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Chowilla Icon Site
Fish Assemblage Condition Monitoring 2017

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

SARDI Publication No. F2008/000907-9
SARDI Research Report Series No. 975

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

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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, 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. In order to 'enhance and restore' the environmental values of the Chowilla Floodplain, the Department of Environment, Water and Natural Resources (DEWNR) developed an Asset Environmental Management Plan 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 condition 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 Chowilla region (i.e. fast-flowing and slow-flowing creeks, backwaters and the River Murray main channel). Due to variation in sampling efficiency during high water levels in 2011, data from this year were excluded from quantitative analyses. Since 2013, additional targeted surveys have also been conducted for Murray cod (*Maccullochella peelii*).

In 2017, a total of 23,573 fish from 14 species were sampled from 22 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 (47%) (*Nematalosa erebi*), Australian smelt (9%) (*Retropinna semoni*), unspecked hardyhead (7%) (*Craterocephalus stercusmuscarum fulvus*), common carp (21%) (Cyprinus carpio) and goldfish (11%) (*Carassius auratus*) most abundant.

The fish assemblage in 2017 was typical of that encountered in the region post large overbank flows, with generally low numbers of small-bodied generalist species (e.g. unspecked hardyhead and carp gudgeon) and high abundances of non-native fishes (e.g. common carp and goldfish).

Condition monitoring data from 2005–2017 indicates that Objective 10 and 11 of the management plan are being met. Over the 13-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, however, some species were specific to one or more mesohabitats. The native species Murray cod, golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and Australian smelt characterised fast-flowing mesohabitats and carp gudegon spp. (*Hypseleotris* spp.) characterised backwaters.

Recruitment indices indicated that small- to medium-bodied native species, unspecked hardyhead, Murray rainbowfish, Australian smelt and bony herring recruited in 2017, although unspecked hardyhead and Murray rainbowfish recruitment decreased from 2016. Murray cod recruitment to sexual maturity (400-600 mm TL) was evident in 2017, but no recruitment of young-of-year (YOY) fish (<200 mm TL) was detected.

Golden perch recruitment to YOY would have been expected post flooding, but was not evident in 2017. The mechanisms for this remain unexplored, although the anoxic blackwater event that occurred throughout the River Murray during overbank flooding in spring/summer of 2016, may have interrupted spawning and/or influenced the survival of early life stages.

Keywords: Chowilla, fish diversity, extent, recruitment, native freshwater fish.

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. The floodplain and associated anabranch system is part of the Riverland Ramsar site and listed in the directory of important wetlands in Australia as a Wetland of International 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 hydro-dynamically variable lotic habitats to relatively stable lentic habitats more representative of a series of interconnected lakes (Baker *et al.* 2000, Walker 2006, Bice *et al.* 2017). Due to approximately 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. Due to the loss of lotic habitats in the River Murray main channel, the diversity of aquatic habitats found in Chowilla is now rare within the lower River Murray (Bice *et al*. 2017).

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 to this, and in order to 'enhance and restore' the environmental values of the Chowilla Floodplain system, the Department of Environment, Water and Natural Resources (DEWNR) developed an Asset Environmental Management Plan (AEMP) as part of

the Chowilla Integrated Natural Resource Management Project (DWLBC 2006) in which 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.

Condition monitoring at TLM Icon Sites is funded by the MDBA to assess biological communities (fish, birds and vegetation) in reference to mandated ecological objectives. Annual quantitative (standardised electrofishing) fish surveys have been undertaken at Chowilla since 2005. Data from these surveys are used to investigate spatial and temporal variation 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 2017 with reference to results from 2005–2016.

METHODS

Fish condition monitoring at Chowilla was initially undertaken in 2005 (Zampatti *et al*. 2008). Eighteen sites were identified, 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 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), thus providing a current network of 22 sites (Figure 1).

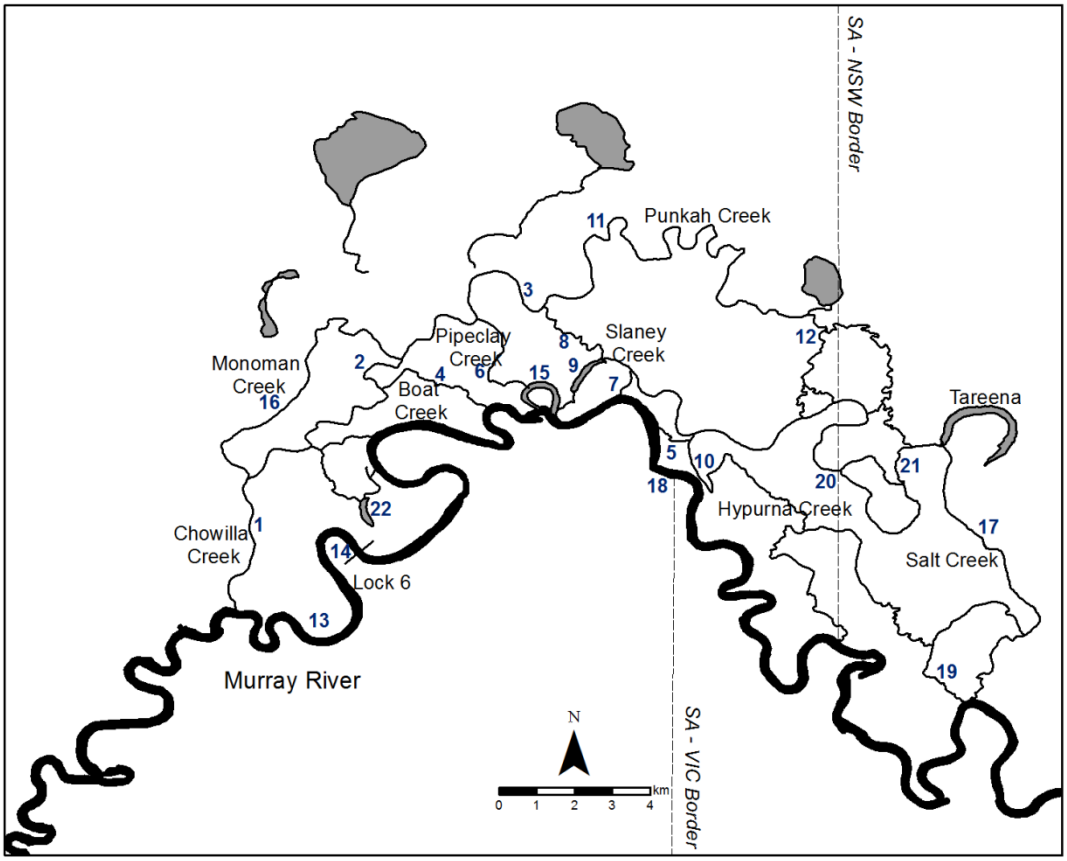

Figure 1. Map of the Chowilla Anabranch and Floodplain system and the adjacent River Murray main channel showing the fish condition monitoring sites 1–22.

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 2005–2017. 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
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 ford	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 immediately 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 (NSW)	Slow-flowing					*	*	*	*	*	*	*	*	*
22	Pilby Billabong	Backwater	*					*	*	*	*	*	*		*
		Total number of sites	**18**	**16**	**15**	**14**	**21**	**22**	**21**	**22**	**22**	**21**	**22**	**21**	**22**

In 2017, 22 sites were sampled from 6–24 March (Table 1, Figure 1). Condition monitoring from 2005–2017 (with the exception of 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 $ML.d^{-1}$) in 2004/05, 2006/07, 2007/08, 2008/09 and 2015/16, 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 and ~50,000 $ML.d^{-1}$ in 2012/13). 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.

Condition monitoring at Chowilla in March 2017 was undertaken following peak flows in the lower River Murray of ~95,000 $ML.d^{-1}$ in early summer 2016, and the operation of Chowilla regulator and ancillary structures (supplementary floodplain regulators and blocking banks) from 10 August to 10 November 2016, during which the upstream water level in Chowilla Creek and Lock 6 was raised to a maximum height of 19.78 m and 19.84 m AHD respectively at end of September 2016. During the period of Chowilla condition monitoring in March 2017 flows had decreased back to within-channel, with QSA varying from 7,524–11,235 $ML.d^{-1}$, whilst discharge in Chowilla Creek varied 3,599–3,957 $ML.d^{-1}$.

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 the March survey, targeted sampling was conducted in May 2017 to provide additional data to assess Objective 11 (maintain successful recruitment of small- and large-bodied native fish) for Murray cod (*Maccullochella peelii*). Spatio-temporally targeted 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). Eight sites (Chowilla Creek downstream of bridge, Chowilla Creek upstream of bridge, Slaney, Salt, Pipeclay and Swifty's Creeks, Bank K and River Murray main channel) were sampled between 15–18 May 2017 (Figure 2) using the methods described above. At each site, however, effort (power-on time) was increased and only specific habitats were targeted (e.g. large wood and flowing water).

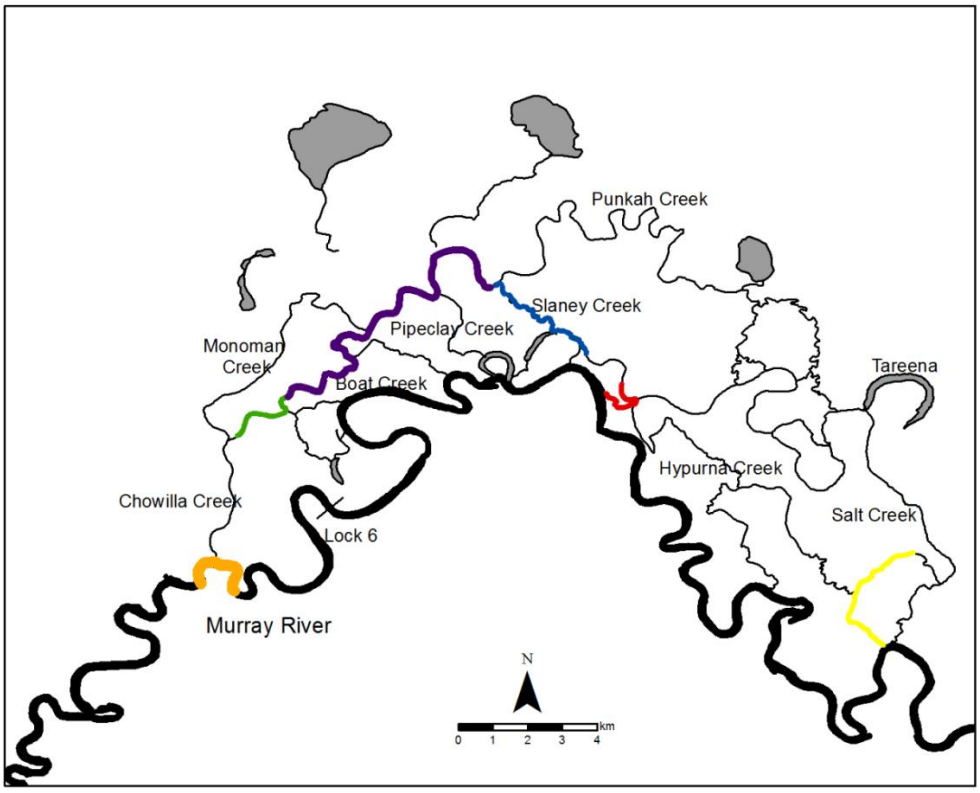

Figure 2. Sites sampled to target Murray cod in May 2017: Salt Creek downstream Bank K (yellow), Salt and Swiftys creeks (red), Slaney Creek (blue), Chowilla Creek downstream bridge (green), Chowilla Creek upstream bridge (purple) and River Murray main channel (orange).

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 thirteen 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 abundance 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 2005–2017 (excluding 2011) and 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) (using the package PRIMER v. 6.1.12 and PERMANOVA+ (Anderson *et al.* 2008) and indicator species analysis (Dufrene and Legendre 1997) using the package PCOrd v. 5.12 (McCune and Mefford 2005). Bray-Curtis (1957) similarities were used to construct the similarity matrices for all multi-variate PERMANOVA analyses and MDS ordinations. Indicator Species Analysis (Dufrene and Legendre 1997) was performed on the data from all sites (except 2011) to compare species relative abundances between years and determine species mesohabitat preferences. α for all statistical analyses = 0.05, or B-Y corrected α = 0.02 for pairwise comparisons.

Dufrene and Legendre's (1997) 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 prefect indicator. Statistical significance of each indicator value is tested by Monte Carlo (randomisation) technique, where the real data

are compared against 5000 runs of randomised data (Dufrene and Legendre 1997). For this study, the groups were assigned according to year or mesohabitat; therefore, this procedure was used for hypothesis testing (planned comparisons). 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 previous years, diversity was defined as the number of fish species (species richness) present within each mesohabitat and extent (distribution) was defined as the number of mesohabitats that each fish species occupied. In 2017 and hereafter, sites were grouped into aquatic mesohabitat categories (Table 1) with the diversity and extent of native fish species calculated using the methodology proposed by Robinson (2013).

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 from 2005–2017. 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 time period incorporates a range of hydrological conditions (i.e. 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 area or cryptic species. Expected to be collected in up to 20% of sites in the zone.	0.10
3	Locally abundant species. Expected to be collected in 20 to 70 % of sites in the zone.	0.45
5	Common and abundant species. Expected to be collected in 70 to 100% of sites in the zone.	0.85
0	Native species not historically recorded in this zone. 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 mesohabitats (i.e. proportion of sites within a mesohabitat where the species was sampled), across the entire study period (2005–2017).

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.

Recruitment of fish species (Ecological Objective 11)

Recruitment indices were developed for six native species that represent variation in the life histories exhibited by fish of the region. This variation is based upon longevity, biology/ecology and spatial scale of life history, and thus, 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 species, 2) Murray cod and 3) golden perch (*Macquaria ambigua ambigua)*. 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 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 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), thus represents recruitment to the adult population. Recruitment of YOY Murray cod was also calculated and is indicated by the proportion of fish <200 mm TL.

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 in 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

RESULTS

Hydrology during study period

From 1996 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, primarily 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 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 Murray in 2010/11 prompted a shift from disconnected lentic weir pool environments to connected lotic environments. The 2011 fish condition monitoring followed this significant overbank flow event (~93,000 $ML.d^{-1}$) and surveys were subsequently delayed until May 2011 (~2 months later than previous years). At this time, flow in the River Murray remained bankfull (~45,000 $ML.d^{-1}$) and water levels were approximately 1.5 m higher than ‘normal’ regulated pool level. Discharge remained relatively high in 2012, although it was substantially less than the 2011 flood year. Peak annual daily discharge continued to decrease from 2013 to early 2016. In October–December 2016, another overbank flow event occurred (QSA peak: ~95,000 $ML.d^{-1}$; Figure 3). Discharge in this event was slightly higher than that experienced in 2011, but duration of overbank flows was relatively short (~3 months) when compared to that in 2011 (~11 months) (Figure 3). During the condition monitoring survey from 6–24 March 2017, flow in the River Murray (QSA) had receded to below bankfull and ranged from 7,524–11,235 $ML.d^{-1}$ (Figure 3).

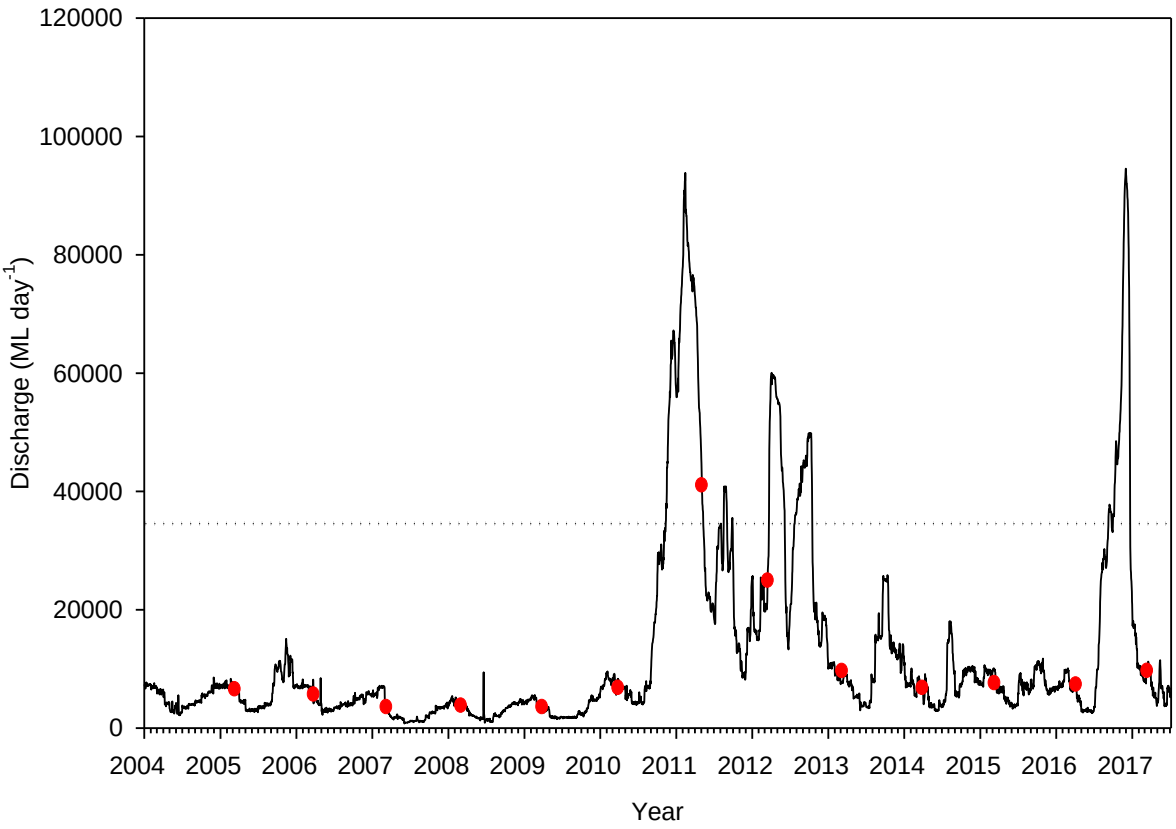

Figure 3. Mean daily flow (ML.d^{-1}) in the River Murray at the South Australian Border (Site A42610010) January 2004–July 2017 (MDBA, unpublished data). Red circles indicate sampling events and the dotted line represents approximate bankfull discharge at Chowilla (~35,000 ML.d^{-1}).

Catch Summary

A total of 23,573 fish, from 14 species (10 native and 4 non-native) were captured in 2017 (Table 5). The most abundant species were the native species bony herring (47%), Australian smelt (9%) and unspecked hardyhead (7%) and the non-native species common carp (21%) and goldfish (11%) (Table 2). 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 2005–2017, a total of 181,730 fish from 16 species (12 native and 4 non-native) were captured over thirteen surveys (Table 5, Appendix 1–11). The most abundant species from 2005–2010 were the small- to medium-bodied native species, unspecked hardyhead,

Australian smelt and bony herring (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 the reductions in numbers of common carp and goldfish. In 2015, total catch and standardised total abundances increased due to increased catches of Australian smelt, bony herring, Murray rainbowfish, unspecked hardyhead, 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 (*Gambusia holbrooki*) and goldfish. In 2017, total catch and standardised total abundance decreased, due primarily to lower catches of bony herring compared to 2016 (Table 5).

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 (e.g. 2015/16) (Table 5). Golden perch abundances remained low in 2017 (Table 5). Low abundances of Murray cod and silver perch were captured each year, with 2017 being characterised by the lowest abundance of Murray cod from all sampling years (Table 5). Standardised abundances of silver perch increased up until 2011 before decreasing in 2012–2017. Freshwater catfish were captured in low abundances in most years except for 2012–2013 when numbers increased, and spangled perch were only captured in 2011 and 2014–2015.

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). Bony herring and Australian smelt were most abundant in 2016 and 2017, respectively (Table 5). 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 all years, except in 2010, when higher numbers of gambusia were sampled (Table 5). Standardised abundances of common carp and goldfish were greatest in 2011 and 2017 (Table 5). Redfin perch (*Perca fluviatilis*) were not captured each year and when present, were sampled in low numbers. Standardised abundance of redfin perch was highest in 2017 (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 2005–2017.

Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Grand Total
Golden perch	69	75	112	94	174	114	802	286	230	148	143	99	139	**2485**
(*Macquaria ambigua ambigua*)	(3.8)	(4.7)	(7.5)	(6.7)	(8.3)	(5.2)	(38.2)	(13.0)	(10.5)	(7.0)	(6.5)	(4.7)	(6.3)	
Murray cod	13	11	14	15	21	15	7	9	7	7	14	13	5	**151**
(*Maccullochella peelii*)	(0.7)	(0.7)	(0.97)	(1.1)	(1.0)	(0.7)	(0.3)	(0.4)	(0.3)	(0.3)	(0.6)	(0.6)	(0.2)	
Silver perch	5	5	1	14	8	20	30	6	7	5	14	7	4	**126**
(*Bidyanus bidyanus*)	(0.3)	(0.3)	(0.1)	(1.0)	(0.4)	(0.9)	(1.4)	(0.3)	(0.3)	(0.2)	(0.6)	(0.3)	(0.2)	
Freshwater catfish	-	-	1	-	3	2	8	20	15	6	4	1	2	**62**
(*Tandanus tandanus*)			(0.1)		(0.1)	(0.1)	(0.4)	(0.9)	(0.7)	(0.3)	(0.2)	(0.1)	(0.1)	
Bony herring	3849	6229	6251	7782	10629	17948	2521	4433	5508	5225	10314	19,221	11,045	**110,955**
(*Nematalosa erebi*)	(213.8)	(389.3)	(416.7)	(555.9)	(506.1)	(815.8)	(114.6)	(201.5)	(250.4)	(248.8)	(468.8)	(915.3)	(502)	
Australian smelt	526	189	740	803	1067	589	484	132	215	151	1029	916	2169	**9010**
(*Retropinna semoni*)	(29.2)	(11.8)	(49.3)	(57.4)	(50.8)	(26.8)	(22.0)	(6.0)	(9.8)	(7.2)	(46.8)	(43.6)	(98.6)	
Murray rainbowfish	458	378	123	213	231	240	686	50	200	235	652	490	195	**4151**
(*Melantaenia fluviatilis*)	(25.4)	(23.6)	(8.2)	(15.2)	(11.0)	(10.9)	(31.2)	(2.3)	(9.1)	(11.2)	(29.6)	(23.3)	(8.9)	
Flat-headed gudgeon	93	6	20	18	70	21	11	20	69	35	65	14	4	**446**
(*Philypnodon grandicepts*)	(5.2)	(0.4)	(1.3)	(1.3)	(3.3)	(1.0)	(0.5)	(0.9)	(3.1)	(1.7)	(3.0)	(0.7)	(0.2)	
Dwarf flat-headed gudgeon	2	-	-	11	2	6	-	-	-	-	3	4	-	**28**
(*Philynodon macrostomus*)	(0.1)			(0.8)	(0.1)	(0.3)					(0.1)	(0.2)		
Unspecked hardyhead	2659	1602	1574	1786	2145	1687	455	26	84	89	656	2441	1687	**16,891**
(*Craterocephalus stercusmuscarum fulvus*)	(147.7)	(100.1)	(104.9)	(127.6)	(102.1)	(76.7)	(20.7)	(1.2)	(3.8)	(4.2)	(29.8)	(116.2)	(76.7)	
Carp gudgeon spp.	398	113	104	73	84	153	92	2	28	222	137	251	181	**1838**
(*Hypseleotris* spp.)	(22.1)	(7.1)	(6.9)	(5.2)	(4.0)	(7)	(4.2)	(0.1)	(1.3)	(10.6)	(6.2)	(12.0)	(8.2)	
Common carp*	234	466	277	185	400	357	11602	2023	1218	590	730	339	5164	**23,585**
(*Cyprinus carpio*)	(13.0)	(29.1)	(18.5)	(13.2)	(19.1)	(16.2)	(527.4)	(92.0)	(55.4)	(28.1)	(33.2)	(16.1)	(234.7)	
Gambusia*	200	61	125	60	107	490	647	12	40	65	126	300	398	**2631**
(*Gambusia holbrooki*)	(11.1)	(3.8)	(8.3)	(4.3)	(5.1)	(22.3)	(29.4)	(0.5)	(1.8)	(3.1)	(5.7)	(14.3)	(18.1)	
Goldfish*	202	296	177	156	551	217	3945	385	55	171	299	331	2517	**9302**
(*Carassius auratus*)	(11.2)	(18.5)	(11.8)	(11.1)	(26.2)	(9.9)	(179.3)	(17.5)	(2.5)	(8.1)	(13.6)	(15.8)	(114.4)	
Redfin perch*	-	-	9	3	7	8	5	3	-	-	3	1	27	**66**
(*Perca fluviatilis*)			(0.6)	(0.2)	(0.3)	(0.4)	(0.2)	(0.1)			(0.1)	(0.1)	(1.2)	
Spangled perch^	-	-	-	-	-	-	1	-	-	1	1	-	-	**3**
(*Leipotherapon unicolour*)							(0.05)			(0.05)	(0.05)			
Total species	**13**	**12**	**14**	**14**	**15**	**15**	**15**	**14**	**13**	**14**	**16**	**15**	**14**	**16**
Total number of sites	**18**	**16**	**15**	**14**	**21**	**22**	**21**	**22**	**22**	**21**	**22**	**21**	**22**	
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**	**181,730**
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**	

*Denotes non-native species, ^ denotes native species captured outside its 'normal' distribution range.

Temporal variation in fish abundance

The relative abundance of fish (all species combined) sampled each year varied substantially between 2005 and 2017 (Figure 4), with significant differences between years (*Pseudo-*$F_{12,\ 244}$ = 7.7203, p < 0.001). Between 2005 and 2011, relative abundance gradually increased then substantially decreased in 2012–2014 (Figure 4). Abundance again increased from 2015–2017, with the highest recorded abundance out of all sampling years occurring in 2016 (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). In 2017, non-native fishes again comprised a large proportion of the catch, but were not as dominant as in 2011 (Figure 4).

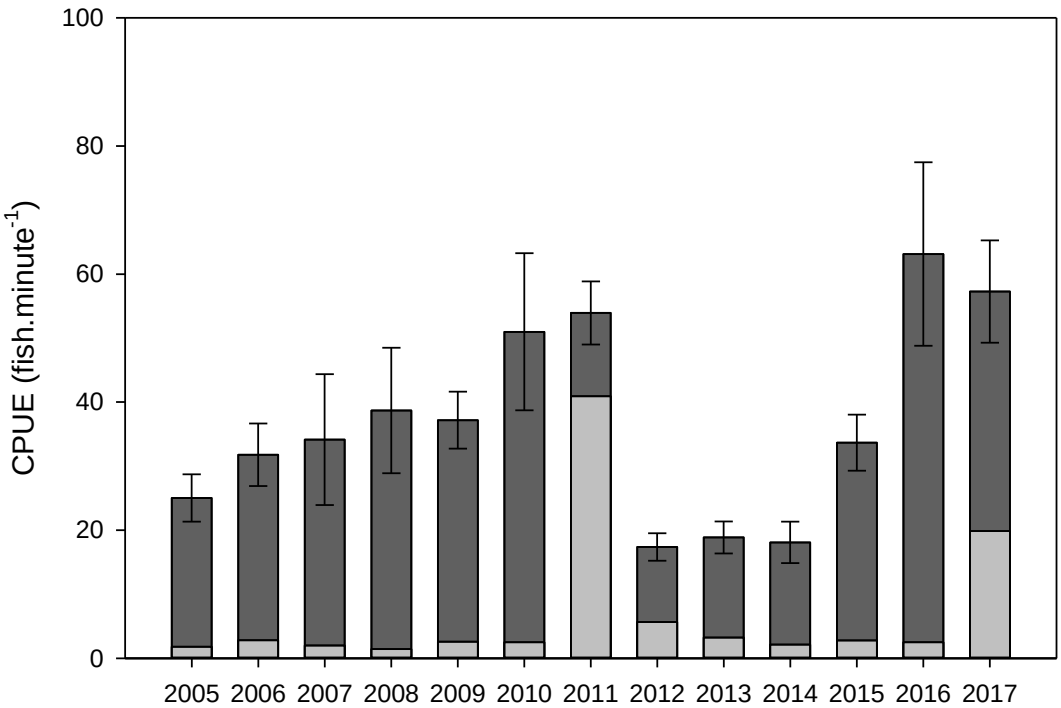

Figure 4. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of fish (all species combined) collected annually during standardised boat electrofishing surveys from 2005–2017 at 22 sites in the Chowilla Anabranch system and adjacent River Murray (dark grey = proportion native species, light grey = proportion of non-native species).

Temporal differences in fish assemblage structure

Two-factor PERAMNOVA showed there was a significant difference between years and mesohabitats but no significant interaction (Table 6). This indicated the fish community changed through time and was different between mesohabitats but the change through time was consistent between mesohabitats.

Pairwise comparisons revealed significant differences in fish assemblages among mesohabitats for all comparisons (α = 0.02) (Table 7). Non-metric multi-dimensional scaling (MDS) demonstrated that fish assemblages sampled in 2005–2010, 2015 and 2016 were similar but distinctly different from assemblages sampled in 2011, 2012–2014 and 2017 (Figure 5). A similar pattern was observed for fish assemblage differences between mesohabitats in all sites for all years (excluding 2011) (Figure 6a –6d).

Table 6. PERMANOVA results comparing the relative abundances of fish between years and mesohabitats over eleven years from 2005–2017, excluding 2011. Significant *P* values are highlighted in bold.

Factor	***df***	***Pseudo-F***	***P***
Year	11, 235	11.351	**0.001**
Mesohabitat	3, 235	15.84	**0.001**
Year x mesohabitat	33, 235	1.0462	0.361

Table 7. PERMANOVA pair-wise comparisons between fish assemblages among different mesohabitats in Chowilla from 2005-2017, excluding 2011. Significant values are highlighted in bold (B-Y corrected α = 0.02).

Pairwise comparison		*t*	*p* value
Mesohabitat	**Mesohabitat**		
Fast	Slow	5.2498	**0.001**
Fast	Backwater	4.6677	**0.001**
Fast	River	2.9996	**0.001**
Slow	Backwater	2.6278	**0.001**
Slow	River	3.8570	**0.001**
Backwater	River	2.5147	**0.001**

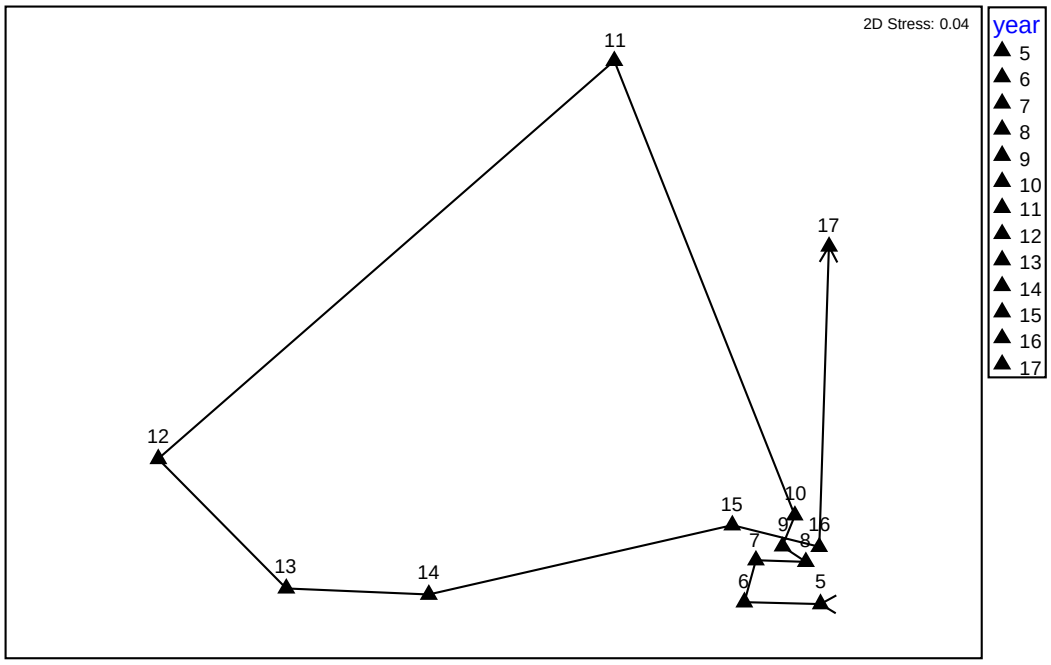

Figure 5. Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled from all years/sites combined.

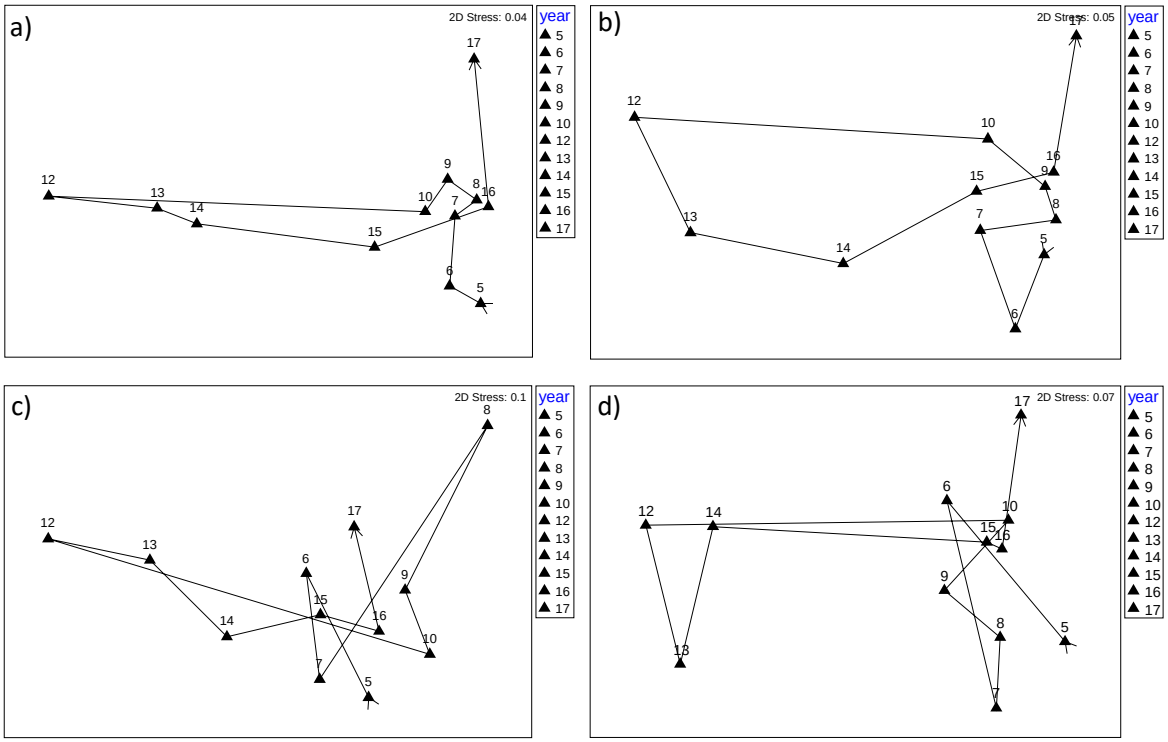

Figure 6. Non-metric multi-dimensional scaling (MDS) plots of a) fast-flowing, b) slow-flowing, c) backwater and d) river mesohabitats sampled from all years/sites combined (excluding 2011).

Indicator species analysis demonstrated that fish assemblages were characterised by small to medium bodied native fishes (unspecked hardyhead, carp gudgeon, dwarf flatheaded gudgeon, eastern gambusia, Murray rainbowfish and bony herring) in low flow years (2005-10, 2015 and 2016) and large-bodied native (golden perch and freshwater catfish) and non-native (common carp, goldfish and redfin perch) fishes post flood years (2012 and 2017) (Table 8). The small-bodied native fish, Australian smelt, also characterised the fish assemblage in 2017 (Table 8).

Table 8. Indicator species analysis comparing the relative abundance of fish amongst years from 2005–2017, excluding 2011. Significant indicators (α = 0.05) signifies that a species occurs in a higher relative abundance in a specific year. 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	Indicator value	*p* value
Unspecked hardyhead	2005	16.69	**0.0384**
Flat-headed gudgeon	2005	16.7	0.0522
Carp gudgeon spp.	2005	21.8	**0.0342**
Murray cod	2007	4.4	0.9192
Dwarf flat-headed gudgeon	2008	20.9	**0.0006**
Silver perch	2008	7.3	0.2975
Gambusia	2010	22.2	**0.0192**
Golden perch	2012	15.2	**0.0004**
Freshwater catfish	2012	14.0	**0.0040**
Spangled perch	2015	2.4	1.0000
Murray rainbowfish	2015	15.5	**0.0204**
Bony Herring	2016	17.2	**0.0340**
Australian smelt	2017	22.7	**0.0020**
Goldfish	2017	43.4	**0.0002**
Common carp	2017	41.6	**0.0002**
Redfin perch	2017	24.0	**0.0002**

From 2005–2017, fast-flowing mesohabitats were characterised by golden perch, Murray cod, silver perch, and Australian smelt (Table 9). Main river channel mesohabitats were characterised by Murray rainbowfish, unspecked hardyhead and redfin perch, and backwater mesohabitats were characterised by carp gudgeons. No species were significantly 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 2005–2017, excluding 2011 (no species were found to be associated with slow-flowing mesohabitats). A significant difference ($P \leq 0.05$) 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	**0.0002**
Murray cod	Fast	**0.0002**
Silver perch	Fast	**0.0060**
Australian smelt	Fast	**0.0002**
Bony Herring	Fast	0.2613
Freshwater catfish	Fast	0.0564
Flat-headed gudgeon	Slow	0.3837
Murray rainbowfish	River	**0.0002**
Spangled perch	River	0.4925
Dwarf flat-headed gudgeon	River	0.1380
Unspecked hardyhead	River	**0.0002**
Redfin perch	River	**0.0078**
Carp gudgeon spp.	Backwater	**0.0090**
Common carp	Backwater	0.3477
Goldfish	Backwater	0.3077
Gambusia	Backwater	0.1854

Targeted Murray cod sampling

A total of 23 Murray cod were collected in 2017 (Table 10). Five were captured during standard condition monitoring in March and the remaining 18 were captured during targeted sampling in eight regions of Chowilla in May 2017. Relative abundances of Murray cod were highest in Slaney and Chowilla creeks (Table 10). Since targeted Murray cod surveys were introduced in 2014, relative abundance for both targeted cod surveys and condition monitoring combined, indicated that Murray cod abundance was similar in 2014–2015 (0.0604 and 0.0607 (fish.min^{-1}), respectively), increased in 2016 (0.08 fish.min^{-1}) and decreased in 2017 (0.04 fish.min^{-1}) (Figure 7).

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 2017.

Species	Targeted survey sites								Standard condition monitoring (*n* = 22 sites)	Total
	Chowilla Creek d/s bridge	Chowilla Creek u/s bridge	River Murray Main channel	Slaney Creek	Swiftys Creek	Pipeclay Creek	Salt Creek	Bank K		
Murray cod (*Maccullochella peelii*)	1 *(0.06)*	3 *(0.12)*	0	12 *(0.18)*	1 *(0.09)*	0	1 *(0.09)*	0	5 *(0.01)*	23 *(0.04)*

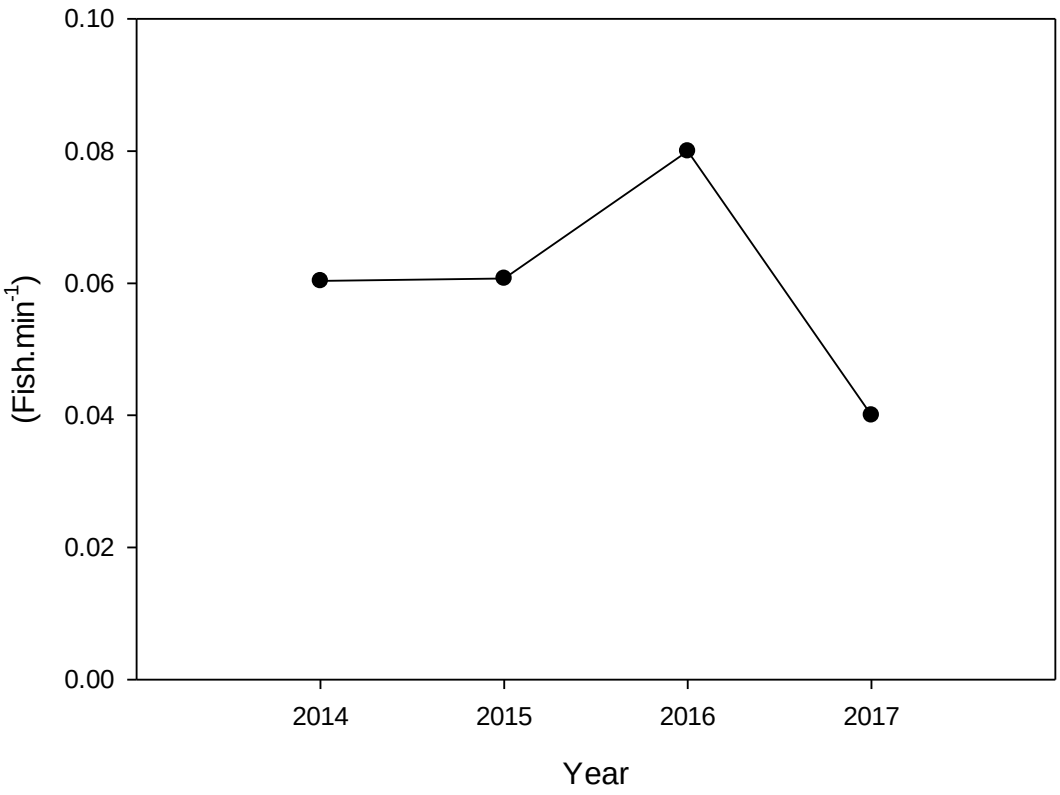

Figure 7. Relative abundance (fish.min^{-1}) of Murray cod from targeted Murray cod surveys and condition monitoring combined since 2014.

Diversity and extent of fish species (Ecological Objective 10)

Diversity

In years 2005–2007, 2009, 2011, 2015 and 2016 diversity was greater than the reference value across all mesohabitats (Figure 8). In years 2008, 2010 and 2012–2014 diversity was less than the reference value across one or more mesohabitats (Figure 8). In 2017, fish diversity was greater than the reference value in slow flowing, backwater and river mesohabitats while only slightly less than the reference value in fast flowing mesohabitats (Figure 8).

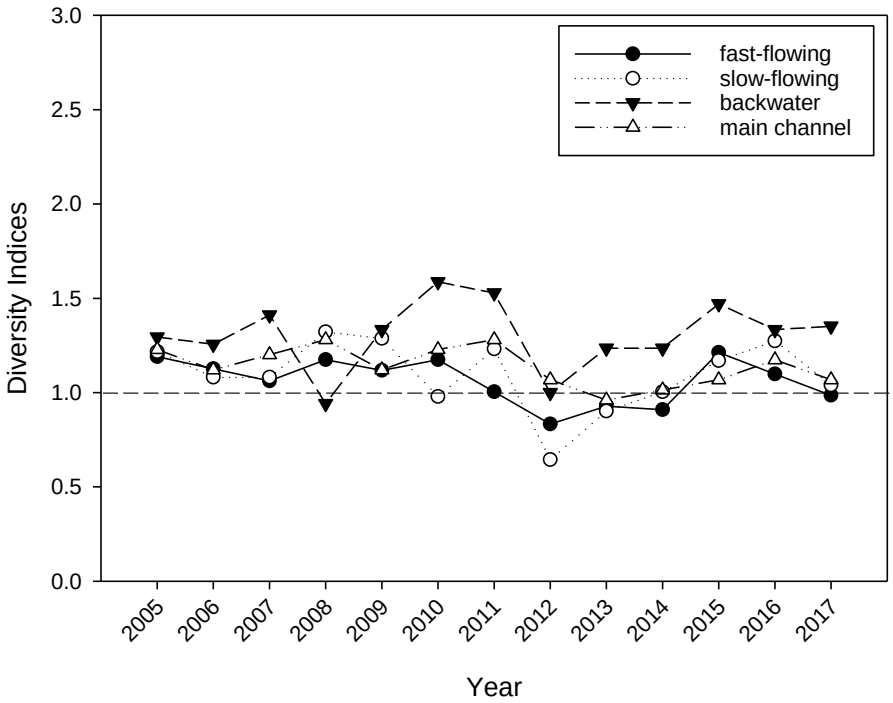

Figure 8. Diversity indices for fast-flowing, slow-flowing, backwater and main channel mesohabitats at the Chowilla Icon Site from 2005–2017.

The mean of mesohabitat diversity indices for each year was calculated to provide an overall icon site diversity score (Figure 9). In all years, except 2012, the icon site diversity score was greater than or equivalent to the reference value (Figure 9).

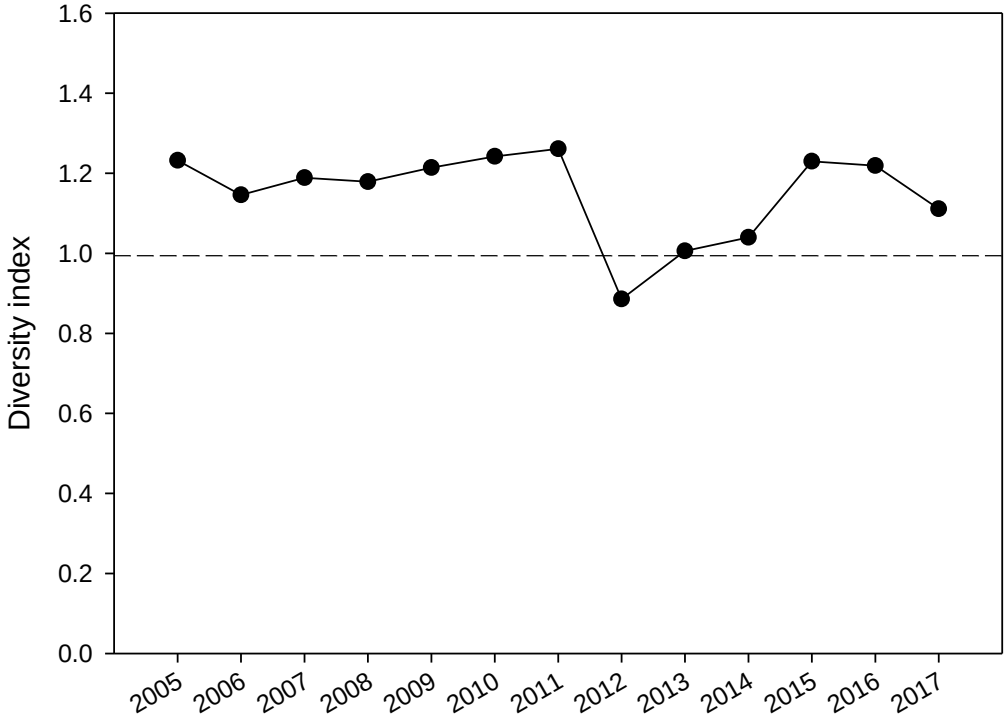

Figure 9. Summary of the calculated Icon Site Diversity Index (DI) from 2005–2017.

Extent

For the large-bodied species golden perch, distribution among mesohabitats was relatively stable across years (Figure 10a). Freshwater catfish had limited distribution from 2005–2010 and 2016–2017, whilst from 2011–2015 distribution either increased or remained stable (Figure 10a). Murray cod distribution varied greatly from year to year (Figure 10a). Silver perch distribution remained relatively stable between years, however, decreases were evident in 2007, 2009 and 2016–2017, whilst distribution increased in 2011 (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 and 2014–2016) (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 flows that occurred post flooding (Figure 10b).

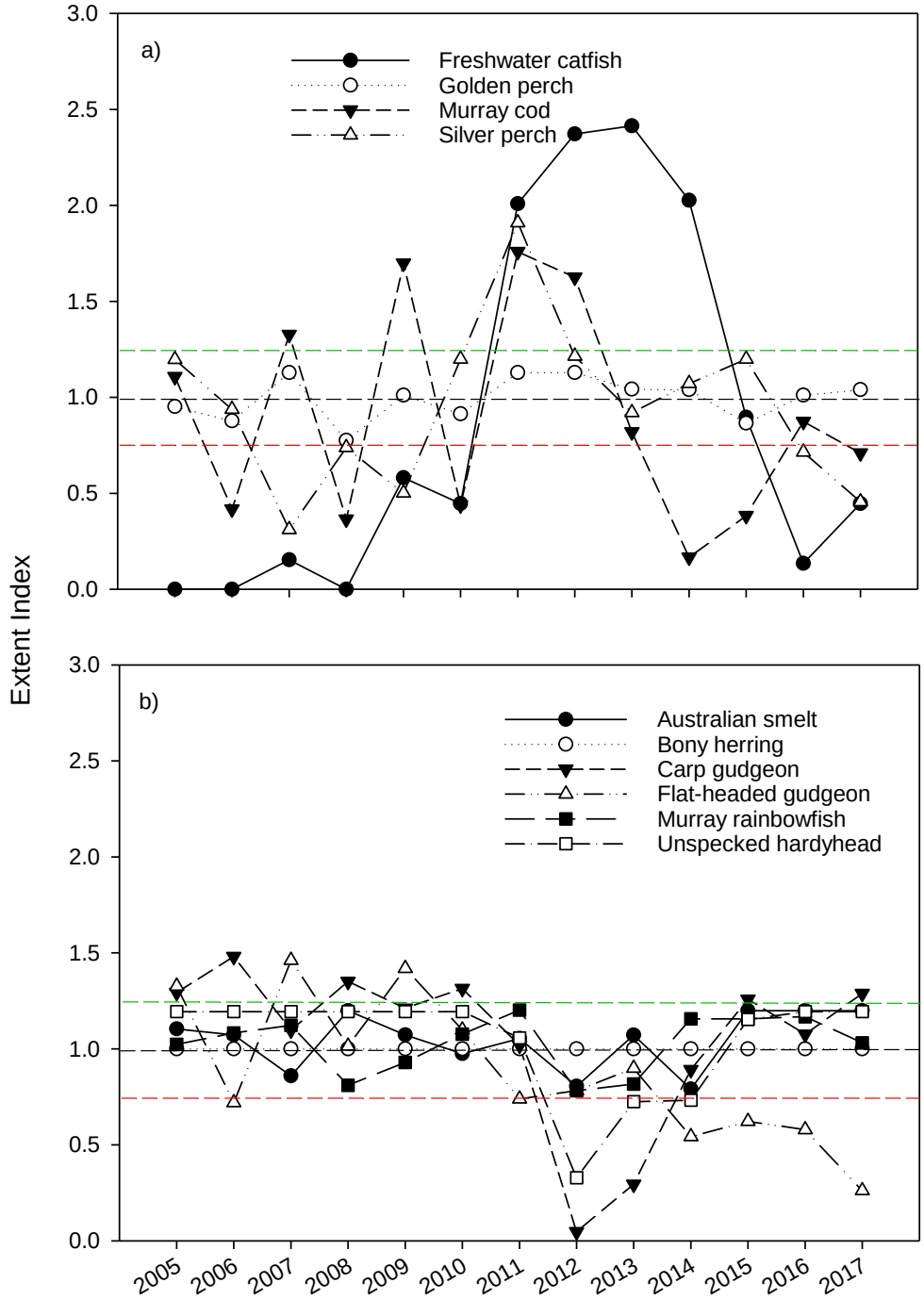

Figure 10. Extent Index (EI) scores for a) large-bodied native species and b) small- to medium-bodied native species at the Chowilla Icon Site from 2005–2017. Black dashed line represents extent equal to the reference, green dashed line extent 25% greater than reference and red dashed line extent 25% lesser than reference.

Recruitment of small- to medium-bodied native species

Recruitment index values varied among sampling years for most small- to medium-bodied species, however, recruitment was evident for all species in most years (Figure 11). Unspecked hardyhead recruitment was enhanced from 2005–2010 and in 2016, but decreased in 2012–2015 and 2017 (Figure 11). Recruitment of Murray rainbowfish was highest in 2005–2006 and 2014–2015 (Figure 11). Australian smelt recruitment was variable, with the highest recruitment observed in 2005, 2007–2010 and 2015–2017 and lowest in 2006 and 2012–2014 (Figure 11). Bony herring recruitment was highest in 2007–2010 and 2015–2017 (Figure 11).

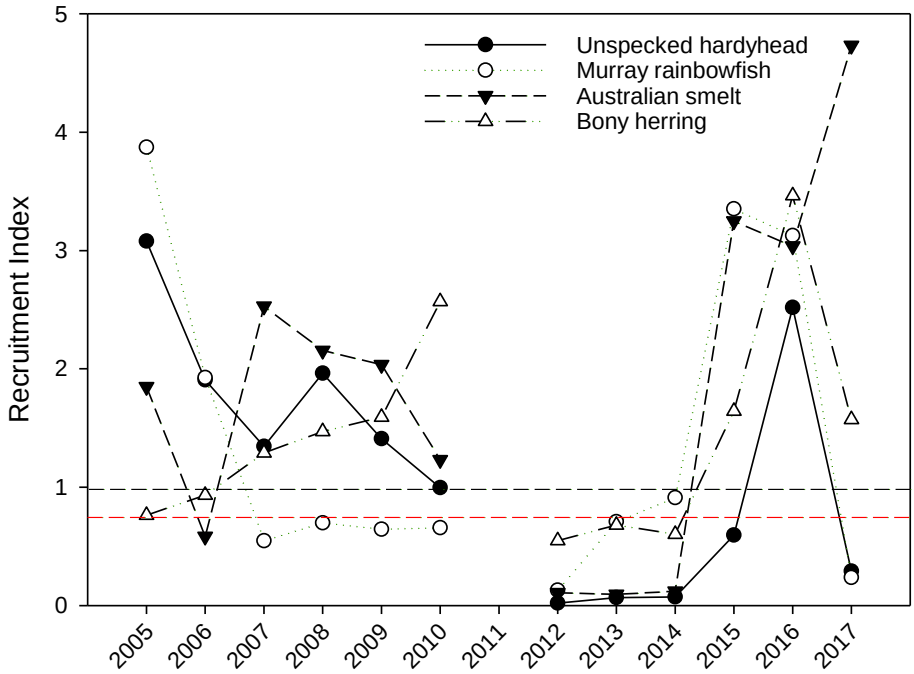

Figure 11. Recruitment Index (*RI*) values for unspecked hardyhead, Murray Rainbowfish, Australian smelt and bony herring from 2005–2017. Values for 2011 are not presented as sampling occurred at atypical time of year due to flooding. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Recruitment of large-bodied native species

Murray cod

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

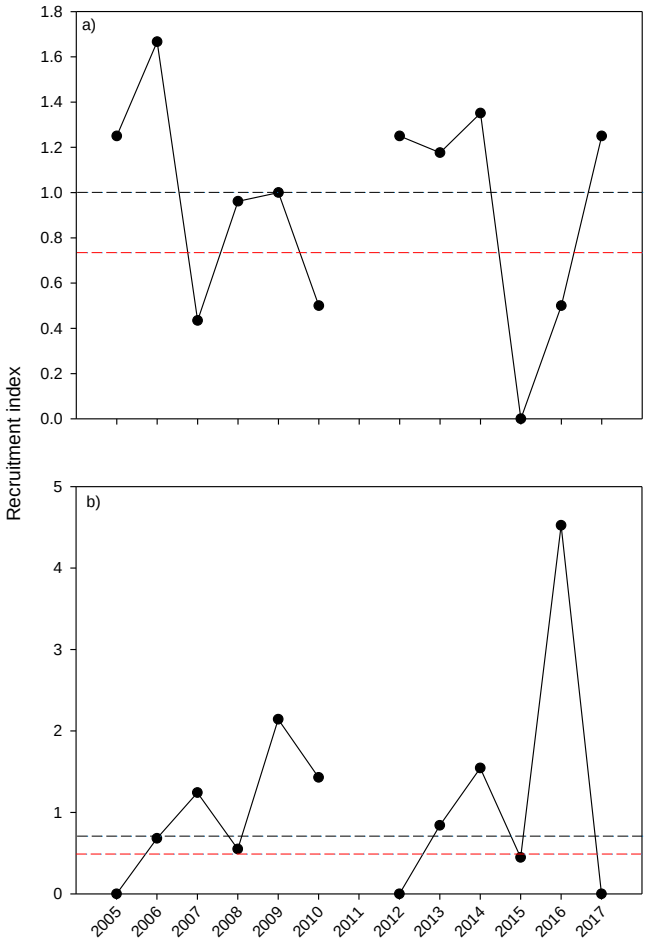

Figure 12. Recruitment Index (*RI*) values for a) Murray cod ranging 400–600 mm TL and b) YOY Murray cod (<200 mm TL) from 2005–2017. Values for 2011 are not presented as sampling occurred at an atypical time of year due to flooding. Dashed black line represents recruitment equal to the reference value 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 RI values exceeded the reference value (Figure 13). Recruitment was limited or absent in the remaining years, including 2017 (Figure 13).

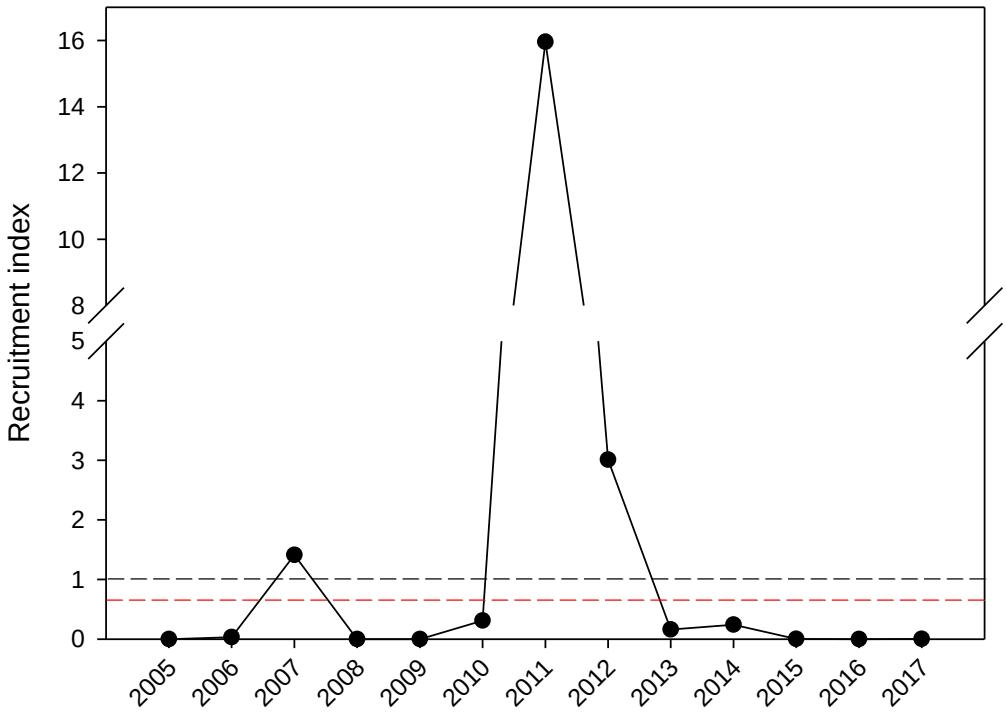

Figure 13. Recruitment Index (RI) values for golden perch from 2005–2017. Dashed black line represents recruitment equal to the reference value and the dashed red line, recruitment 75% of the reference value.

Recruitment of non-native species

The 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 14 and 15). Nevertheless, for common carp, recruitment of age 0+ fish was temporally variable and strong cohorts were evident in 2006, 2009–2012, and 2014–2017, whilst for goldfish, strong cohorts of 0+ fish recruitment were evident in 2006, 2008–2009, and 2014–2017. In 2017, both common carp and goldfish exhibited broad size ranges with small (most likely YOY) individuals representing ~60% and ~84%, respectively, of sampled populations (Figure 14 and 15).

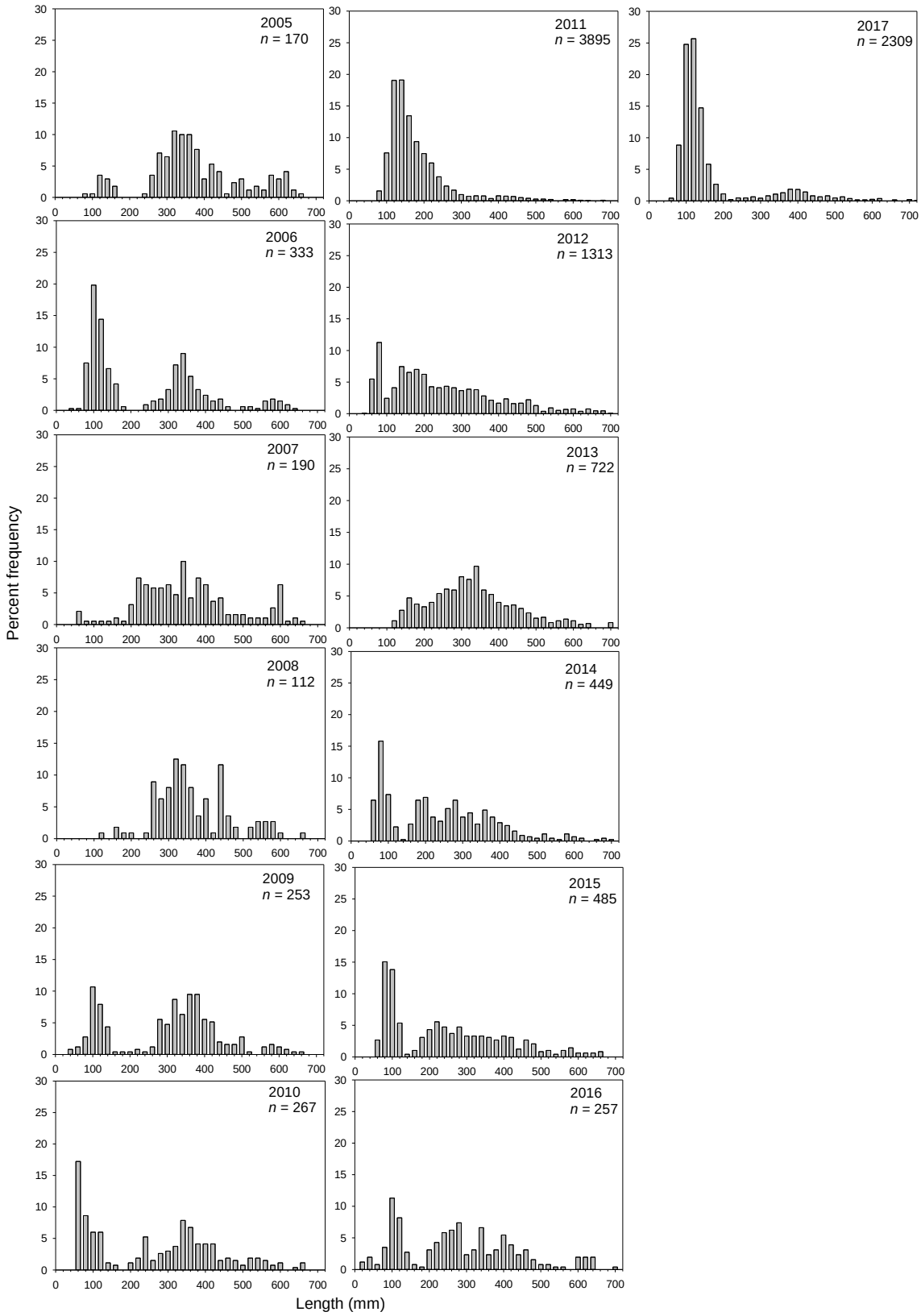

Figure 14. Length distribution of common carp captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2017.

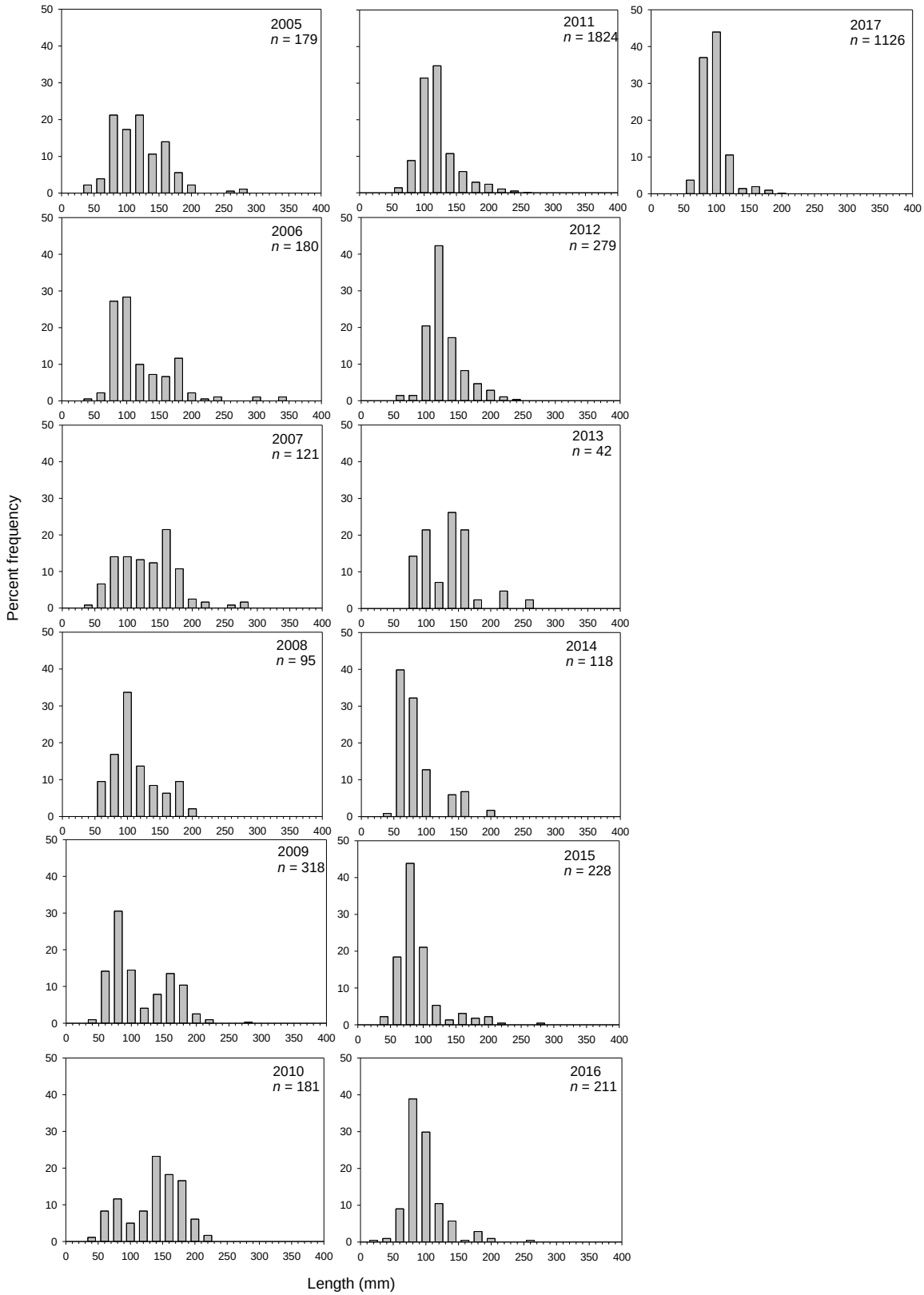

Figure 15. Length distribution of goldfish captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2017.

DISCUSSION

Condition monitoring of fish assemblages at Chowilla from 2005–2017 indicates Ecological Objectives 10 and 11 (as defined in the Chowilla Environmental Water Management Plan) are being met. Over the 13-year sampling period, the diversity and extent of native species have been maintained.

Abundance

In 2017, 14 species were sampled at 22 sites in 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, common carp and goldfish the most abundant. The assemblage in 2017 was similar to that in 2011, with both years being characterised by extensive flooding in the River Murray in the spring/summer prior to monitoring.

From 2005–2010, bony herring and unspecked hardyhead were significantly more abundant in lentic habitats (backwater and River Murray mesohabitats) and a decline in relative abundance in 2011 was likely due to reduced cover of submerged aquatic macrophytes following flooding. Both species are significant indicators of low-flow years in main-channel habitats of the lower River Murray, when benign hydraulic conditions (i.e. lentic habitats) and suitable instream habitats (i.e. submerged aquatic macrophytes) prevail (Bice *et al*. 2013). The abundance of both species increased in association with low flows in the River Murray in 2015–2016, but again decreased in 2017 post flooding.

The abundance of Australian smelt from 2005–2017 was variable, with the species generally most abundant during years of low flow. Australian smelt eggs and larvae are often found in low-flow environments (King 2004) and higher flows are considered to disturb spawning sites and reduce survival (Milton and Arthington 1985). Successful recruitment of Australian smelt via survival of eggs and larvae has been found to be greatest during times of environmental stability (Milton and Arthington 1985; Webb *et al.* 2010), with no evidence of an increase in spawning or recruitment with flooding (King *et al*. 2003).

Contrary to this, in 2017, post overbank flooding, Australian smelt abundances were the highest recorded since sampling commenced at Chowilla in 2005. The mechanisms for this increased abundance post high flows remain unexplored, but may relate to increased riverine productivity post-flooding (*sensu* Junk *et al.* 1989) and a reduction in flows (back within the river channel by January 2017) providing suitable spawning and recruitment conditions for Australian smelt.

The abundance of carp gudgeon also varied from 2005–2017, with highest abundances generally recorded in low-flow years, and substantial decreases in abundance following periods of high within-channel or overbank flows (e.g. 2012–2013). Similar patterns have been observed throughout the lower River Murray where carp gudgeons are abundant during times of low flow and absent from the catch post over-bank flooding, likely due to the reduced cover of submerged aquatic macrophytes in main channel habitats (Bice *et al.* 2014). Like Australian smelt, however, high abundances of carp gudgeons were collected in Chowilla in 2017 after overbank flooding in spring/summer 2016. Again, this may be related to the timing and duration of flooding in 2016 (spring–early summer), in comparison to extended spring–autumn flooding in 2010–2011, and therefore conducive conditions to reproduction and recruitment in 2016–2017.

Golden perch were most abundant in 2011, post widespread flooding in the MDB, and least abundant in 2005–10 and 2014–16. Golden perch are flow-cued spawners 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 the Chowilla region followed extensive overbank flooding in 2010–11 (Zampatti and Leigh 2013b) and to a lesser extent in 2017. Increased abundance in 2017, in comparison to 2016, was not related to the recruitment of young-of-year fish, but may have been promoted by immigration.

Freshwater catfish were 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 and 2014–2016). 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 late 2016, the abundance of freshwater catfish at Chowilla remained low in 2017.

Murray cod were generally captured in low abundances (7–21 individuals.year^{-1}) in the Chowilla condition monitoring surveys, however, annual targeted surveys in May–June 2014–2017 resulted in higher catches (*n* = 40, *n* = 38, *n* = 60 and *n* = 23, respectively). Based on integrated condition monitoring and targeted Murray cod survey data, there was a decrease in abundance of Murray cod collected at Chowilla in 2017 (Figure 6). Reduced abundance of Murray cod in 2017 may be due to mortality associated with anoxic blackwater coincident with widespread flooding in the River Murray in spring/summer 2016 (SARDI unpublished data).

Common carp and goldfish were the most abundant non-native species in most years. Abundances of common carp and goldfish were greatest following years of increased discharge and water level (within-channel and overbank) as observed 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).

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 species diversity in the Chowilla region has either increased or been maintained over the duration of this condition monitoring project (2005–2017). It is likely that the diverse aquatic habitats of Chowilla (e.g. anabranching creeks, backwaters, wetlands, terminal lakes and main river channel), promote mesohabitat heterogeneity and a diverse native fish assemblage (Lloyd 1990, Pierce 1990; Zampatti *et al*. 2011).

The extent of most species throughout the available aquatic mesohabitats in each sampling year has either increased or been maintained. Nevertheless, distinct species characterise mesohabitats. Over the 13-year sampling period (2005–2017), Murray cod, golden perch, silver perch, and Australian smelt characterised fast-flowing mesohabitats, carp gudgeon characterised backwater mesohabitats and Murray rainbowfish, unspecked hardyhead and redfin perch characterised River Murray mesohabitats. 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.

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 annual recruitment in most years, with the exception of unspecked hardyhead and Australian smelt in 2012–2014 and Murray rainbowfish and unspecked hardyhead in 2017. 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 flow (Baumgartner *et al*. 2013). As such, these species in the Chowilla region displayed higher rates of recruitment in low flow years (2005–2010 and 2015–2016), and limited recruitment following high flow periods in 2012–2014 and to a lesser extent in 2017.

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 2014–2017 has augmented the catch of Murray cod in Chowilla and the adjacent River Murray and has facilitated the development of a reproductive (fish 400–600 mm TL) and YOY (fish <200 mm TL) recruitment index.

The Murray cod recruitment index for sexually mature individuals (400–600 mm TL) indicates that since 2005 some level of recruitment has occurred in all years excluding 2015. Increases in recruitment were observed in 2005–2006, 2012–2014 and 2017, which could be attributed to the presence of young-of-year (YOY) fish in length-frequency data 3–4 years prior, thus indicating successful survival of these fish (Fredberg and Zampatti 2017). The YOY recruitment index for Murray cod was variable with a distinct peak in YOY recruitment in 2016. This peak in recruitment was present throughout the lower River Murray, during a low flow year (Ye *et al.* 2017). The mechanism remains unresolved.

Golden perch recruitment was episodic from 2005–2017, 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 higher 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 Murray, strong recruitment of golden perch generally occurs when spring-summer flows in the lower River Murray exceed 14,000 $ML.d^{-1}$ (Zampatti and Leigh 2013a). Unexpectedly, golden perch recruitment was not evident in 2017 despite overbank flooding in late 2016. This in part may have been attributed to an anoxic blackwater event that occurred throughout the MDB during overbank flooding in spring/summer of 2016, which in-turn may have disturbed golden perch spawning and/or survival of early lifestages.

Recruitment of non-native species

Increased recruitment of YOY common carp and goldfish corresponded with increased discharge and water levels that occurred in the Chowilla region prior to condition monitoring surveys 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/or recruitment habitat.

CONCLUSIONS

Annual monitoring of fish assemblages at Chowilla from 2005–2017 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

Thirteen years of annual condition monitoring at Chowilla has provided valuable information on the ecology of freshwater fish at Chowilla and the lower River Murray, but in some cases, the underlying causal mechanisms of observed responses remain speculative. We propose that hypothesis based manipulative experiments could be used in conjunction with condition monitoring to further test and refine our current conceptual understanding of fish ecology in the lower River Murray, particularly in relation to contemporary management interventions at Chowilla (e.g. the Chowilla Creek regulator and new fishway structures).

Some research questions in order of priority include:

- Importance of Chowilla as a recruitment source for golden perch, 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 fish (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 artificial floodplain inundation.
- Spatio-temporal variation in spawning and recruitment of Murray cod, golden perch and common carp in the Chowilla system in relation to natural and artificial floodplain inundation using the Chowilla regulator.
- 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.

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APPENDICIES

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**																					
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**18**	**19**	**20**	**21**	**22**	**Grand 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**