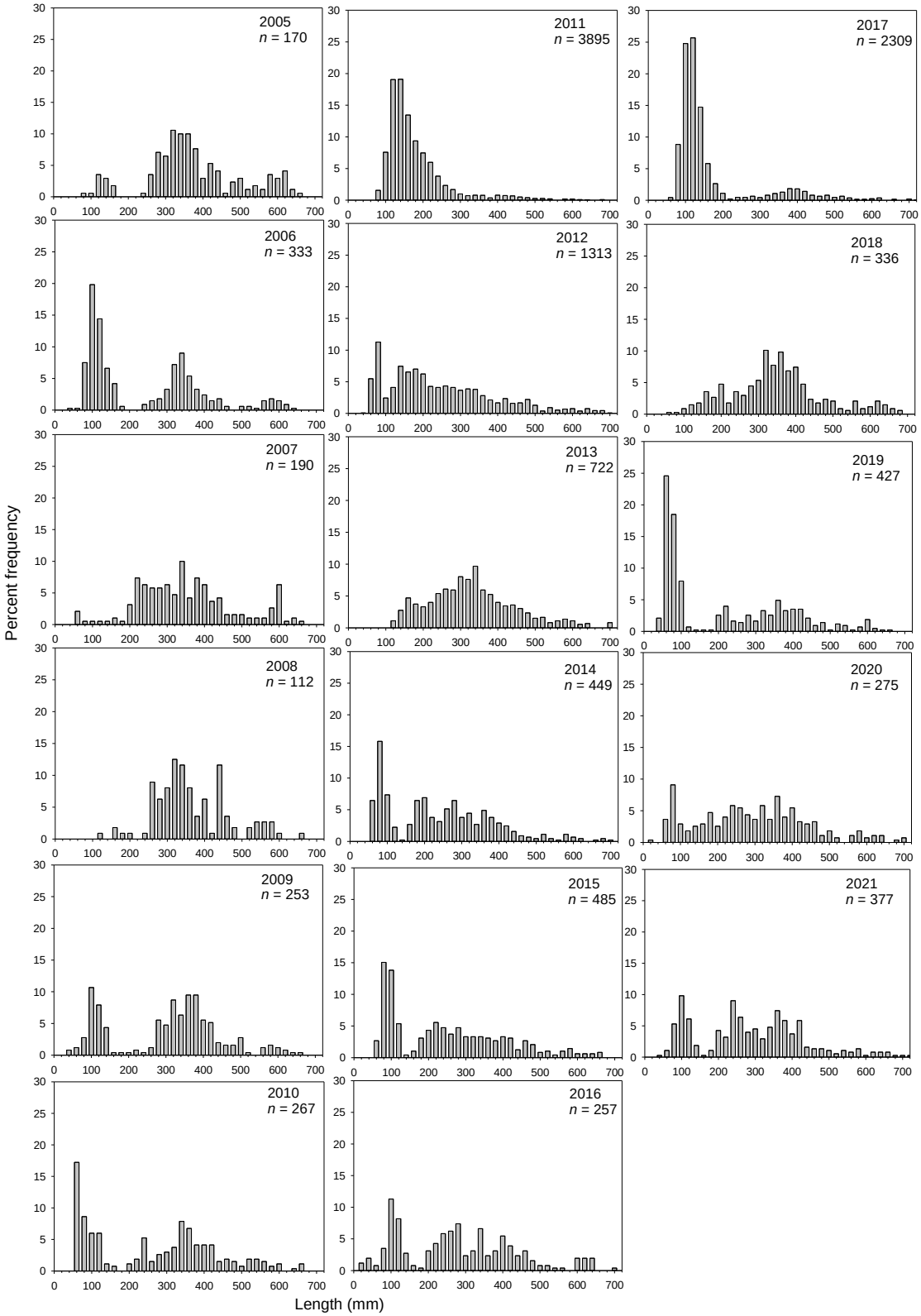

Figure 13. Length distribution of common carp captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2021.

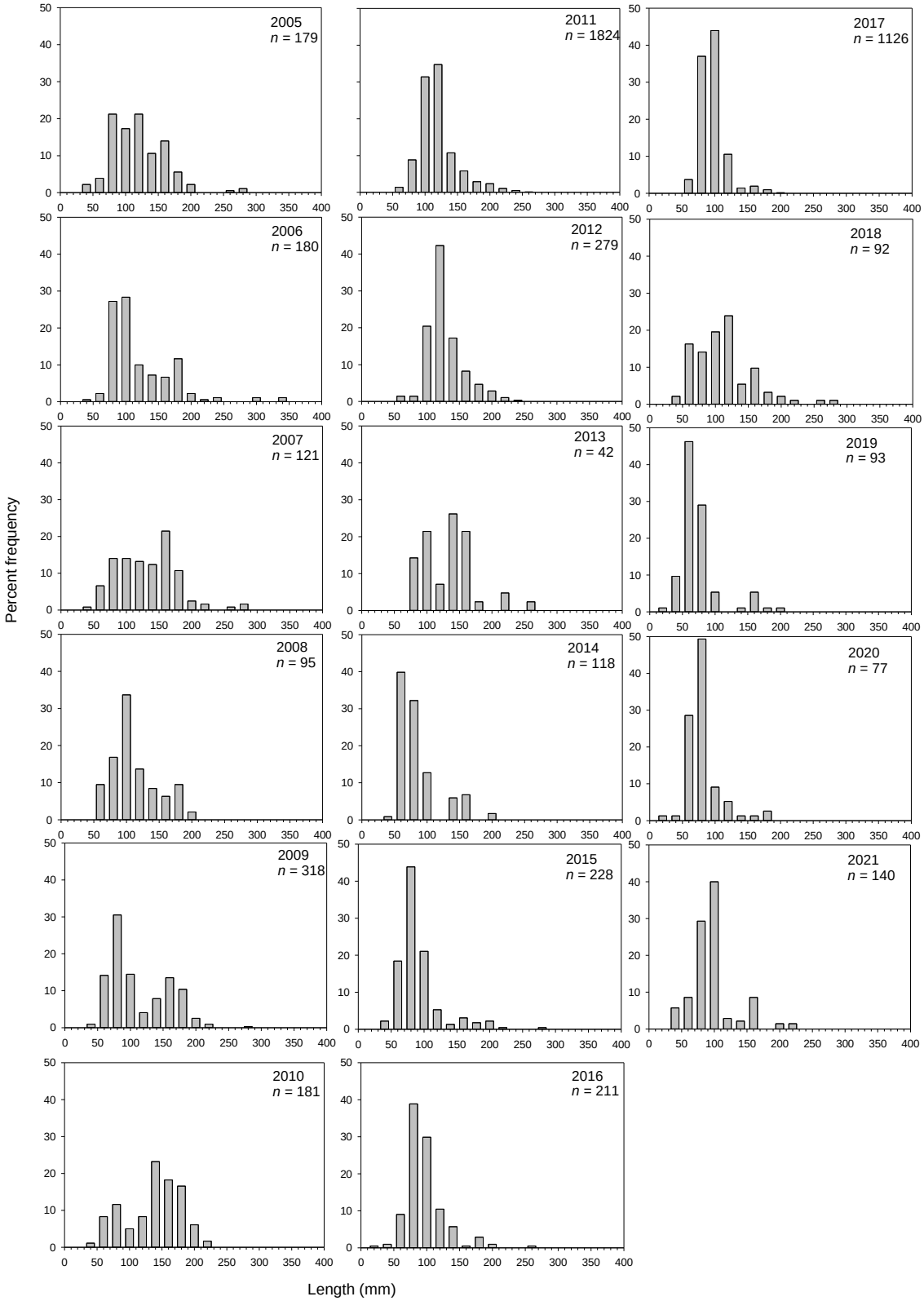

Figure 14. Length distribution of goldfish captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2021.

4. DISCUSSION

Condition monitoring of fish assemblages at Chowilla from 2005–2021 indicates Ecological Objectives 10 and 11 (as defined in the Chowilla Environmental Water Management Plan) are being met. Over the 17-year sampling period, the diversity and extent of native species have been maintained.

Abundance and assemblage structure

In 2021, 14 fish species were sampled at Chowilla and the adjacent River Murray main channel. The fish assemblage consisted of 10 native and 4 non-native species, with bony herring, Australian smelt, unspecked hardyhead and common carp the most abundant. The fish assemblage in 2021 was similar to that in 2005–2010, 2015–2016 and 2018–2020, with each of these years being characterised by low flows in the lower River Murray.

Fish assemblages at Chowilla during low flow years are typically characterised by high abundances of small- and medium-bodied generalist species including bony herring, unspecked hardyhead, Australian smelt and carp gudgeon. These flow-related patterns of abundance are commonly observed in the lower River Murray main channel (Bice *et al.* 2014). 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). During periods of regulated low flow and benign hydraulics, such habitats proliferate in the creeks of Chowilla, and in the lower River Murray main channel, but are diminished during and immediately following periods of high flow (Bice *et al.* 2014). Furthermore, specifically for Australian smelt, eggs and larvae are often found in low water velocity environments (King 2004) and higher flows (and water velocities) are considered to disturb spawning sites and reduce survival (Milton and Arthington 1985). Indeed, recruitment of Australian smelt is typically greatest during times of environmental stability (Milton and Arthington 1985; Webb *et al.* 2010). Overall, in the lower River Murray, 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 main river channels.

In contrast to small-bodied generalist species, golden perch were most abundant in 2011, post widespread flooding in the MDB, and least abundant in 2005–2010, 2016 and 2018–2021 in association with low River Murray flows. Golden perch are periodic strategists that spawn and

recruit in association with increased discharge (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003; Zampatti and Leigh 2013a), and substantial increases in abundance in 2011 in the Chowilla region were a result of enhanced recruitment in association with overbank flooding (Zampatti and Leigh 2013b). Yet, following a succession of low flow years (2015–2021), except for a flood in 2016, the abundance of golden perch at Chowilla has remained low. Ongoing reductions in abundance are likely associated with: limited spawning and recruitment as a result of low flows, emigration of adult fish to upstream regions (Zampatti *et al.* 2018), and mortality during a widespread hypoxic blackwater event associated with flooding in 2016 (Thiem *et al.* 2017).

Freshwater catfish were also most abundant in years following elevated within-channel or overbank flow (i.e. 2011–2013) and least abundant during low flow years (i.e. 2005–2010, 2014–2016 and 2018–2021). High flows in the lower River Murray from 2011–2013 generally promoted increased abundances of freshwater catfish (Ye *et al.* 2015), but these have reduced as flows in the lower River Murray have declined post 2013. Despite high flows in 2016-17, the abundance of freshwater catfish at Chowilla has remained low from 2017–2021.

Murray cod were generally captured in low abundances (7–38 individuals.year^{-1}) in the Chowilla condition monitoring surveys, however, annual targeted surveys in May–June 2014–2021 have resulted in higher catches (23–90 individuals.year^{-1}). Based on integrated condition monitoring and targeted Murray cod survey data, relative abundance in 2021 remained high, but was slightly lower than that in 2020. In 2021, increased abundance was primarily driven by high abundance of YOY fish in combination with higher abundances of fish reaching reproductive maturity (e.g. 400-600 mm TL).

In most years, common carp and goldfish were the most abundant non-native species. Abundances were greatest following years of increased discharge and water level (within-channel and overbank) as occurred in 2011 and 2017. Throughout the southern MDB, increased water levels and floodplain inundation (natural and engineered) lead to increases in carp abundance (King *et al.* 2003; Stuart and Jones 2006; Bice and Zampatti 2011). In 2021, following a low flow year, common carp abundances were again low, as too was recruitment to YOY.

Diversity and extent (Ecological Objective 10)

Species diversity in each mesohabitat and across years was similar, with the majority of mesohabitats and years having a greater diversity index value than the reference value. This indicates that fish species diversity in the Chowilla region has either been maintained or increased over the period of 2005–2021. Indeed, this was evident in 2021, with the highest diversity score recorded among all sampling years. This was driven by increases in species diversity across all mesohabitats. The extent of most species has also been maintained or increased, across all mesohabitats. Nevertheless, distinct species remain characteristic of certain mesohabitats. Over the 17-year sampling period (2005–2021), Murray cod, golden perch, silver perch, Australian smelt and freshwater catfish have characterised fast-flowing mesohabitats. Since 2018, however, the extent of Murray cod distribution throughout the Chowilla region has increased significantly, which could be attributed to YOY fish being sampled at additional sites and in different mesohabitats (e.g. Pipeclay Creek and Isle of Mann backwater). Historically, species such as Murray cod, golden perch and silver perch were abundant in flowing riverine environments of the lower Murray (Cadwallader 1978; Mallen-Cooper and Brand 2007). The general loss of lotic habitats from the main channel of the lower Murray has corresponded with decreases in abundance of these species, thus highlighting the importance of flowing water mesohabitats in Chowilla (Mallen-Cooper and Zampatti 2018).

Recruitment of native species (Ecological Objective 11)

Recruitment indices for the small-bodied species Murray rainbowfish, unspecked hardyhead, Australian smelt and the medium-bodied bony herring indicate recruitment occurred in all years, but was below the reference values for unspecked hardyhead and Australian smelt in 2012–2014, for unspecked hardyhead in 2017 and 2019–2020, and for Murray rainbowfish in 2017–2018. These small-bodied generalist species are widespread and abundant throughout the lower River Murray (Baumgartner *et al.* 2008; Davies *et al.* 2008; Zampatti *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). Indeed, in the Chowilla region, these species displayed higher rates of recruitment in low flow years and limited recruitment following high flow periods.

Assessing the recruitment of Murray cod based on condition monitoring data alone is challenging due to the paucity of fish collected (e.g. Leigh and Zampatti 2012; Wilson *et al.* 2012). Additional targeted sampling in 2014–2021 has augmented the catch of Murray cod in Chowilla and the

adjacent River Murray and has facilitated the development of two recruitment indices: 1) YOY (fish <200 mm TL) and 2) fish entering reproductive maturity (fish 400–600 mm TL).

The YOY recruitment index for Murray cod was variable with distinct peaks in YOY recruitment in 2016, 2018 and 2020–2021. In these years, YOY Murray cod were also present throughout the main channel of the lower River Murray (Ye *et al.* 2020); nevertheless, a mechanism for increased YOY recruitment during these low flow years remains unresolved. In 2017 and 2019, Murray cod YOY recruitment decreased substantially from the previous year. Decreased recruitment coincided with operation of the Chowilla Regulator the preceding spawning season (i.e. September–November 2016 and 2018), which may have promoted hydraulic conditions less conducive to larval survival and subsequent recruitment (Fredberg and Zampatti 2018; Gibbs *et al.* 2020). In 2021, the recruitment index only slightly decreased from the previous year, despite this, recruitment for YOY Murray cod could still be classed as high when compared to all other sampling years.

The recruitment index for Murray cod 400–600 mm TL indicates that recruitment of fish to reproductive maturity has occurred annually in all years since sampling commenced in 2005, except 2015. Enhanced recruitment to maturity was observed in 2005–2006, 2012–2014, 2017 and 2021, which may be correlated with increases in the abundance of YOY fish 3–4 years prior, thus indicating successful survival of these fish (Fredberg and Zampatti 2017). From 2015–2020, the annual recruitment to reproductive maturity index has been below the reference value, with the exception of 2017. Whilst some of these years correlate with poor recruitment to YOY several years prior, the converse is also apparent, suggesting a potential decline in Murray cod recruitment to maturity. Variability in recruitment of Murray cod at Chowilla warrants further investigation; mixed-effects modelling that assesses recruitment strength in association with various factors (e.g. hydrology, regulator operation, hydraulics) may be a valid future approach (Tonkin *et al.* 2020).

Golden perch recruitment was episodic from 2005–2021, with the recruitment index indicating the most prominent recruitment in 2011, and to a lesser extent in 2007 and 2012 in association with antecedent overbank flooding or elevated within-channel flows in the lower River Murray. This is consistent with contemporary models of the flow-related ecology of golden perch that suggest spawning and recruitment of golden perch is stimulated by increases in discharge contained within the river channel or overbank (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003). In the lower River Murray, strong recruitment of golden perch generally occurs when spring-summer

flows exceed ~15,000 ML.d^{-1} (Zampatti and Leigh 2013a). Given this, we would predict limited recruitment of golden perch in the Chowilla region from 2015–2021, as flows in this period have predominantly remained low, with the exception of overbank flooding in 2016/17, which was associated with a hypoxic blackwater event. In the absence of any substantial recruitment over the past 9 years, abundances of golden perch in Chowilla and the lower River Murray more broadly, continue to decline.

Recruitment of non-native species

Increased recruitment of YOY common carp and goldfish in the Chowilla region generally corresponds with increased discharge and water levels e.g. in 2006, 2011, 2014 and 2017. Increases in water level may enhance recruitment of common carp and goldfish by increasing spawning effort and/or the availability of appropriate spawning and nursery habitat. In 2019, despite low flows in the lower River Murray and the Chowilla region, increased YOY recruitment for both common carp and goldfish occurred. This could be associated with operation of the Chowilla regulator from August–December 2018 and subsequent floodplain inundation (Bice and Zampatti, 2011). In the following low, within-channel flow, years (2020–2021), common carp recruitment was low.

5. CONCLUSIONS

Annual monitoring of fish assemblages at Chowilla from 2005–2021 indicates the diversity and spatial distribution of native fishes have been maintained and that ecological objectives 10 and 11 of the Chowilla Environmental Water Management Plan are being met.

Future Research Needs

Seventeen years of annual condition monitoring at Chowilla has provided valuable information on the ecology of freshwater fish at Chowilla and the lower River Murray. Some underlying causal mechanisms of observed responses remain speculative and require hypothesis-based research in conjunction with condition monitoring to further test and refine our conceptual understanding of fish ecology in the lower River Murray, particularly in relation to contemporary management interventions at Chowilla (such as operation of the Chowilla Regulator).

Some research questions in order of priority include:

- Investigating factors influencing recruitment variability of Murray cod at Chowilla using mixed-effects modelling approaches (*sensu* Tonkin *et al* 2020).
- The influence of site-scale management (e.g. regulator operation) on recruitment and abundance of common carp at Chowilla.
- The importance of Chowilla as a recruitment source for Murray cod and common carp in the lower River Murray, including the movement of adult and juvenile fish.
- The movement and habitat use of native (e.g. Murray cod) and exotic fish (e.g. common carp) in the Chowilla system 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.
- Impact of river-scale blackwater events on the ecology and population dynamics of large-bodied native fish (e.g. golden perch and Murray cod) in the Chowilla region and adjacent River Murray.

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APPENDIX 1. Total number of species captured at each site in 2005.

2005	**Site Number**																		
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**18**	**22**	**Grand Total**
Golden perch	7	7	2	5	1	4	9	10	0	6	1	3	2	4	2	3	3	0	69
Murray cod	0	2	0	1	2	1	2	4	0	0	0	0	0	0	0		1	0	13
Silver perch	1	0	0	0	1	0	0	0	0	0	0	0	2	0	1			0	5
Bony herring	503	75	183	27	390	217	433	93	61	184	164	148	124	325	104	727	90	1	3849
Australian smelt	35	9	36	5	166	18	50	29	29	19	26	20	48	15	1	17	3	0	526
Murray rainbowfish	15	16	10	17	46	10	27	18	0	13	6	7	124	83	17	4	45	0	458
Flathead gudgeon	2	1	10	0	2	2	4	3	0	3	0	4	10	12	0	2		38	93
Dwarf flathead gudgeon	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0			0	2
Unspecked hardyhead	131	8	166	20	57	307	48	18	34	79	23	34	413	712	300	101	157	51	2659
Carp gudgeon spp	3	5	24	5	4	21	14	4	3	7	0	8	24	23	0	97	6	150	398
Freshwater catfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0
Common carp	13	10	15	17	19	8	7	11	3	14	12	13	6	16	36	19	9	6	234
Gambusia	0	3	26	53	10	9	1	2	3	8	0	11	3	6	4	16	3	42	200
Goldfish	4	1	27	1	0	8	1	1	40	17	19	28	7	1	4	16	1	26	202
Redfin perch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0
Total species	**10**	**11**	**10**	**10**	**11**	**11**	**11**	**11**	**8**	**10**	**7**	**10**	**12**	**10**	**9**	**10**	**10**	**7**	**13**
Total fish/site	**714**	**137**	**499**	**151**	**698**	**605**	**596**	**193**	**174**	**350**	**251**	**276**	**764**	**1197**	**469**	**1002**	**318**	**314**	**8708**

APPENDIX 2. Total number of species captured at each site in 2006.

2006	Site Number																
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Grand Total**
Golden perch	7	14	1	10	4	4	6	6	0	1	0	0	6	13	2	1	75
Murray cod	0	3	0	2	2	0	1	3	0	0	0	0	0	0	0	0	11
Silver perch	1	0	1	0	1	0	0	0	0	0	0	0	2	0	0	0	5
Bony herring	835	147	889	98	183	84	851	85	104	209	184	216	695	545	138	966	6229
Australian smelt	5	9	5	1	74	15	22	12	1	6	3	1	27	7	0	1	189
Murray rainbowfish	18	21	4	12	73	23	81	21	0	3	5	5	40	38	5	29	378
Flathead gudgeon	0	0	1	1	0	0	1	0	0	1	0	0	1	0	0	1	6
Dwarf flathead gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unspecked hardyhead	53	53	124	38	113	444	118	28	93	76	16	26	227	119	10	64	1602
Carp gudgeon spp	16	6	11	2	3	17	14	1	1	9	5	1	3	9	2	13	113
Freshwater catfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common carp	13	6	57	9	24	23	19	11	13	47	52	48	25	21	47	51	466
Gambusia	3	1	1	23	0	5	6	4	0	5	0	7	5	0	1	0	61
Goldfish	17	1	13	3	0	17	3	0	15	27	40	24	27	64	8	37	296
Redfin perch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total species	**10**	**10**	**11**	**11**	**9**	**9**	**11**	**9**	**6**	**9**	**7**	**8**	**11**	**8**	**8**	**9**	**12**
Total fish/site	**968**	**261**	**1107**	**199**	**477**	**632**	**1122**	**171**	**227**	**384**	**305**	**328**	**1058**	**816**	**213**	**1163**	**9431**

APPENDIX 3. Total number of species captured at each site in 2007.

2007	Site Number															
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Grand Total**
Golden perch	5	8	17	7	4	9	18	9	5	7	5	8	6	2	2	112
Murray cod	0	3	0	1	1	0	1	7	0	0	0	1	0	0	0	14
Silver perch	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Bony herring	201	145	170	132	2104	274	935	461	237	170	87	183	90	51	1010	6251
Australian smelt	7	38	5	11	142	92	319	44	12	0	0	55	9	0	6	740
Murray rainbowfish	6	13	13	15	14	3	26	6	6	0	1	8	7	2	3	123
Flathead gudgeon	0	0	4	2	0	1	0	0	2	1	1	3	3	2	1	20
Dwarf flathead gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unspecked hardyhead	13	28	15	89	100	145	353	17	34	5	5	298	158	215	99	1574
Carp gudgeon spp	6	3	2	5	0	16	50	0	7	1	0	5	2	0	7	104
Freshwater catfish	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Common carp	20	10	24	9	23	11	12	23	16	26	10	21	13	42	17	277
Gambusia	1	2	3	56	2	30	7	0	8	2	4	1	0	2	7	125
Goldfish	3	2	10	3	1	6	1	1	35	20	16	1	5	12	61	177
Redfin perch	0	0	0	0	0	0	0	0	0	0	0	1	4	2	2	9
Total species	**10**	**10**	**10**	**12**	**9**	**10**	**10**	**8**	**10**	**8**	**8**	**12**	**10**	**9**	**11**	**14**
Total fish/site	**263**	**252**	**263**	**331**	**2391**	**587**	**1722**	**568**	**362**	**232**	**129**	**585**	**297**	**330**	**1215**	**9528**

APPENDIX 4. Total number of species captured at each site in 2008.

2008	Site Number														
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	**19**	**Grand Total**
Golden perch	9	7	3	3	4	8	22	3	0	3	5	3	10	14	94
Murray cod	0	1	0	0	1	0	3	2	0	0	0	0	0	8	15
Silver perch	1	0	0	0	6	0	1	2	0	0	0	0	0	4	14
Bony herring	193	252	391	311	2573	297	1439	783	231	172	246	192	465	237	7782
Australian smelt	16	61	39	20	274	26	116	63	19	33	9	15	25	87	803
Murray rainbowfish	14	30	0	17	42	5	32	12	0	4	4	15	13	25	213
Flathead gudgeon	4	0	4	1	0	1	0	0	0	3	1	1	3	0	18
Dwarf flathead gudgeon	1	1	2	0	0	1	0	0	0	0	0	1	5	0	11
Unspecked hardyhead	40	95	53	274	220	252	423	23	23	56	7	103	164	53	1786
Carp gudgeon spp	8	4	3	6	5	5	16	1	1	10	0	2	11	1	73
Freshwater catfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common carp	18	12	8	16	29	8	11	24	5	8	14	3	23	6	185
Gambusia	4	2	3	12	1	16	1	1	0	5	2	3	2	8	60
Goldfish	8	2	21	1	0	0	3	7	49	24	25	2	3	11	156
Redfin perch	0	0	0	0	0	0	1	0	0	0	0	0	2	0	3
Total species	**12**	**11**	**10**	**10**	**10**	**10**	**12**	**11**	**6**	**10**	**9**	**11**	**12**	**11**	**14**
Total fish/site	**316**	**467**	**527**	**661**	**3155**	**619**	**2068**	**921**	**328**	**318**	**313**	**340**	**726**	**454**	**11213**

APPENDIX 5. Total number of species captured at each site in 2009.

2009	Site Number																					
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Grand Total
Golden perch	8	17	4	13	5	10	20	14	0	3	3	5	9	11	3	1	7	11	11	9	10	174
Murray cod	0	4	0	0	0	0	3	1	0	0	0	0	2	0	0	0	0	0	5	0	6	21
Silver perch	0	0	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	2	0	1	8
Bony herring	474	817	947	276	808	970	1615	311	459	395	136	103	399	321	169	407	415	260	291	506	550	10629
Australian smelt	3	206	60	13	223	101	220	68	8	21	1	4	6	12	0	3	6	38	44	8	22	1068
Murray rainbowfish	4	10	0	36	15	15	21	1	0	6	1	2	8	36	5	0	3	34	15	3	16	231
Flathead gudgeon	3	1	9	0	1	0	0	0	2	7	2	2	0	15	2	11	4	3	5	0	3	70
Dwarf flathead gudgeon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Unspecked hardyhead	106	105	22	342	95	258	76	47	93	100	10	22	87	209	75	152	35	138	43	64	66	2145
Carp gudgeon spp	11	0	3	2	7	2	5	0	2	4	0	1	0	18	2	5	1	7	5	3	6	84
Freshwater catfish	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
Common carp	23	17	22	14	11	7	6	16	75	7	10	23	11	16	19	16	23	31	9	23	21	400
Gambusia	1	2	0	17	2	14	0	2	3	9	2	1	1	12	4	9	4	6	7	7	4	107
Goldfish	40	5	41	2	4	10	0	1	69	17	24	17	45	28	61	57	34	9	7	42	38	551
Redfin perch	2	0	0	0	0	0	0	0	0	1	0	0	0	2	0	2	0	0	0	0	0	7
Total species	**11**	**10**	**8**	**10**	**12**	**10**	**9**	**9**	**8**	**10**	**9**	**10**	**9**	**12**	**9**	**10**	**10**	**10**	**12**	**10**	**12**	**15**
Total fish/site	**675**	**1184**	**1108**	**716**	**1174**	**1388**	**1968**	**461**	**711**	**570**	**189**	**180**	**568**	**681**	**340**	**663**	**532**	**537**	**444**	**666**	**743**	**15499**

APPENDIX 6. Total number of species captured at each site in 2010.

2010	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	9	11	4	4	4	14	14	7	3	1	1	1	6	17	5	0	1	3	7	0	2	0	114
Murray cod	0	4	1	1	0	0	3	2	0	0	0	0	0	0	0	0	0	0	4	0	0	0	15
Silver perch	0	9	1	0	2	0	0	4	0	0	0	0	1	0	1	0	0	0	2	0	0	0	20
Bony herring	940	274	781	177	1805	516	605	526	970	813	517	175	846	1334	820	5251	600	352	360	193	83	10	17947
Australian smelt	31	7	41	6	204	28	38	6	21	36	1	0	26	29	27	13	23	41	11	0	0	0	589
Murray rainbowfish	10	5	3	31	14	11	27	0	2	4	0	1	9	28	19	7	3	61	3	0	1	1	240
Flathead gudgeon	0	0	0	1	0	0	1	0	1	3	2	1	1	0	0	1	1	2	1	0	0	6	21
Dwarf flathead gudgeon	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	4	6
Unspecked hardyhead	38	14	34	72	15	20	16	1	26	38	18	2	124	706	101	52	32	86	21	2	3	267	1688
Carp gudgeon spp	10	2	5	2	2	4	4	1	8	8	5	0	6	8	1	1	2	11	1	0	0	72	153
Freshwater catfish	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
Common carp	41	22	30	13	11	12	8	9	35	12	15	11	43	15	21	14	5	15	3	16	4	2	357
Gambusia	8	2	12	25	2	5	3	1	10	34	23	4	6	22	39	35	7	44	17	2	2	187	490
Goldfish	42	5	6	3	3	5	0	3	14	2	9	8	23	19	16	11	14	6	2	4	2	20	217
Redfin perch	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	0	0	2	0	1	0	0	8
Total species	**9**	**11**	**11**	**12**	**10**	**9**	**10**	**10**	**12**	**10**	**9**	**8**	**11**	**11**	**10**	**9**	**10**	**12**	**12**	**6**	**7**	**9**	**15**
Total fish/site	**1129**	**355**	**918**	**336**	**2062**	**615**	**719**	**560**	**1092**	**951**	**591**	**203**	**1091**	**2183**	**1050**	**5385**	**688**	**624**	**432**	**218**	**97**	**569**	**21867**

APPENDIX 7. Total number of species captured at each site in 2011.

2011	Site Number																					Grand
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**18**	**19**	**20**	**21**	**22**	**Total**
Golden perch	50	30	22	25	54	39	41	20	16	37	46	61	80	26	11	10	98	39	49	46	2	802
Murray cod	0	1	1	0	0	0	1	0	0	0	0	1	3	0	0	0	0	0	0	0	0	7
Silver perch	2	7	2	0	2	1	0	0	0	1	1	0	1	3	0	0	7	3	0	0	0	30
Bony herring	62	31	76	7	70	74	209	59	171	61	41	213	142	161	65	644	226	83	59	54	13	2521
Australian smelt	14	72	75	2	4	37	50	7	6	0	44	47	10	28	0	45	1	1	18	22	1	484
Murray rainbowfish	69	22	15	35	26	44	16	9	26	55	44	22	52	93	18	8	47	27	40	14	4	686
Flathead gudgeon	1	1	2	0	0	0	0	0	0	0	1	0	0	0	1	1	3	0	1	0	0	11
Unspecked hardyhead	33	5	15	0	4	10	12	6	31	3	11	2	26	16	113	31	13	0	0	5	119	455
Carp gudgeon spp	1	1	8	0	0	0	0	1	8	1	2	1	2	0	0	13	3	1	5	0	45	92
Freshwater catfish	0	0	0	0	1	0	0	0	1	0	0	0	1	2	0	0	0	0	0	0	3	8
Common carp	536	587	225	1228	268	389	220	154	443	464	622	700	195	578	848	394	1052	613	806	1088	192	11602
Gambusia	13	22	5	23	70	8	34	4	8	19	7	8	2	9	2	48	21	1	47	9	287	647
Goldfish	210	56	70	310	46	112	27	56	116	155	545	248	77	158	33	408	103	364	344	493	14	3945
Redfin perch	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	5
Spangled perch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Total species	**12**	**12**	**12**	**7**	**10**	**9**	**9**	**9**	**10**	**9**	**11**	**10**	**12**	**11**	**8**	**10**	**11**	**10**	**9**	**9**	**10**	**15**
Total fish/site	**993**	**835**	**516**	**1630**	**545**	**714**	**610**	**316**	**826**	**796**	**1364**	**1303**	**591**	**1075**	**1091**	**1602**	**1574**	**1134**	**1369**	**1732**	**680**	**21296**

APPENDIX 8. Total number of species captured at each site in 2012.

2012	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	11	6	18	25	8	25	15	15	1	21	23	4	13	18	7	11	5	11	17	10	20	2	286
Murray cod	0	0	0	0	0	1	3	3	0	0	0	0	1	0	0	0	0	0	0	0	1	0	9
Silver perch	0	0	1	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	6
Bony herring	701	29	176	43	293	211	338	206	134	165	102	100	196	93	277	440	99	567	94	47	55	67	4433
Australian smelt	2	1	2	0	14	9	77	2	4	2	0	0	1	1	0	0	0	7	6	3	0	1	132
Murray rainbowfish	0	1	0	4	0	4	14	0	0	0	0	0	6	3	1	1	1	4	8	1	0	2	50
Flathead gudgeon	0	0	3	0	0	0	1	0	0	0	1	0	1	0	2	0	6	2	2	0	2	0	20
Unspecked hardyhead	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	23	26
Carp gudgeon spp	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Freshwater catfish	0	2	0	2	5	1	0	1	0	1	0	0	0	4	1	0	0	0	3	0	0	0	20
Common carp	94	30	99	272	18	100	16	144	28	158	54	58	155	72	53	165	78	91	56	72	177	33	2023
Gambusia	0	0	1	2	0	0	0	0	0	0	0	0	0	2	0	1	0	4	0	0	0	2	12
Goldfish	3	10	20	21	7	34	9	17	2	44	20	14	22	109	1	19	6	0	13	10	2	2	385
Redfin perch	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3
Total species	**5**	**7**	**8**	**8**	**7**	**8**	**10**	**7**	**5**	**6**	**5**	**4**	**10**	**9**	**7**	**7**	**7**	**8**	**8**	**6**	**7**	**8**	**14**
Total fish/site	**811**	**79**	**320**	**371**	**346**	**385**	**475**	**388**	**169**	**391**	**200**	**176**	**397**	**303**	**342**	**638**	**197**	**687**	**199**	**143**	**258**	**132**	**7407**

APPENDIX 9. Total number of species captured at each site in 2013.

2013	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	3	16	12	11	9	28	27	8	1	16	6	9	10	0	12	10	7	4	12	20	8	1	230
Murray cod	0	1	1	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7
Silver perch	0	2	0	0	1	0	0	0	0	0	0	2	0	0	1	0	0	0	1	0	0	0	7
Bony herring	422	173	247	52	203	576	269	89	175	487	119	160	1012	182	93	313	187	138	121	126	214	150	5508
Australian smelt	6	3	2	0	62	28	25	30	23	1	3	3	3	11	3	0	4	2	1	3	1	1	215
Murray rainbowfish	0	2	0	24	36	39	25	0	1	8	0	0	7	8	10	0	0	29	7	0	1	3	200
Flathead gudgeon	3	0	1	5	0	0	2	0	0	7	0	0	0	1	0	0	42	3	0	1	2	2	69
Unspecked hardyhead	0	1	0	8	1	14	0	0	8	1	0	0	5	1	3	0	1	4	0	0	0	37	84
Carp gudgeon spp	0	0	0	14	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	1	10	28
Freshwater catfish	0	0	2	3	4	0	0	1	0	0	0	0	0	2	0	1	0	1	0	0	1	0	15
Common carp	74	41	77	61	47	84	54	48	11	63	58	69	19	14	97	61	53	41	24	124	55	43	1218
Gambusia	0	0	0	11	0	8	1	0	0	3	1	0	0	3	0	0	0	8	0	0	0	8	43
Goldfish	0	0	2	8	3	2	3	0	7	0	8	3	1	0	6	1	0	1	0	0	1	6	52
Total species	**5**	**8**	**8**	**10**	**9**	**8**	**10**	**6**	**7**	**8**	**6**	**6**	**7**	**8**	**8**	**5**	**7**	**10**	**6**	**5**	**10**	**10**	**13**
Total fish/site	**508**	**239**	**344**	**197**	**366**	**779**	**408**	**179**	**226**	**586**	**195**	**246**	**1057**	**222**	**225**	**386**	**296**	**231**	**166**	**274**	**285**	**261**	**7,676**

APPENDIX 10. Total number of species captured at each site in 2014.

2014	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	7	13	13	14	10		17	7		8	5	1	2	2	5	12	5	3	7	5	11	1	148
Murray cod		2						5															7
Silver perch		1			1									1		1			1				5
Bony herring	381	266	156	51	1290		420	76	117	183	154	211	332	272	63	313	231	119	182	211	161	36	5225
Australian smelt	8	13	1		62		7	19	8	3	4	5	5	6			2		3	2	3		151
Murray rainbowfish	5	7	7	18	18		19	6	2	20	6	3	25	41	17	3	3	5	5		7	18	235
Flathead gudgeon				2			5										8	2			1	17	35
Unspecked hardyhead	1	2			1		3		4	8	1			20	18	8		1				22	89
Carp gudgeon spp	1			2			6			1			1	4	2	3	2			1	2	197	222
Freshwater catfish		1		1	1							1					1	1					6
Common carp	13	15	21	38	13		51	29	19	60	37	14	33	16	40	43	19	27	9	37	29	27	590
Gambusia				2	1		2			3				1	6			4				46	65
Goldfish	11	1	2	1	1		8	1	1	22	12	9	17	8	9	33	5	14	3	1	2	10	171
Spangled perch														1									1
Total species	**8**	**10**	**6**	**9**	**10**		**10**	**7**	**6**	**9**	**7**	**7**	**7**	**11**	**8**	**8**	**9**	**9**	**7**	**6**	**8**	**9**	**14**
Total fish/site	**427**	**321**	**200**	**129**	**1398**		**538**	**143**	**151**	**308**	**219**	**244**	**415**	**372**	**160**	**416**	**276**	**176**	**210**	**257**	**216**	**374**	**6950**

APPENDIX 11. Total number of species captured at each site in 2015.

2015	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	6	11	7	10	5	11	13	6	3	16	7	1	3	3		5	6		6	11	13		143
Murray cod		4	1	1	3		3	1											1				14
Silver perch		1			1	1	2		1				2		4				2				14
Bony herring	983	719	332	94	514	610	1335	451	215	250	414	383	1317	719	168	406	266	254	377	245	192	70	10314
Australian smelt	38	88	19	10	155	187	189	61	12	37	44	9	37	13	14	6	21	11	57	9	6	6	1029
Murray rainbowfish	61	50	11	38	70	19	74	18	5	35	15		43	32	9	13	4	69	68	12	4	2	652
Flathead gudgeon	1											1		2			50	2	5	1	3		65
Dwarf flathead gudgeon		1		1												1							3
Unspecked hardyhead	26		9	71	3	17	12	2	50	15	2	4	64	190	57	14	24	59	7	5	1	24	656
Carp gudgeon spp	5	2	6	10	1	4	8	3	9	10	2		8	18	1	10	5	2	2			31	137
Freshwater catfish				1	2												1						4
Common carp	78	13	73	28	14	19	11	36	68	59	29	31	38	19	30	59	25	7	26	36	20	11	730
Gambusia			3	26			1		5	33	2	2	3		4	4	7	16	3	1		16	126
Goldfish	5	3	21	8		3	2	1	25	44	39	14	59	11	5	24	15	1	5	4	2	8	299
Redfin perch													2					1					3
Spangled Perch																	1						1
Total species	**9**	**10**	**10**	**12**	**10**	**9**	**11**	**9**	**10**	**9**	**9**	**8**	**10**	**9**	**9**	**10**	**12**	**10**	**12**	**9**	**8**	**8**	**16**
Total fish/site	**1203**	**892**	**482**	**298**	**768**	**871**	**1650**	**579**	**393**	**499**	**554**	**445**	**1574**	**1007**	**292**	**542**	**425**	**422**	**559**	**324**	**241**	**168**	**14190**

APPENDIX 12. Total number of species captured at each site in 2016.

2016	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	3	6	4	4	8	6	10	13		1	3	2	2	7	1	2	8	2	4	1	12		99
Murray cod		1			3		4	2				2							1				13
Silver perch		3		1										1					1		1		7
Bony herring	1507	1294	1147	172	4153	901	4211	429	367	73	340	250	1059	255	10	1550	344	96	579	173	311		19221
Australian smelt	52	72	13	29	145	96	104	45	24	14	9	10	84	20	22	22	51	27	49	9	19		916
Murray rainbowfish	32	17	3	61	37		29	12	2	1	4	1	49	77	23	18	7	28	63	1	25		490
Flathead gudgeon				1						1				3			5	1	2		1		14
Dwarf flathead gudgeon			1											1			1				1		4
Unspecked hardyhead	83	32	7	353	38	25	60	7	287	12	7	1	309	657	221	78	69	35	113	20	27		2441
Carp gudgeon spp	22		8	41	3	5	19	2	17	19	4	2	14	19	1	35	13	1	9	2	15		251
Freshwater catfish						1																	1
Common carp	20	5	15	14	9	10	5	9	23	15	24	18	21	24	18	27	15	9	26	12	20		339
Gambusia	1	1	8	108	9	1	9		8	11	16	2	3	3	16	4	18	17	27	23	15		300
Goldfish	8		10	18	2		1	2	33	22	55	6	15	28		50	31	5	16	15	14		331
Redfin perch																	1						1
Total species	**9**	**9**	**10**	**11**	**10**	**8**	**10**	**9**	**8**	**10**	**9**	**10**	**9**	**12**	**8**	**9**	**12**	**10**	**12**	**9**	**12**	**0**	**15**
Total fish/site	**1728**	**1431**	**1216**	**802**	**4407**	**1045**	**4452**	**521**	**761**	**169**	**462**	**294**	**1556**	**1095**	**312**	**1786**	**563**	**221**	**890**	**256**	**461**	**0**	**24428**

APPENDIX 13. Total number of species captured at each site in 2017.

2017	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	1	19	4	12	16	4	5	13	2	6	1	2	11	2	6	12	5	6	7	1	4		139
Murray cod		1						3													1		5
Silver perch		1			2								1										4
Bony herring	1031	282	87	117	1757	445	975	102	496	670	243	215	1786	288	223	650	382	136	600	139	136	285	11045
Australian smelt	31	235	17	9	202	470	437	47	6	31	14	16	152	162	2	2	160	3	153	3	14	3	2169
Murray rainbowfish	3	49		9	6	17	13	2	4	5			15	20	3	4	2	15	16		9	3	195
Flathead gudgeon						1											2					1	4
Unspecked hardyhead	25	90	18	50	177	99	124	12	14	18	4	3	596	207	31	13	43	36	36	8	31	52	1687
Carp gudgeon spp	2	9	5	31	5	9		1		4	1	1	5	13	2	3	9	6	10	12		53	181
Freshwater catfish					1													1					2
Common carp	243	206	148	348	185	138	75	56	124	242	97	67	559	128	458	261	176	250	135	284	392	592	5164
Gambusia		7	7	194	18	10	3	4	5	5	8	9	1	13	24	2	8	21	4	20	9	26	398
Goldfish	223	56	88	129	67	129	21	13	70	156	135	46	270	103	40	186	66	20	35	225	302	137	2517
Redfin perch		2	1		1	2	1			3			1	1		2	4		2	3	4		27
Total species	**8**	**11**	**8**	**9**	**11**	**10**	**8**	**10**	**8**	**9**	**8**	**8**	**10**	**10**	**9**	**10**	**11**	**10**	**10**	**9**	**10**	**9**	**14**
Total fish/site	**1559**	**955**	**374**	**899**	**2436**	**1322**	**1653**	**253**	**721**	**1137**	**503**	**359**	**3396**	**937**	**789**	**1135**	**857**	**494**	**998**	**695**	**902**	**1152**	**23537**

APPENDIX 14. Total number of species captured at each site in 2018.

2018	Site Number																					
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**Grand Total**
Golden perch	7	4	1	13	8	8	6	5		2		4	6	3	6	6	1	6	2	9	15	112
Murray cod		2	1	1	1		5	4					1					2	1			18
Silver perch		1		1	5								1						1			9
Bony herring	547	1002	530	195	1982	1064	1352	400	132	97	243	155	903	520	86	809	219	229	509	102	75	11151
Australian smelt	166	67	178	9	74	731	79	151	161	25	26	64	147	166	2	19	64	7	178	35	28	2377
Murray rainbowfish	6	2	1	19	103	27	17	8		15		1	30	168	36	20		50	47	3	4	557
Flathead gudgeon									4				1	4	1		5	3	8	6	1	33
Unspecked hardyhead	14	14	6	136	103	116	45		74	36			170	557	128	12	12	24	45	1	1	1494
Carp gudgeon spp	3	1	3	9	1	4	1		1	6			1	8	2	8	4	4	7	3	2	68
Freshwater catfish	1			2	2																	5
Common carp	34	8	28	27	37	11	16	29	22	30	17	14	22	47	49	45	19	9	8	33	34	539
Gambusia			3	86	2	6			2		1	5	2		6	1	3	8	17	18		160
Goldfish	14		5	5		1		1	4	14		3	10	1	8	110	1	7		1	3	188
Redfin perch															1		2	9		1		13
Total species	**9**	**9**	**10**	**12**	**11**	**9**	**8**	**7**	**8**	**8**	**4**	**7**	**12**	**9**	**11**	**9**	**10**	**12**	**11**	**11**	**9**	**14**
Total fish/site	**792**	**1101**	**756**	**503**	**2318**	**1968**	**1521**	**598**	**400**	**225**	**287**	**246**	**1294**	**1474**	**325**	**1030**	**330**	**358**	**823**	**212**	**163**	**16724**

APPENDIX 15. Total number of species captured at each site in 2019.

2019	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	5	3		4	6	3	3	3		3	1	2	2	3	5	1	1	7	8	1	7		68
Murray cod	1		1			1	1	6				1							2				13
Silver perch				1	2										1				1				5
Bony herring	1353	998	346	107	708	1362	1245	458	337	175	165	201	2525	904	249	1867	668	226	982	276	337	41	15530
Australian smelt	31	88	12	10	55	177	108	21	29	5	15	13	15	26		11	2		30	1	6	25	680
Murray rainbowfish	5			15	46	12	20			5	2		8	8	22	4	1	32	15	1	5	3	204
Flathead gudgeon																	1					5	6
Dwarf flathead gudgeon																						1	1
Unspecked hardyhead	10	3	3	40	27	83	22		16	57	3	3	18	57	113	15	20	21	1	11	1	1	525
Carp gudgeon spp	10			5		5	10	1	1	3	1		3	6		25		2	3		1	17	93
Freshwater catfish				1	1																		2
Common carp	36	8	29	40	31	24	13	12	20	92	52	20	10	1	33	52	17	18	40	15	33	104	700
Gambusia			1							1	2				1	2	2	3	3	1		11	27
Goldfish		1	5	9	1	1		7	2	10	15	3	3	2		9	2		6	2	1	67	146
Redfin perch		1	1	2						2			2	1		4	3		1	3	1		21
Total species	**8**	**6**	**7**	**10**	**9**	**9**	**8**	**7**	**6**	**9**	**9**	**7**	**8**	**9**	**7**	**10**	**10**	**7**	**12**	**9**	**9**	**10**	**15**
Total fish/site	**1451**	**1102**	**398**	**234**	**877**	**1668**	**1422**	**508**	**405**	**353**	**256**	**243**	**2586**	**1008**	**424**	**1990**	**717**	**309**	**1092**	**311**	**392**	**275**	**18021**

APPENDIX 16. Total number of species captured at each site in 2020.

2020	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	5	6	2	3	2	1	1					2	1		9	2	4	2			6		46
Murray cod	1	1	1	2	3	6	10	6				1			1	0	0	1					33
Silver perch																							
Bony herring	1109	1313	1262	335	1972	2906	4504	1033	336	624	306	364	1984	1380	313	799	871	280		222	615	83	22611
Australian smelt	26	62	114	37	46	146	62	96	148	74	24	71	26	120	2	13	32	7		33	24	1	1164
Murray rainbowfish	7	1	5	59	45	8	10	1		2	1		5	20	84	3	3	19		3	17		293
Flathead gudgeon				1		2				1		1		3	4	1	7			1	6	75	102
Dwarf flathead gudgeon																						1	1
Unspecked hardyhead				77	5	17	7		9	4		1	5	348	408	3	7	17		12	2		922
Carp gudgeon spp	2		1	3		7	7		1	6	1		1	20	7	4	8	2		5	4	30	109
Freshwater catfish					1	1									1								3
Common carp	9	11	23	11	26	17	11	17	15	50	8	17	9	7	44	24	6	7		9	31	60	412
Gambusia				11		2	2			12	1			3	51		7			10		4	103
Goldfish	2	1	3	2				1	2	16				1	2	2	19			9	2	28	90
Redfin perch					1				3	5	2		1	1	1	2	14	1		5			36
Total species	**8**	**7**	**8**	**11**	**8**	**11**	**9**	**6**	**6**	**9**	**6**	**7**	**7**	**10**	**13**	**11**	**12**	**9**	**0**	**10**	**9**	**8**	**14**
Total fish/site	**1161**	**1395**	**1411**	**541**	**2101**	**3113**	**4614**	**1154**	**514**	**794**	**343**	**457**	**2032**	**1903**	**927**	**853**	**978**	**336**	**0**	**309**	**707**	**282**	**25925**

APPENDIX 17. Total number of species captured at each site in 2021.

2020	Site Number																						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Grand Total**
Golden perch	1	5	1	5	5	2						4	1	3	2	4	8	6	2		12		61
Murray cod		5		4	5	2	7	5				3		1					6				38
Silver perch					2			2								1							5
Bony herring	796	2261	355	227	3451	2100	3176	534	47	566	470	239	285	1817	5	617	645	580	3111	509	438		22229
Australian smelt	120	130	43	30	175	216	232	113	110	138	41	41	79	260	8	46	180	79	573	72	34		2720
Murray rainbowfish	10	17	28	55	17	4	14	1		3	2	7	29	13	4	5	20	41	77	1	24		372
Flathead gudgeon	5		1				3	1	6	3		2	1	15	27	4	7	3	6	2	2		88
Dwarf flathead gudgeon																							0
Unspecked hardyhead	23	13	15	41	56	187	10		32	14		3	62	323	265	34	12	56	14	7	1		1168
Carp gudgeon spp	2		1	2		9	5	1		1		1	15	39	5	3	1	4	4	5	4		102
Freshwater catfish					1														1				2
Common carp	24	10	25	15	34	14	15	22	7	47	20	16	23	12	32	42	5	23	38	24	36		484
Gambusia	2	3	1	17	2	2			3	7	1		6	12	230		6	32	2	5			331
Goldfish	10		7	11		8		2		46	8	14	8	2	18	25	8	11	9	9	4		200
Redfin perch	3	1			1	1				5	3				2	6	25	1	8	4	6		66
Total species	**11**	**9**	**10**	**10**	**11**	**11**	**8**	**9**	**6**	**10**	**7**	**10**	**10**	**11**	**11**	**11**	**11**	**11**	**13**	**10**	**10**		**14**
Total fish/site	**996**	**2445**	**477**	**407**	**3749**	**2545**	**3462**	**681**	**205**	**830**	**545**	**330**	**509**	**2497**	**598**	**787**	**917**	**836**	**3851**	**638**	**561**		**27866**