Inland Waters & Catchment Ecology

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Chowilla Icon Site Fish Assemblage Condition Monitoring 2016

J. Fredberg and B. P. Zampatti

SARDI Publication No. F2008/000907-8
SARDI Research Report Series No. 940

SARDI Aquatics Sciences
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March 2017

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT
Government of South Australia Department of Environment, Water and Natural Resources
Australian Government
MURRAY–DARLING BASIN AUTHORITY
SOUTH AUSTRALIA
Government of South Australia Primary Industries and Regions SA
SARDI SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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This publication may be cited as:
Fredberg, J. and Zampatti, B.P. (2017). Chowilla Icon Site Fish Assemblage Condition Monitoring 2016. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication F2008/000907-8. SARDI Research Report Series No. 940. 58pp.

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Printed in Adelaide: February 2017

SARDI Publication No. F2008/000907-6
SARDI Research Report Series No. 839

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Date: 2 March 2017

Distribution: DEWNR, SAASC Library, SARDI Waite Executive Library, Parliamentary Library, State Library and National Library

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ACKNOWLEDGEMENTS

Thanks to the SARDI staff who assisted with field sampling and laboratory processing for this project; namely, Ian Magraith, Paul Jennings, David Fleer, Phillipa Wilson, Neil Wellman, David Short, Arron Strawbridge and Thiago Vasques Mari. We also thank Chris Bice for his advice and assistance in undertaking statistical analyses.

Tony Herbert, Allison Stokes, Todd Wallace, Richard Watts and Mark Schultz (Department of Environment, Water and Natural Resources, DEWNR) managed the project at different stages, developed targets and provided input into site selection. Robbie Bonner, Darryl Jones, Warren Beer and Tony Waye (SA Water) provided space for us to live at Lock 6 and generous hospitality. Thanks to Phil Strachan, Erin Lenon and Simon Frankel (DEWNR) for facilitating access to various parts of the Chowilla Game Reserve, and Jock and James Robertson for access to the Chowilla lease.

Thanks to the reviewers who constructively reviewed a draft of this report. Funding for the 2016 condition monitoring survey was provided by the Murray-Darling Basin Authority (MDBA) Living Murray Initiative through the Department of Environment, Water and Natural Resources and the project was managed by Jan Whittle.

“The living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian, Australian Capital Territory and Commonwealth governments, coordinated by the Murray-Darling Basin Authority.”

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 wide range of aquatic habitats that are now rare in the region, and these habitats support a diverse native fish community. Nevertheless, the Chowilla Floodplain 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 were chosen 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 March 2016, a total of 24,428 fish from 15 species were sampled from 21 sites within Chowilla and the adjacent River Murray main channel. This was the highest annual abundance of fish recorded from 2005–16. The fish assemblage consisted of 11 native and 4 non-native species, with bony herring (*Nematalosa erebi*), unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Australian smelt (*Retropinna semoni*), and Murray rainbowfish (*Melanotaenia fluviatilis*) most abundant.

The fish assemblage in 2016 was most similar to that in the period 2005–10 and 2015, when drought and associated low flows promoted benign hydraulic conditions in the lower River Murray and abundant submerged macrophytes, an important habitat for small-bodied generalist fishes.

Condition monitoring data from 2005–2016 indicate that Objective 10 and 11 of the management plan are being met. Over the 12 year sampling period, species diversity (species richness) and distribution were similar each year. Most species were widespread throughout the available aquatic mesohabitats; however, some species were specific to one or more mesohabitats. In all years, species diversity was generally highest in fast-flowing mesohabitats and lowest in backwater mesohabitats. The native species Murray cod, golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), and Australian smelt (*Retropinna semoni*) characterised fast-flowing mesohabitats and non-native goldfish (*Carrasius auratus*) characterised backwaters.

Length-frequency distributions indicate that small- to medium-bodied native species, unspecked hardyhead, Murray rainbowfish, Australian smelt and bony herring successfully recruited in 2016. Recruitment was also detected for Murray cod (i.e. presence of age 0–1+ fish). In 2016, 19 individual small Murray cod (<200 mm) were captured, the highest out of all sampling years (2005-15). The addition of a targeted approach since 2013 for assessing Murray cod recruitment has resulted in higher catch rates of Murray cod. Combined data from targeted Murray cod surveys and condition monitoring indicate Murray cod relative abundances have remained stable from 2014-16. The presence of cod <200 mm in most years indicates that Murray cod recruitment occurs consistently within Chowilla.

Golden perch recruitment to young-of-year was absent in 2016, most likely due to low flows in the lower Murray and Darling rivers in spring–summer 2015–16 and the lack of a distinct within-channel flow pulse (nominally required to be ≥14,000 ML/d to promote golden perch spawning and recruitment in the lower River Murray). In 2016, fish spawned in the Darling River in 2009 continued to comprise a large proportion of the sampled population (~46%) along with distinct cohorts spawned in 2010/11 and 2011/12. The number of freshwater catfish collected in 2016 was again too low (n = 1) to enable assessment of recruitment and a targeted survey approach may be required to accurately assess catfish recruitment.

Twelve years of annual condition monitoring has provided valuable information on the ecology of freshwater fish at Chowilla and the lower River Murray. The range of responses to hydrological variability suggests that consideration of the individual life histories of native and non-native fishes will be required to successfully manage the rehabilitation of fish populations in the lower River Murray, particularly in regards to flow restoration.

INTRODUCTION

The Chowilla Anabranch and Floodplain system (hereafter Chowilla) contains the largest remaining area of undeveloped floodplain habitat in the lower River Murray. It is comprised of 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, a Wetland of International Importance for nationally threatened species, habitats and communities. Furthermore, it is considered an *Icon Site* under the Murray-Darling Basin Authority's *The Living Murray Program* (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 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 (Walker and Thoms 1993; Baker *et al.* 2000; Walker 2006). 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.

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, a Chowilla Floodplain Environmental Water Management Plan (MDBA 2012) has been 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.

The aim of the current condition monitoring program is to assess the fish community at Chowilla in reference to these 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 summarises the results of fish condition monitoring undertaken in 2016 with reference to results from 2005–2015.

METHODS

Fish condition monitoring at the Chowilla Icon Site 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 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).

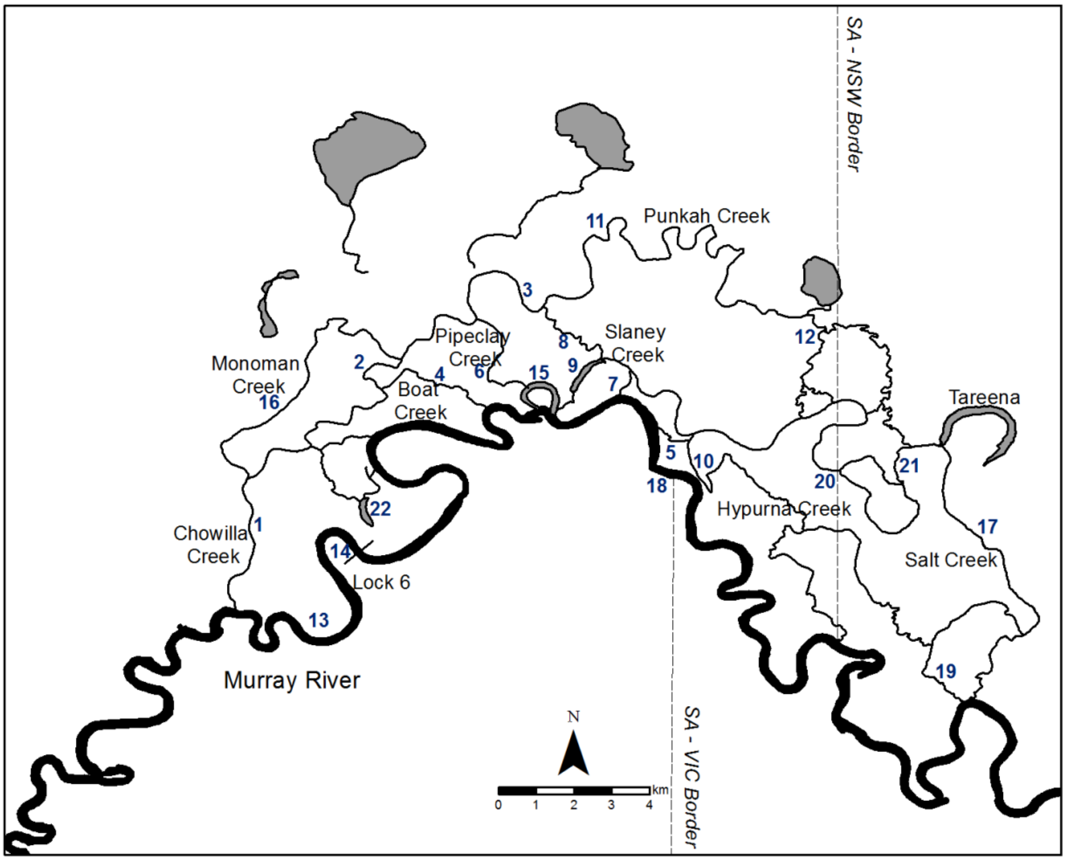

Figure 1. Map of the Chowilla Anabranch and Floodplain system and the adjacent River Murray main channel showing the fish condition monitoring sites 1–22.

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 2005–2016. 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
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**

In 2016, 21 sites were sampled from 15 March to 1 April (Table 1, Figure 1). Site 22 (Pilby Billabong) was not sampled in 2016 as it was dry. Condition monitoring from 2005–2016 (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 fish 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 and 2008/09, 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/April 2016 was undertaken following a peak flow in the lower River Murray of ~12,000 ML.d^{-1} in October 2015, and the operation of Chowilla regulator and ancillary structures (i.e. supplementary floodplain regulators and blocking banks) from 6 October to 18 December 2015 during which the upstream water level in Chowilla Creek was raised to a maximum height of 17.86 m AHD on the 15 November 2015. Over the period of regulator operation, discharge in Chowilla Creek varied from 2965–4283 ML.d^{-1} and QSA from 6500–11,405 ML.d^{-1}. Over the same period, flows in Slaney and Pipeclay Creeks were increased up to a maximum of 742 and1583 ML.d^{-1}, respectively.

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 and measured for length (± 1 mm, caudal fork length, FL or total length, TL). Where large numbers of an individual species were collected a sub sample of 20 individuals were measured for length.

In addition to March/April surveys, targeted sampling was conducted in May 2016 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 total length) 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 from 16-27 May 2016 (Figure 2) using the methods described above. At each site, however, effort (power-on time) was increased and specific habitats were targeted (e.g. large wood and flowing water).

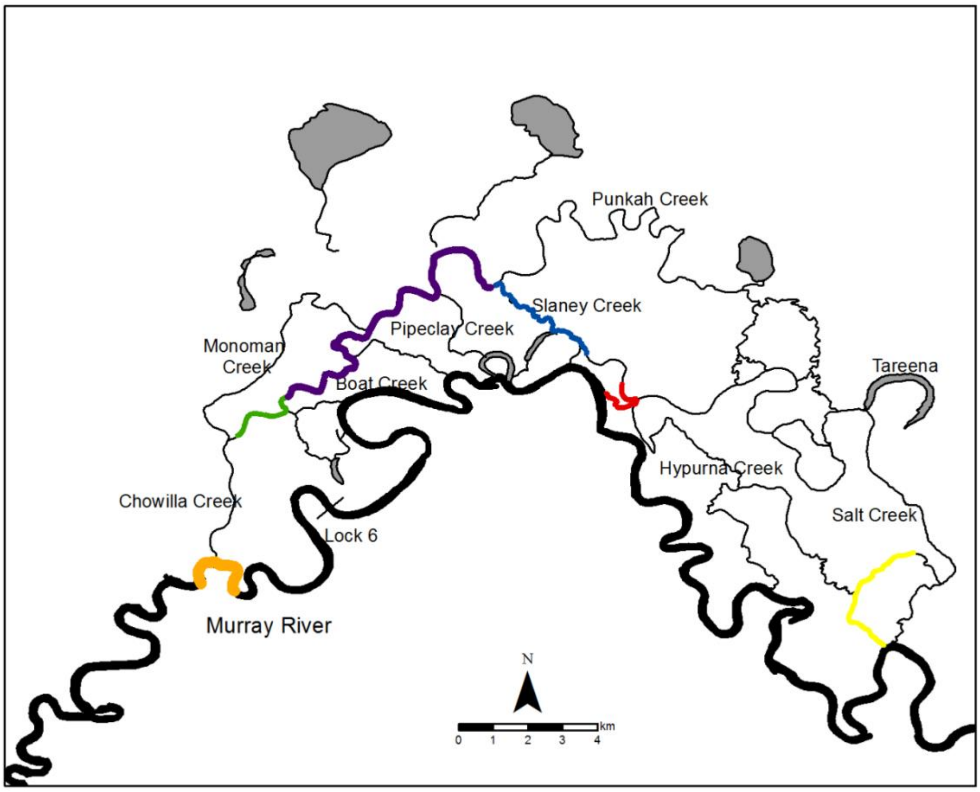

Figure 2. Sites sampled to target Murray cod in May 2016: Salt Creek downstream Bank K (yellow), Salt and Swiftys creeks (red), Slaney Creek (blue), Chowilla Creek downstream bridge (green), Chowilla Creek upstream bridge (purple) and River Murray main channel (orange).

Abundance

Fish abundance is not a specific target in the Environmental Water Management Plan; nevertheless, changes in abundance may reflect environmental conditions. As such, the abundance of individual fish species was investigated over the twelve 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}).

Temporal variation in fish assemblages was investigated by assessing changes in total fish abundance (all species combined) and individual species abundance. Differences in the mean abundance (CPUE, fish.min^{-1}) of fish sampled between years were analysed using uni-variate single-factor PERMANOVA (permutational ANOVA and MANOVA) in the software package PRIMER v. 6.1.12 and PERMANOVA+ (Anderson *et al.* 2008). Non-Metric Multi-Dimensional Scaling (MDS) was generated from fish abundance and mesohabitat data (sites combined for each year) to visualize assemblages and mesohabitats from different years in two dimensions.

To identify the representative species for each year, Indicator Species Analysis (Dufrene and Legendre 1997) was performed on all sites, over all years. This, however, did not include data from 2011.

Spatio-temporal differences in fish assemblages (species and relative abundances (fish.minute^{-1})) between years (2005–2016; 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). Indicator species analysis (Dufrene and Legendre 1997) was used to calculate the indicator value (site fidelity and relative abundance) of species between mesohabitats over the eleven years or particular years across all mesohabitats using the package PCOrd v. 5.12 (McCune and Mefford 2005). A perfect indicator remains exclusive to a particular mesohabitat and exhibits strong site fidelity during sampling (Dufrene and Legendre 1997). Statistical significance was determined for each species indicator value using the Monte Carlo (randomisation) technique. All multivariate analyses used Bray-Curtis (1957) similarities to construct the similarity matrices (McCune and Mefford 2006).

Diversity and distribution of fish species (Ecological Objective 10)

Sites were grouped into aquatic mesohabitat categories (Table 1) and the diversity and distribution of fish species were described for each mesohabitat. Diversity was defined as the number of fish species (species richness) present within each mesohabitat. Distribution was defined as the number of mesohabitats that each fish species was present in during 2016.

Recruitment of fish species (Ecological Objective 11)

Length frequency distributions were considered to be an appropriate method to investigate the recruitment of individual fish species. Length data were used to generate length-frequency histograms for the native small- to medium-bodied species; unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Murray rainbowfish (*Melanotaenia fluviatilis*), Australian smelt (*Retropinna semoni*) and bony herring (*Nematalosa erebi*), and large-bodied species; freshwater catfish (*Tandanus tandanus*), golden perch (*Macquaria ambigua ambigua*) and Murray cod. Length frequency histograms were also generated for the non-native species common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*).

Golden perch exhibit considerable variation in length-at-age in the Murray-Darling Basin (MDB) (Anderson *et al.* 1992; Mallen-Cooper and Stuart 2003). Therefore, to accurately assess the recruitment of golden perch, we investigated both length and age frequency. To determine the age-structure of golden perch, thin sectioned otoliths were prepared from a sub sample of fish (n = ~50 per year) representing the size range of fish captured during the surveys (adults and juveniles). Individuals were measured (to the nearest mm) and the otoliths (sagittae) removed. Whole sagittae were embedded in clear casting resin and a single 400–600 μm transverse section was prepared (Anderson *et al.* 1992). Sections of sagittae were examined using a dissecting microscope (x 25) under transmitted light. Estimates of age were determined independently by three readers which in turn counted the number of discernible opaque zones (annuli) from the primordium to the otolith edge. Young-of-year (YOY, age 0+) fish were defined as individuals lacking clearly discernible annuli.

Murray cod may also show variability in length-at-age (Zampatti *et al.* 2014) but we elected not to use a destructive ageing technique due to the conservation status of this species (listed as vulnerable under the *Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act 1999*) and instead only used length frequency distributions to investigate recruitment.

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 inflow volumes 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 was still bankfull (~45,000 $ML.day^{-1}$) 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 2013–2016, reaching a maximum discharge of ~25,000 $ML.d^{-1}$ in October 2013 and ~18,000 $ML.d^{-1}$ in August 2014. During the condition monitoring survey from 15 March to 1 April 2016, flow in the River Murray ranged 6,057–8,298 $ML.day^{-1}$ (Figure 3).

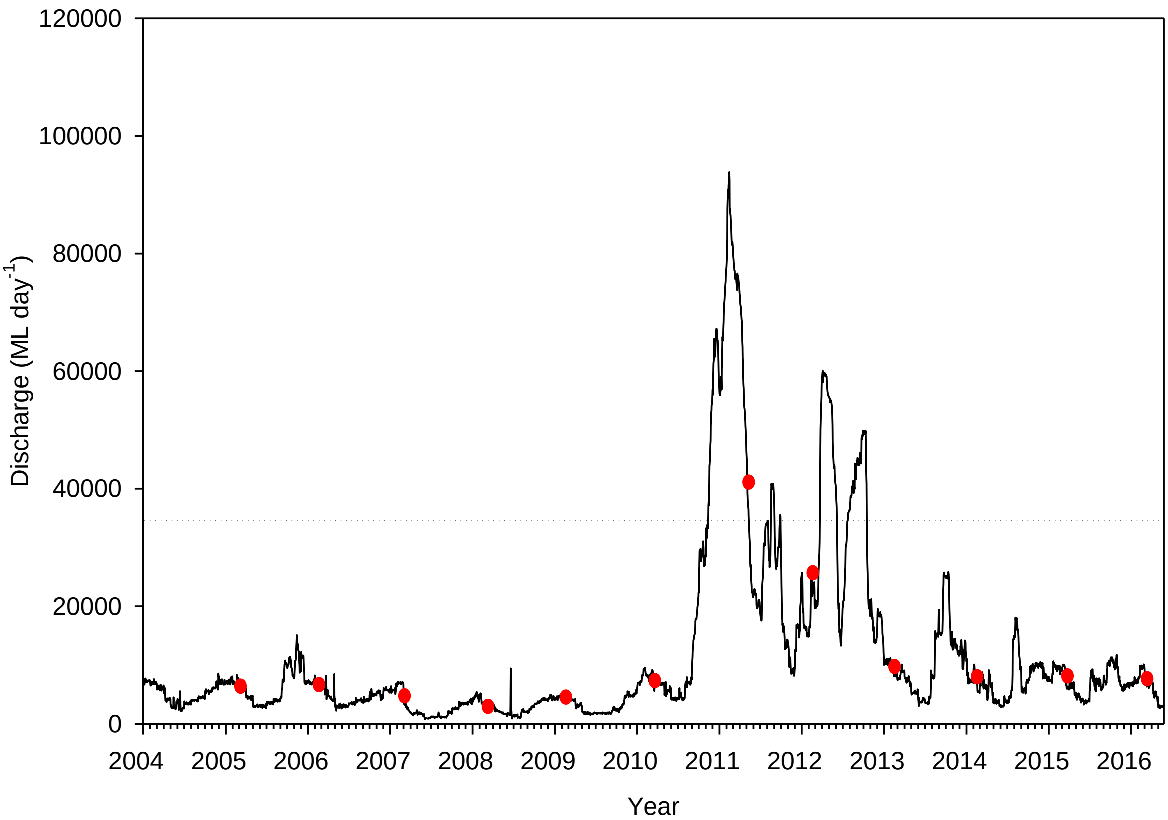

Figure 3. Mean daily flow (ML day^{-1}) in the River Murray at the South Australian Border (Site A42610010) January 2004–April 2016. Red circles indicate sampling events and the dotted line represents approximate bankfull discharge at Chowilla (~35,000 ML.day^{-1}).

Catch Summary

A total of 24,428 fish, from 15 species (11 native and 4 non-native) were captured in the 2016 condition monitoring surveys (Table 2). The most abundant species were all native, namely bony herring, unspecked hardyhead, Australian smelt and Murray rainbowfish (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 2005–2016, a total of 158,193 fish representing 16 species (12 native and 4 non-native) were captured over twelve sampling events (Table 2, Appendix 1–10). The most abundant species from 2005–2010 were the small- to medium-bodied native species, unspecked hardyhead, Australian smelt and bony herring (Table 2). 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 2). Total catch and standardised total abundances decreased following 2011, due primarily to the large reduction in numbers of common carp and goldfish. In 2015, total catch and standardised total abundances increased due mainly to increased catches of Australian smelt, bony herring, Murray rainbowfish, unspecked hardyhead, common carp and goldfish. 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.

Abundance of native fish

Golden perch was the most abundant large-bodied native species sampled, with standardised abundance highest in years following significant overbank flooding in 2010/11, and decreasing in the years following (i.e. 2012–2016) (Table 2). Low abundances of Murray cod and silver perch were captured each year (Table 2). Like golden perch, standardised abundances of silver perch increased up until 2011 before decreasing in 2012–2016, although a slight increase in abundance in 2015 was evident. Freshwater catfish were captured in low abundances in most years except for 2012 and 2013 when numbers increased, and spangled perch (*Leipotherapon unicolour*) were only captured in 2011, 2014 and 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 2). Australian smelt and bony herring were most abundant in 2009 and 2016, respectively (Table 2). Dwarf flat-headed gudgeon (*Philypnodon macrostomus*) were not captured each year and when present, were sampled in low abundance (Table 2).

Abundance of non-native fish

Common carp and goldfish were the most abundant non-native species in all years, except in 2010, when high numbers of gambusia were sampled (Table 2). Standardised abundances of common carp and goldfish were greatest in 2011 (Table 2). Redfin perch (*Perca fluviatilis*) were not captured each year and when present, were sampled in low abundance (Table 2).

Table 2. Total and standardised (fish.site^{-1}) abundances of fish captured from condition monitoring sites sampled in the Chowilla Anabranch system and adjacent River Murray 2005–2016.

Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total
Golden perch	69	75	112	94	174	114	802	286	230	148	143	99	**2346**
(*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)	
Murray cod	13	11	14	15	21	15	7	9	7	7	14	13	**146**
(*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)	
Silver perch	5	5	1	14	8	20	30	6	7	5	14	7	**122**
(*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)	
Freshwater catfish	-	-	1	-	3	2	8	20	15	6	4	1	**60**
(*Tandanus tandanus*)			(0.1)		(0.1)	(0.1)	(0.4)	(0.9)	(0.7)	(0.3)	(0.2)	(0.1)	
Bony herring	3849	6229	6251	7782	10629	17948	2521	4433	5508	5225	10314	19,221	**99,910**
(*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)	
Australian smelt	526	189	740	803	1067	589	484	132	215	151	1029	916	**6841**
(*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)	
Murray rainbowfish	458	378	123	213	231	240	686	50	200	235	652	490	**3956**
(*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)	
Flat-headed gudgeon	93	6	20	18	70	21	11	20	69	35	65	14	**442**
(*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)	
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	**15,204**
(*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)	
Carp gudgeon spp.	398	113	104	73	84	153	92	2	28	222	137	251	**1657**
(*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)	
Common carp*	234	466	277	185	400	357	11602	2023	1218	590	730	339	**18,421**
(*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)	
Gambusia*	200	61	125	60	107	490	647	12	40	65	126	300	**2233**
(*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)	
Goldfish*	202	296	177	156	551	217	3945	385	55	171	299	331	**6785**
(*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)	
Redfin perch*	-	-	9	3	7	8	5	3	-	-	3	1	**39**
(*Perca fluviatilis*)			(0.6)	(0.2)	(0.3)	(0.4)	(0.2)	(0.1)			(0.1)	(0.1)	
Spangled perch^	-	-	-	-	-	-	1	-	-	1	1.0	-	**3**
(*Leipotherapon unicolour*)							(0.05)			(0.05)	(0.05)		
Total species	**13**	**12**	**14**	**14**	**15**	**15**	**15**	**14**	**13**	**14**	**16**	**15**	**16**
Total number of sites	**18**	**16**	**15**	**14**	**21**	**22**	**21**	**22**	**22**	**21**	**22**	**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**	**158,193**
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**	

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

Temporal variation in total fish abundance

The relative abundance of fish (all species combined) sampled per year varied substantially between 2005 and 2016 (Figure 4), with significant differences between years ($Pseudo\text{-}F_{11, 234}$ = 6.8977, $p < 0.001$). Between 2005 and 2011, relative abundance gradually increased then substantially decreased in the following years of 2012–2014 (Figure 4). Abundance again increased in 2015 and 2016, 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 the non-native species common carp and goldfish comprised the majority of catch (Figure 4).

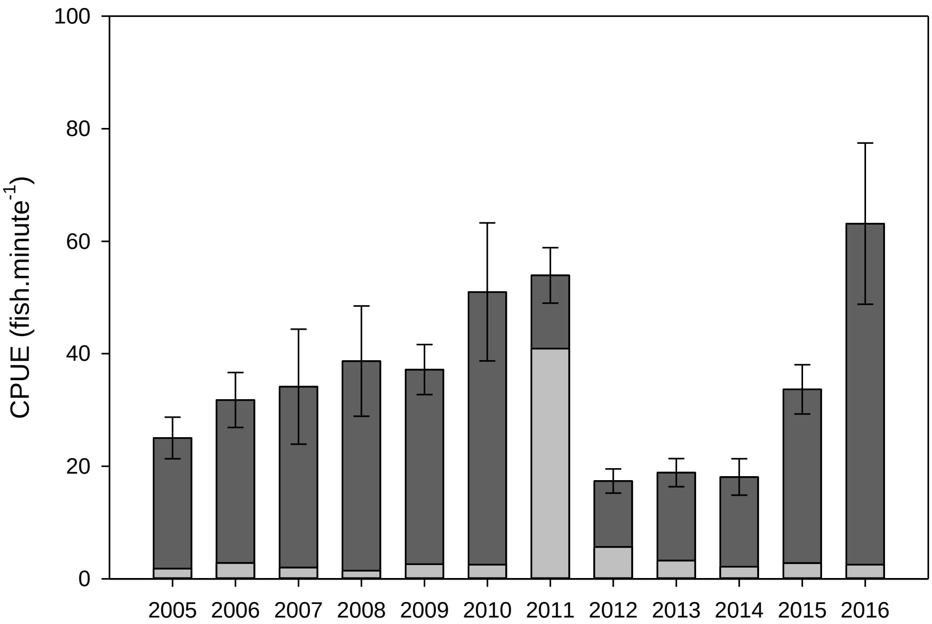

Figure 4. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of fish (all species combined) collected annually during standardised boat electrofishing surveys from 2005–2016 at 22 sites in the Chowilla Anabranch system and adjacent River Murray (dark grey = proportion native species, light grey = proportion of non-native species).

Spatio-temporal differences in fish assemblage

Two-factor PERMANOVA indicated that there were significant differences in the fish community between years ($Pseudo\text{-}F_{10,\ 213}$ = 10.403, p < 0.001) and mesohabitats ($Pseudo\text{-}F_{3,\ 213}$ = 14.787, p < 0.001), and interaction between these factors was non-significant ($Pseudo\text{-}F_{30,\ 213}$ = 1.0286, p = 0.406) (Table 3).

Pairwise comparisons revealed assemblages were significantly different between years in 40 of 55 comparisons (i.e. α = 0.01, B-Y corrected) (Table 4). Pairwise comparisons also revealed significant differences in fish assemblages among mesohabitats for all comparisons (α = 0.02) (Table 5). Supporting this, non-metric multi-dimensional scaling (MDS) ordination shows the trajectory for fish assemblages sampled in 2005–2010, 2015 and 2016 were similar but distinctly different from assemblages sampled in 2011 and 2012–2014 (Figure 5a). Whilst groupings of mesohabitats in all sites for all years indicated that fish assemblages differed between mesohabitats (Figure 5b).

Table 3. PERMANOVA results comparing the relative abundances of fish between years and mesohabitats over eleven years from 2005–2016, excluding 2011. Significant *P* values are highlighted in bold (α = 0.05).

Factor	***df***	***Pseudo-F***	***P***
Year	10,213	10.403	**<0.001**
Mesohabitat	3,213	14.787	**<0.001**
Year x mesohabitat	30,213	1.0286	0.406

Table 4. PERMANOVA pair-wise comparisons between fish assemblages at Chowilla from 2005-2016. PERMANOVA was performed on Bray-Curtis similarity matrices. Significant values are highlighted in bold (B-Y corrected α = 0.01).

Pairwise comparison		*t*	*p* value	Pairwise comparison		*t*	*p* value
Year	**Year**			**Year**	**Year**		
2005	2006	2.0759	**0.003**	2008	2012	4.4116	**0.001**
2005	2007	1.7149	0.016	2008	2013	3.2646	**0.001**
2005	2008	1.4751	0.056	2008	2014	2.8607	**0.001**
2005	2009	1.7916	**0.009**	2008	2015	1.3095	0.103
2005	2010	1.7361	**0.006**	2008	2016	1.3543	0.085
2005	2012	5.6335	**0.001**	2009	2010	1.5648	0.045
2005	2013	4.3183	**0.001**	2009	2012	5.277	**0.001**
2005	2014	3.6083	**0.001**	2009	2013	4.1416	**0.001**
2005	2015	2.1350	**0.001**	2009	2014	3.6239	**0.001**
2005	2016	1.5006	0.045	2009	2015	2.1778	**0.003**
2006	2007	1.9151	**0.004**	2009	2016	2.0724	**0.004**
2006	2008	1.6167	0.028	2010	2012	5.285	**0.001**
2006	2009	2.019	**0.002**	2010	2013	4.1265	**0.001**
2006	2010	2.2114	**0.001**	2010	2014	3.3979	**0.001**
2006	2012	4.472	**0.001**	2010	2015	1.7646	0.021
2006	2013	3.3736	**0.001**	2010	2016	1.4274	0.079
2006	2014	2.5693	**0.001**	2012	2013	1.8576	**0.004**
2006	2015	1.7927	**0.007**	2012	2014	2.6327	**0.001**
2006	2016	2.1108	**0.001**	2012	2015	5.1292	**0.001**
2007	2008	1.7657	0.018	2012	2016	5.9210	**0.001**
2007	2009	1.4457	0.086	2013	2014	1.9138	**0.009**
2007	2010	1.6396	0.022	2013	2015	3.6359	**0.001**
2007	2012	4.1658	**0.001**	2013	2016	4.4699	**0.001**
2007	2013	3.215	**0.001**	2014	2015	2.7298	**0.001**
2007	2014	2.7038	**0.001**	2014	2016	3.6925	**0.001**
2007	2015	2.2938	**0.001**	2015	2016	1.5379	0.028
2007	2016	2.2930	**0.002**				
2008	2009	1.1603	0.268				
2008	2010	1.3037	0.138				

Table 5. PERMANOVA pair-wise comparisons between fish assemblages among different mesohabitats in Chowilla from 2005-2016. PERMANOVA was performed on Bray-Curtis similarity matrices. Significant values are highlighted in bold (B-Y corrected α = 0.02)

Pairwise comparison		***t***	***p* value**
Mesohabitat	**Mesohabitat**		
Fast	Slow	5.0555	**0.001**
Fast	Backwater	4.5263	**0.001**
Fast	River	3.0024	**0.001**
Slow	Backwater	2.6148	**0.001**
Slow	River	3.6065	**0.001**
Backwater	River	2.3505	**0.001**

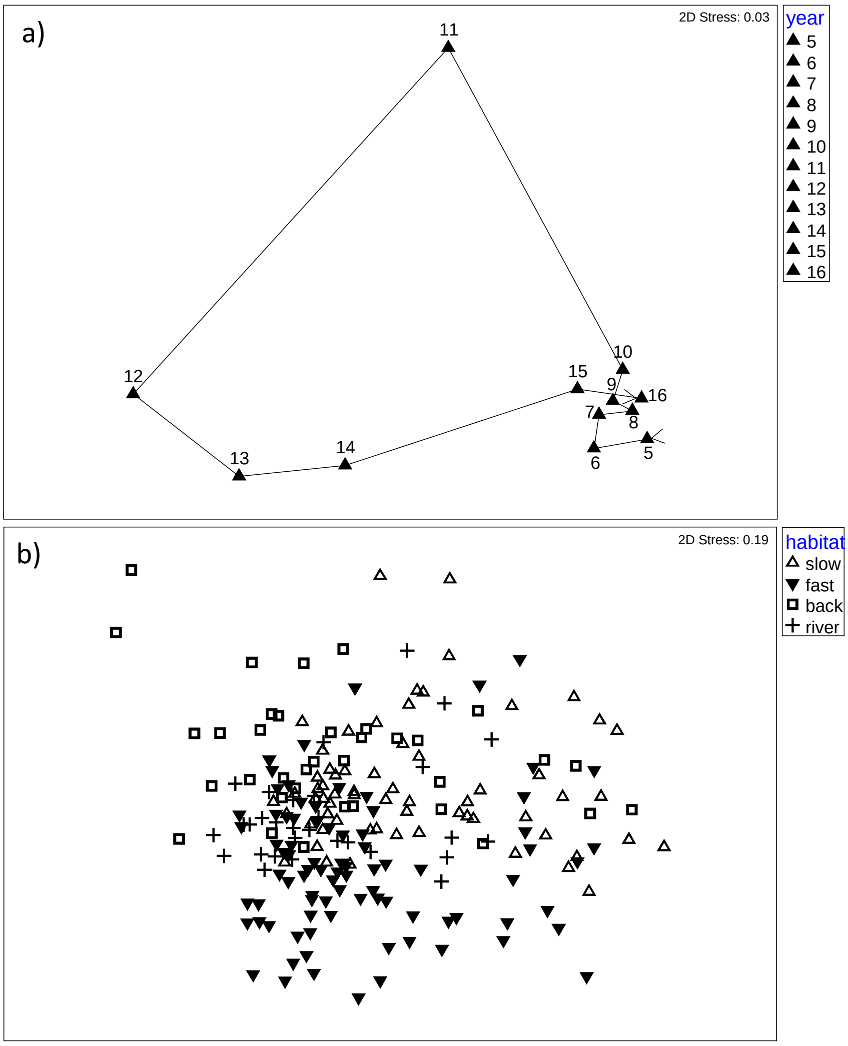

Figure 5. Non-metric multi-dimensional scaling (MDS) plot of a) fish assemblages sampled from all years/sites combined and b) Mesohabitat groupings from all years/sites combined.

Indicator species analysis indicated that unspecked hardyhead characterised the fish assemblage in 2005 (Table 6). In 2008, dwarf flat-headed gudgeon and Australian smelt characterised the fish assemblage, whilst common carp, golden perch and freshwater catfish were the key indicator species in 2010 (Table 6). In 2011, six species characterised the fish assemblage; Murray rainbowfish, eastern gambusia, goldfish, common carp, golden perch and silver perch (Table 6). Freshwater catfish, golden perch and common carp characterised the fish assemblage in 2012 (Table 6). In 2016, carp gudgeon and bony herring characterised the fish assemblage (Table 6).

Table 6. Indicator species analysis comparing the relative abundance of fish amongst years from 2005–2016, 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	13.0	**0.0062**
Flat-headed gudgeon	2005	11.0	0.0716
Murray cod	2007	4.9	0.8812
Redfin perch	2007	7.1	0.0990
Dwarf flat-headed gudgeon	2008	18.1	**0.0010**
Australian smelt	2008	12.5	**0.0048**
Silver perch	2008	5.1	0.7628
Goldfish	2009	11.0	0.1372
Gambusia	2010	15.3	0.0786
Common carp	2012	12.2	**0.0002**
Golden perch	2012	11.4	**0.0008**
Freshwater catfish	2012	11.2	**0.0146**
Spangled perch	2014	2.4	0.8708
Murray rainbowfish	2015	11.4	0.0786
Carp gudgeon spp.	2016	13.0	**0.0100**
Bony Herring	2016	10.6	**0.0432**

From 2005–2016, fast-flowing mesohabitats were characterised by golden perch, Murray cod, silver perch, and Australian smelt (Table 7). Main river channel mesohabitats were characterised by Murray rainbowfish, unspecked hardyhead and redfin perch, and backwater mesohabitats were characterised by goldfish (Table 7). No species were significantly associated with slow-flowing mesohabitats.

Table 7. Indicator species analysis comparing the relative abundance of fish in three of the four aquatic mesohabitats from 2005–2016, 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	**0.0176**
Australian smelt	Fast	**0.0002**
Bony Herring	Fast	0.1986
Freshwater catfish	Fast	0.0684
Murray rainbowfish	River	**0.0002**
Spangled perch	River	0.4767
Dwarf flat-headed gudgeon	River	0.1708
Unspecked hardyhead	River	**0.0004**
Redfin perch	River	**0.0022**
Gambusia	River	0.0642
Flat-headed gudgeon	River	0.3735
Carp gudgeon spp.	Backwater	0.4719
Common carp	Backwater	0.2773
Goldfish	Backwater	**0.0132**

Targeted Murray cod sampling

A total of 60 Murray cod were collected in 2016 (Table 8). Twelve were captured during standard condition monitoring in March/April and the remaining 48 were captured during targeted sampling in eight regions of Chowilla in May 2016. Relative abundances of Murray cod were highest in Slaney and Swiftys creek.

Table 8. 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 2016.

Species	Targeted survey sites								Standard condition monitoring (*n* = 21 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*)	5 *(0.10)*	6 *(0.10)*	0	28 *(0.24)*	2 *(0.22)*	1 *(0.03)*	2 *(0.14)*	4 *(0.13)*	12 *(0.03)*	60 *(0.07)*

Diversity and distribution of fish species (Target 10)

In 2016, species richness was highest in both fast and slow-flowing mesohabitats (*n* = 14) and lowest in backwater mesohabitats (*n* = 9) (Table 9). Most species were widespread across all mesohabitat types; however, freshwater catfish were only captured in fast-flowing mesohabitats and redfin perch (*n* = 1) was only captured in slow-flowing mesohabitats (Table 9). Murray cod were absent from backwater and main channel habitats, whilst silver perch, flat-headed and dwarf flat-headed gudgeon were absent from backwater mesohabitats (Table 9).

Table 9. Fish species present in each mesohabitat type for the 2016 fish condition monitoring surveys.* denotes presence.

Common names	**Fast-flowing**	**Slow-flowing**	**Backwater**	**Main channel**
Golden perch	*	*	*	*
Murray cod	*	*		
Silver perch	*	*		*
Freshwater catfish	*			
Bony herring	*	*	*	*
Australian smelt	*	*	*	*
Murray rainbowfish	*	*	*	*
Flat-headed gudgeon	*	*		*
Dwarf Flat-headed gudgeon	*	*		*
Unspecked hardyhead	*	*	*	*
Carp gudgeon spp.	*	*	*	*
Common carp*	*	*	*	*
Gambusia*	*	*	*	*
Goldfish*	*	*	*	*
Redfin perch*		*		
Total species	**14**	**14**	**9**	**12**

Recruitment of small- to medium-bodied native species

The length frequency distributions for small- to medium-bodied species unspecked hardyhead and Murray rainbowfish show broad ranges in size distribution each year and modes that are likely to represent an annual cohort of YOY fish (Figure 6 and 7). Similarly, Australian smelt likely recruited annually with the exception of 2011 when only large fish (>60 mm) were sampled (Figure 8). Length-frequency distributions of bony herring indicated annual recruitment, and in 2016 a high proportion of the sampled population (~79%) were likely YOY (<100 mm TL) (Figure 9).

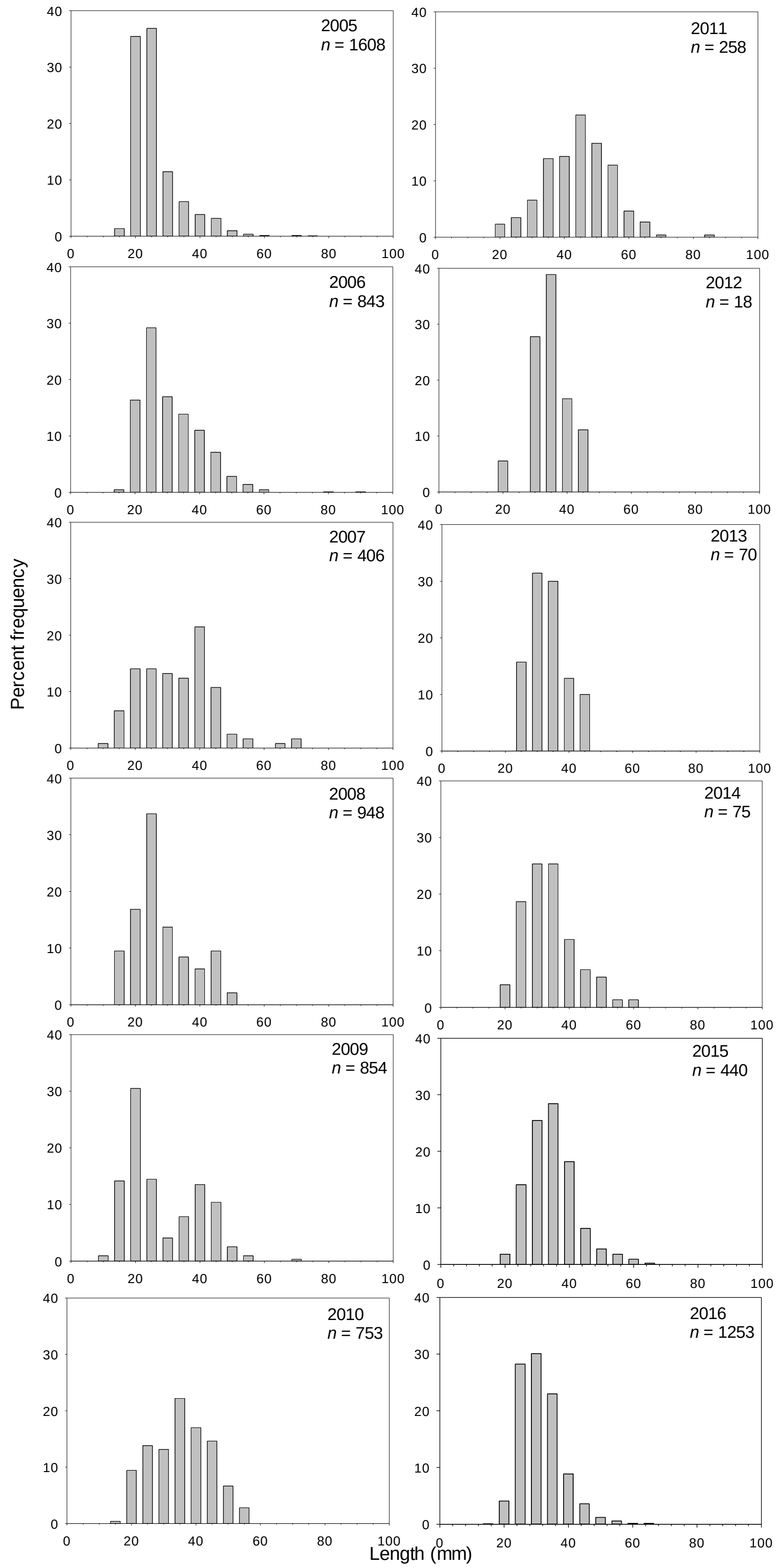

Figure 6. Length distribution of unspecked hardyhead captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

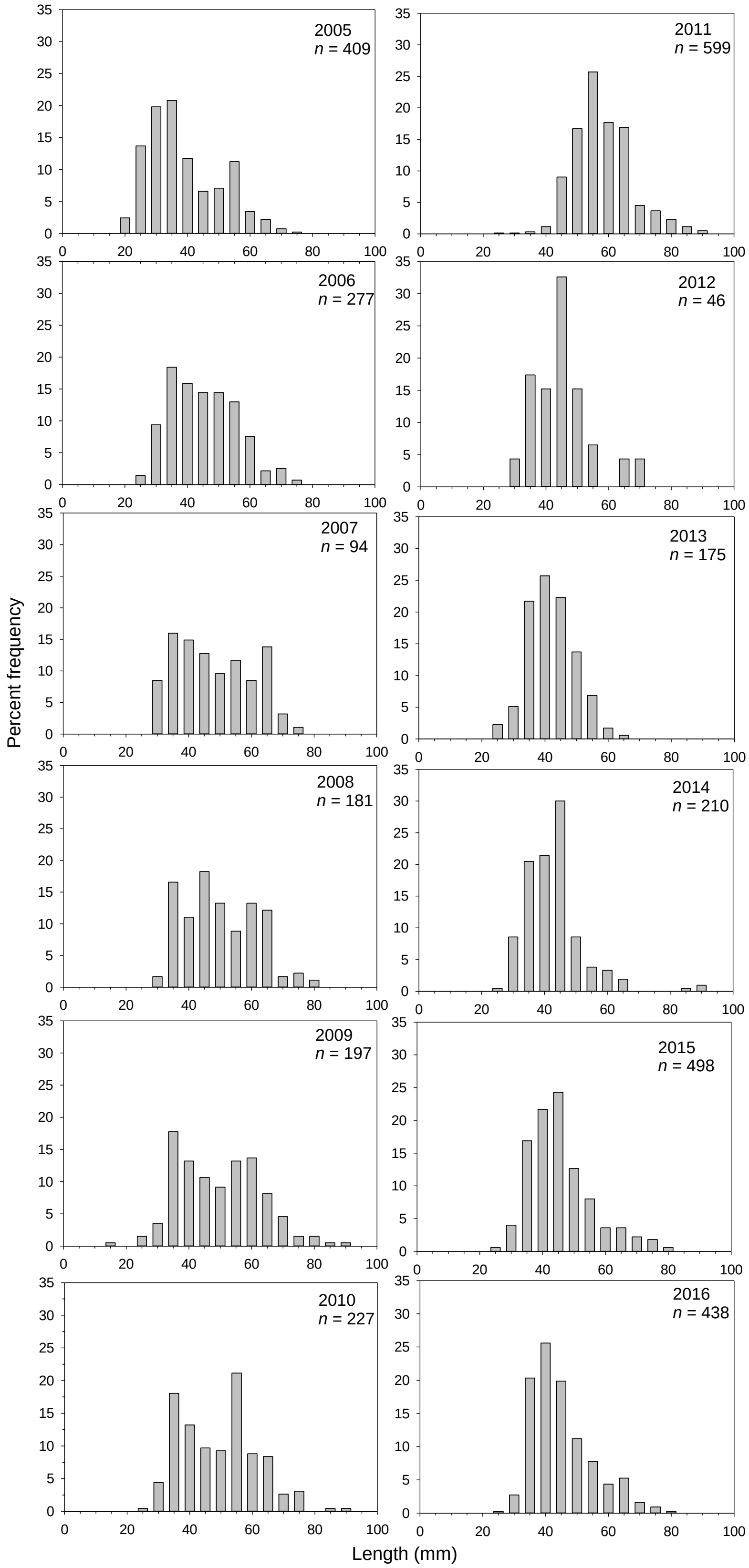

Figure 7. Length distribution of Murray rainbowfish captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

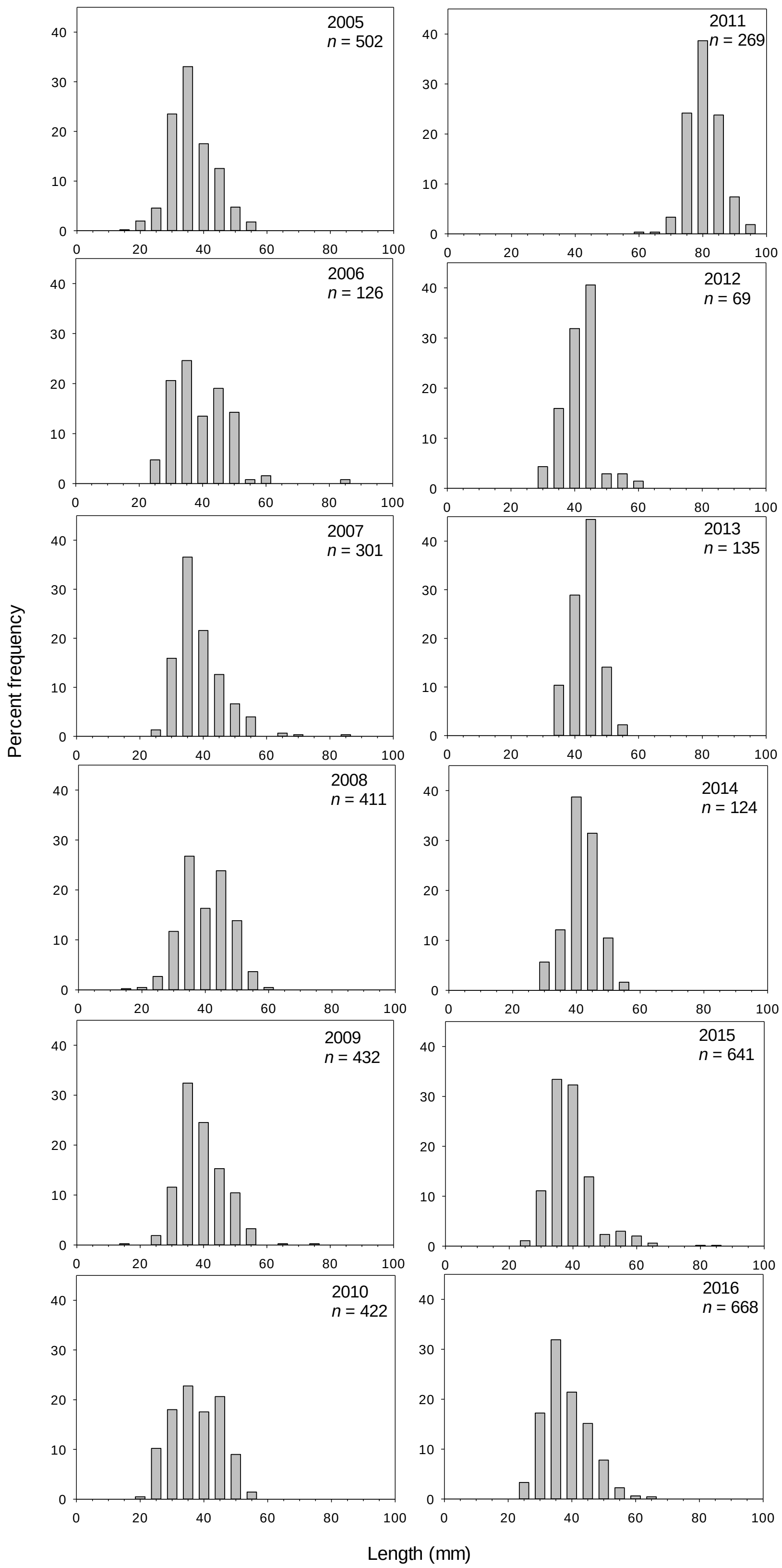

Figure 8. Length distribution of Australian smelt captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

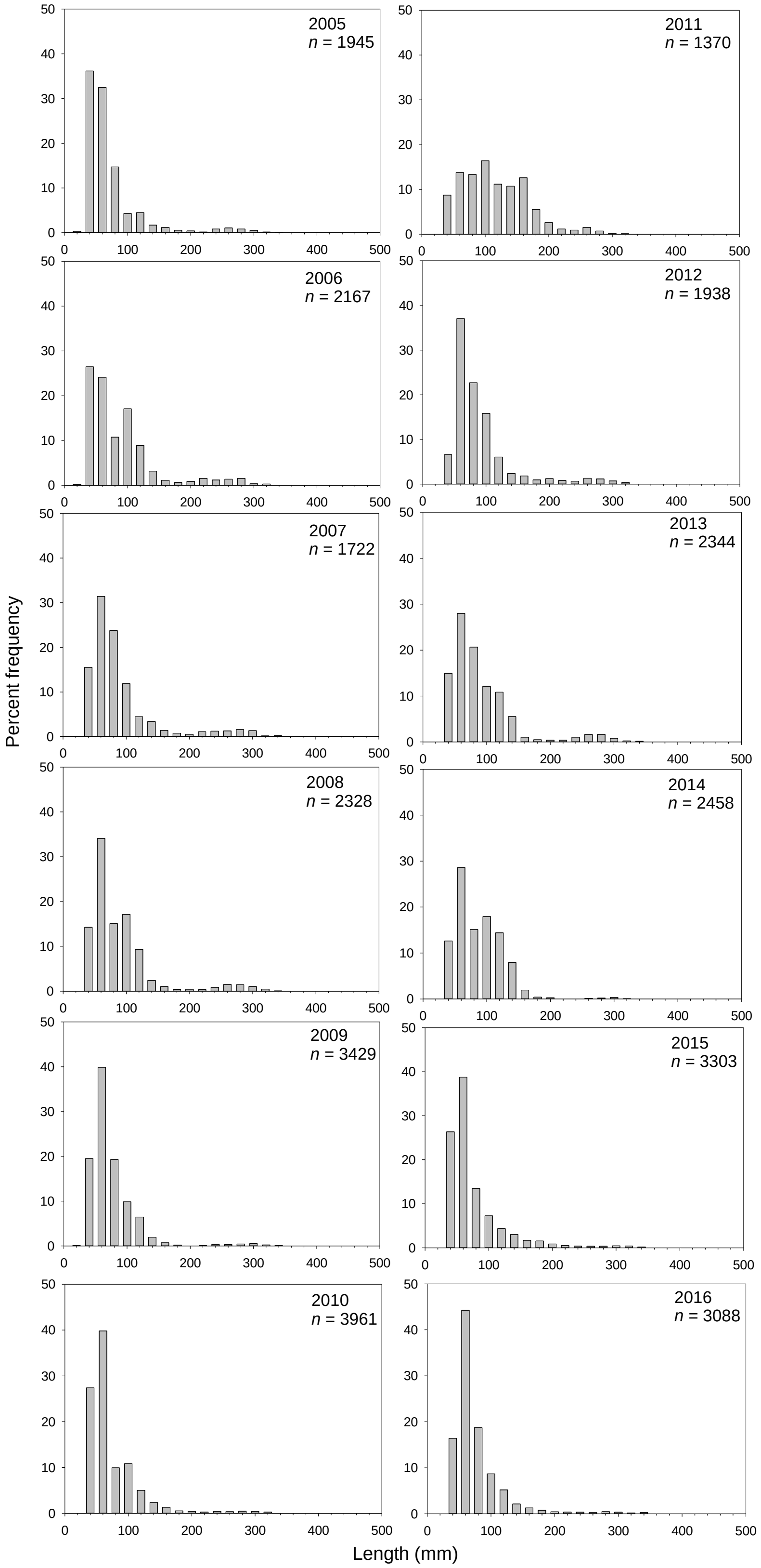

Figure 9. Length distribution of bony herring captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

Recruitment of large-bodied native species

Golden perch

Despite a broad size range of golden perch in Chowilla, recruitment is variable (Figure 10a and b). Over a 12-year period (2005–2016) cohorts of age 0+ fish were only evident in 2006, and annually from 2010–2014 (Figure 10b). In 2016, golden perch ranged in length from 180-460 mm (Figure 10a). These fish were 3 to 6 years old, with 5 and 6 year old fish comprising over 77% of the sampled population (Figure 10b).

Murray cod

The length frequency distributions of Murray cod were similar each year with fish ranging in length from 81–1300 mm (Figure 11). The number of fish below 400 mm was generally low from 2005–2012 (0–4 individuals) (Figure 11). In 2013, 2014 and 2015, however, Murray cod as small as 95, 88 and 81 mm TL, respectively, were collected, and preliminary ageing using thin-sectioned otoliths revealed these fish were YOY (SARDI unpublished data). Importantly, YOY fish were only found during targeted sampling conducted in May in these years. In 2016, a distinct size-class of juvenile fish was evident with 32% (n = 19) of fish ranging 100-200 mm, likely corresponding to age 0+ or 1+ (Figure 11).

Freshwater catfish

Freshwater catfish recruitment was detected in 2011 (fish ≤ 100 mm TL; Davis 1977), but individuals collected in subsequent years were likely greater than 1 year old. Only one individual freshwater catfish was collected at Chowilla in 2016, with a TL of 401 mm (Figure 12).

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 13, 14). Nevertheless, for common carp, recruitment of age 0+ fish was temporally variable and strong cohorts were evident annually in 2006, 2009–2012, and 2014–2016, whilst for goldfish, strong cohorts of 0+ fish recruitment were evident annually in 2006, 2008–2009, and 2014–2016. In 2016, both common carp and goldfish exhibited broad size ranges with small (most likely YOY) individuals representing ~18% and ~76%, respectively, of sampled populations (Figure 13 and 14).

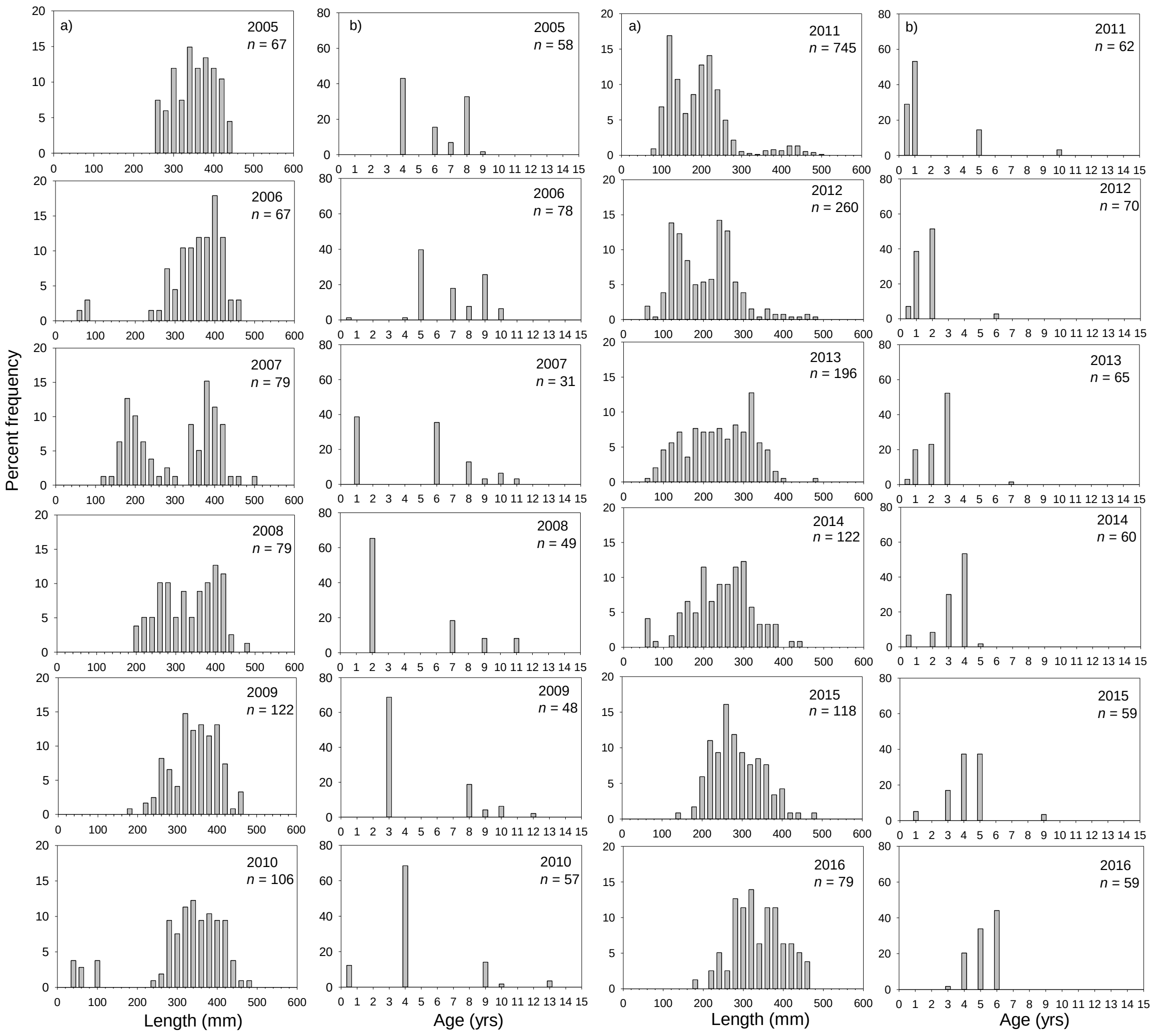

Figure 10. Length distribution (a) and age structure (b) of golden perch captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

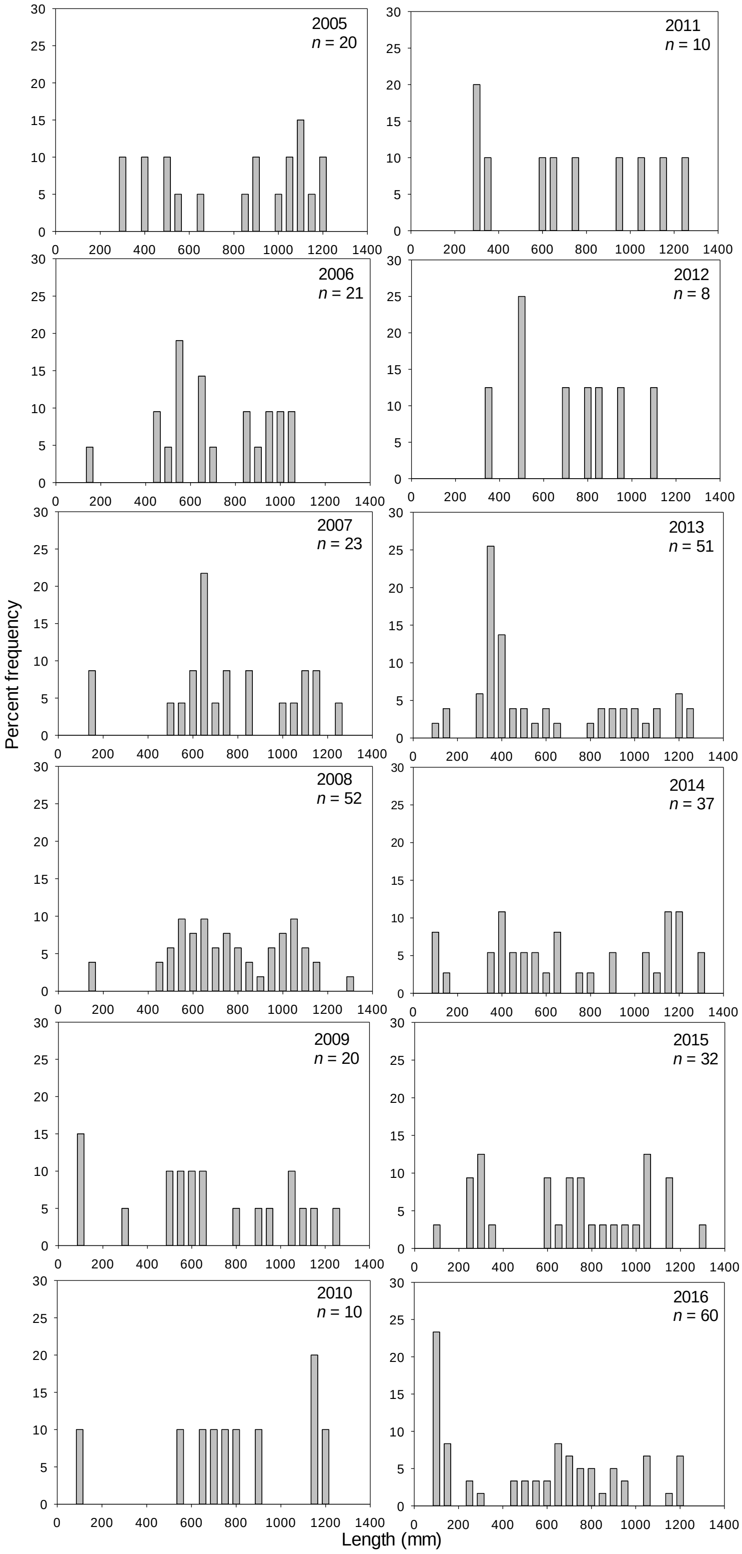

Figure 11. Length distribution of Murray cod captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016. Note years 2008, 2013, 2014, 2015 and 2016 include data from additional targeted sampling for Murray cod at Chowilla.

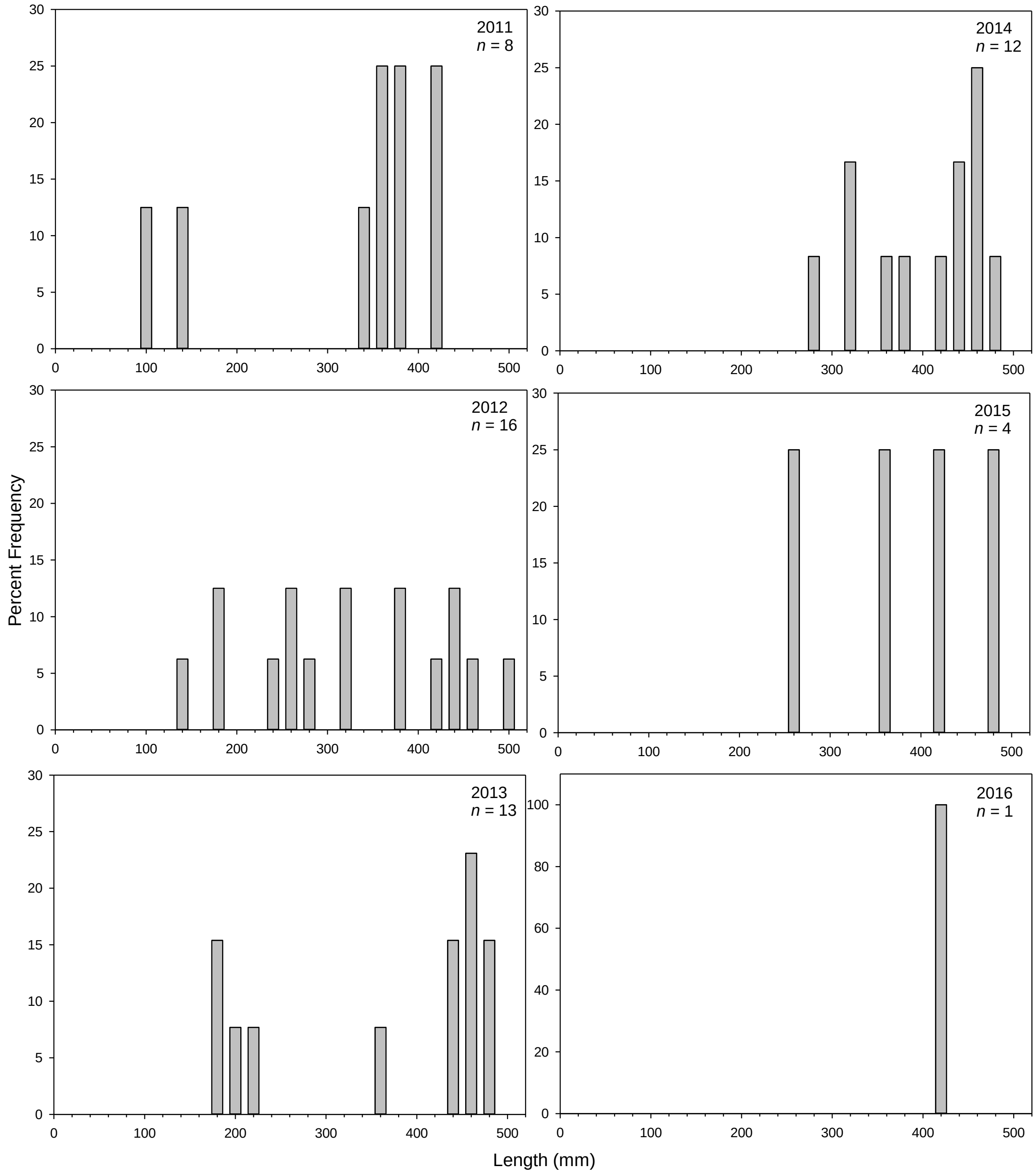

Figure 12. Length distribution of freshwater catfish captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2011–2016. Note year 2014 includes length data from additional sampling conducted at Chowilla for assessing Murray cod recruitment.

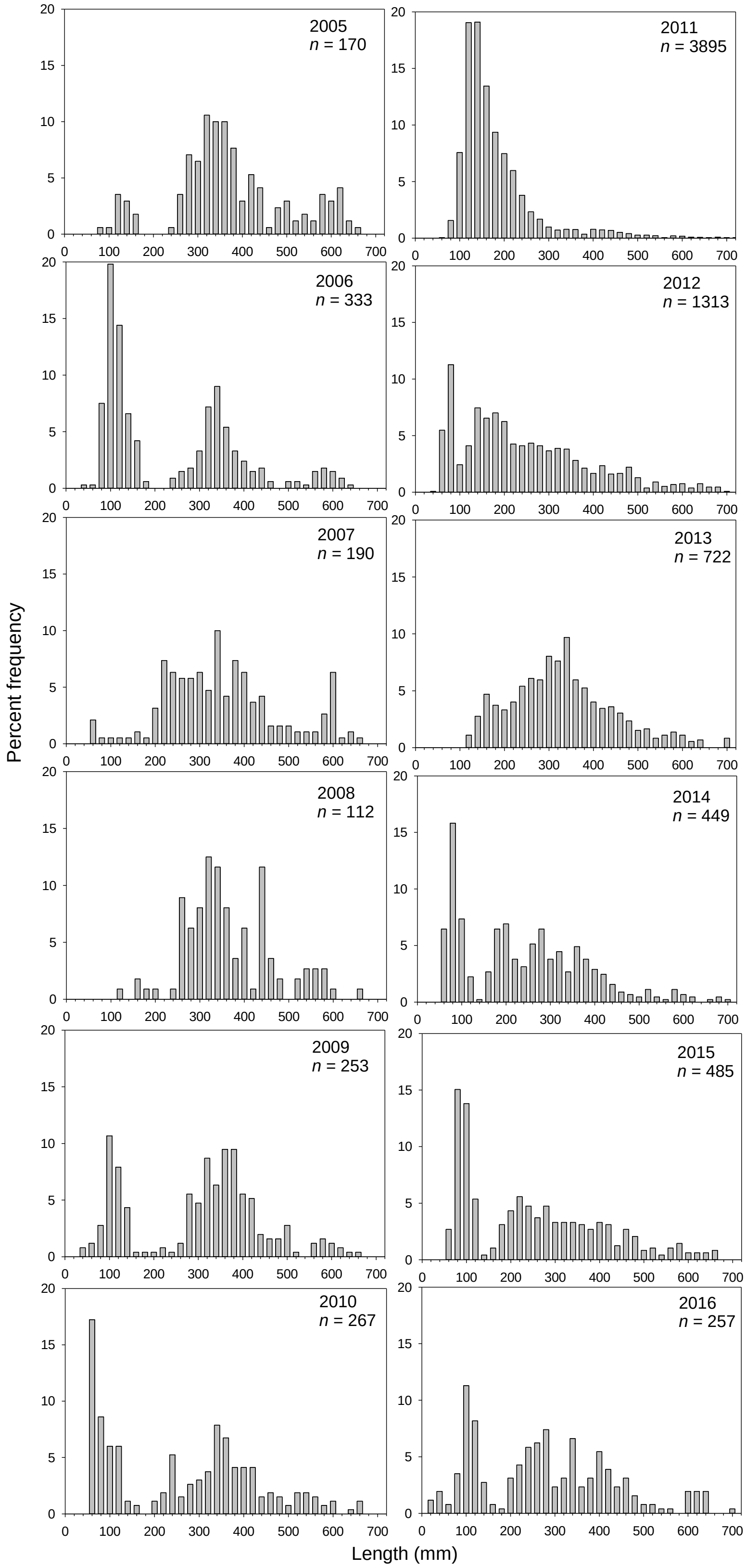

Figure 13. Length distribution of common carp captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

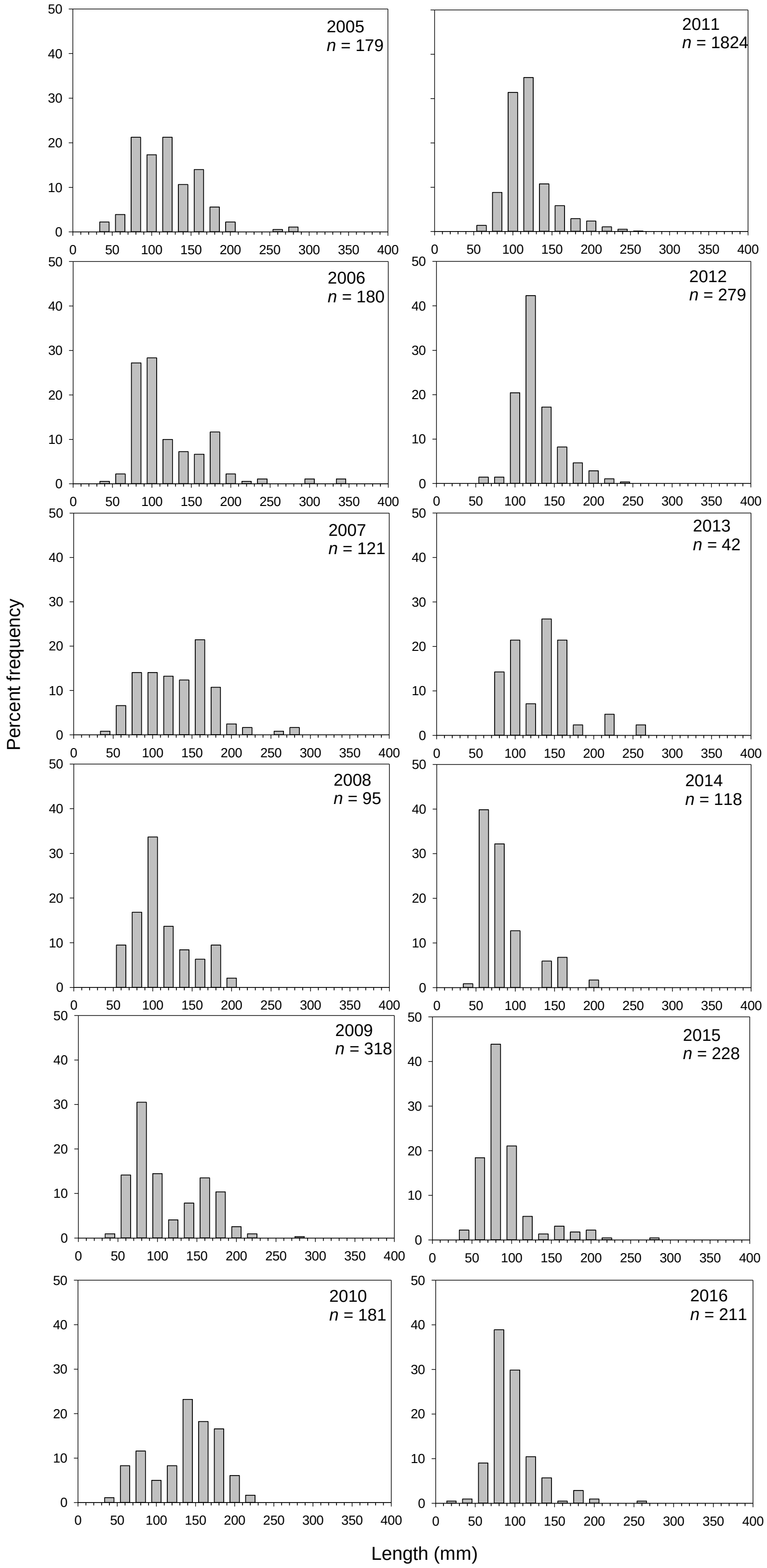

Figure 14. Length distribution of goldfish captured at all sites sampled within Chowilla and the adjacent River Murray main channel from 2005–2016.

DISCUSSION

Abundance

In March 2016, 15 fish species were sampled at 21 sites in Chowilla and the adjacent River Murray main channel. The fish assemblage consisted of 11 native and 4 non-native species, with bony herring, unspecked hardyhead, Australian smelt, Murray rainbowfish and common carp the most abundant. The assemblage in 2016 was similar to that in 2005–10 and 2015.

From 2005–10, 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 (Bice *et al*. 2013). The abundance of unspecked hardyhead reduced further in 2012 but then increased in subsequent years and the abundance of bony herring increased in 2012–16, relative to 2011. This was likely due to a return to favourable hydraulic conditions (i.e. lentic habitats) and increased habitat availability (i.e. submerged aquatic macrophytes) for these species.

The abundance of Australian smelt from 2005–16 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). Similar responses to flow are observed at Chowilla.

The abundance of carp gudgeon was also variable from 2005–16, 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. 2012–13). Similar patterns have been observed throughout the lower River Murray where carp gudgeons were abundant during times of low flow (e.g. 2008) and absent from the catch post over-bank flooding (e.g. 2012), likely due to the reduced cover of submerged aquatic macrophytes in main channel habitats (Bice *et al.* 2014).

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). Changes in the abundance of large-bodied native species such as golden perch and silver perch at Chowilla, and more broadly in the lower River Murray, appear to be related to the direct influence of elevated flow (Zampatti and Leigh 2013b; Bice *et al*. 2014).

Freshwater catfish were most abundant in years following elevated within-channel or overbank flow (i.e. 2011–13) and least abundant during low flow years (i.e. 2005–2010 and 2014–16). High flows in the lower River Murray from 2011–13 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.

Murray cod were generally captured in low abundances (7–21 individuals.year^{-1}) in the Chowilla condition monitoring surveys, however, conducting targeted surveys in May–June 2014, 2015 and 2016 resulted in higher catches (n = 40, n = 38 and n = 60, respectively). Based on condition monitoring data alone, there appeared to be a decrease in the total numbers of Murray cod collected following overbank flows in 2010 (Table 2). Murray cod are typically sampled from fast-flowing and River Murray main channel mesohabitats in the Chowilla region (Leigh *et al*. 2010; Zampatti *et al*. 2011; Wilson *et al*. 2012). The area and extent of flowing habitats increased as a result of increased flow in 2011–13 and it is possible that Murray cod were more widespread than in previous years, increasing the difficulty of sampling fish. Similarly, in the mid–upper reaches of the River Murray capture efficiency of Murray cod decreases with increasing flows (Lyon *et al.* 2014). There is also the potential that the reduced abundance of Murray cod from 2011–2013 was due to mortality caused by the large-scale blackwater event and related low dissolved oxygen concentrations (≤1.5 mg.L^{-1}) associated with widespread flooding in the River Murray in summer 2010/11 (Leigh and Zampatti 2013). Nevertheless, when condition monitoring is integrated with targeted sampling data, Murray cod relative abundances at Chowilla have remained relatively stable from 2014–16.

Common carp and goldfish were the most abundant non-native species in most years. The abundances of common carp and goldfish were greatest following years of increased discharge and water level (within-channel and overbank), and artificial floodplain inundation. 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 distribution (Ecological Objective 10)

Species diversity (species richness) and distribution were similar each year. Most species were widespread throughout the available aquatic mesohabitats; some species, however, were specific to one or more mesohabitats. From 2005–16, species diversity has generally been highest in fast-flowing mesohabitats and lowest in backwater mesohabitats. Backwater habitats are commonly characterised by shallow, uniform depths and a lack of flow, consequently they are less physically complex than other mesohabitats and this is likely to support a less diverse range of species (Gorman and Karr 1978; Schlosser 1982; Mérigoux *et al*. 1998).

Over the 12 year sampling period (2005–2016), native species (Murray cod, golden perch, silver perch, and Australian smelt) characterised fast-flowing mesohabitats, goldfish characterised backwater mesohabitats and Murray rainbowfish, unspecked hardyhead and redfin perch characterised riverine 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)

Length frequency data for the small-bodied species, unspecked hardyhead, Murray rainbowfish and Australian smelt, and medium-bodied bony herring indicate annual recruitment from 2005–2016, with the exception of Australian smelt in 2011. 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). These species recruited in both high and low flow years in the Chowilla region, but were most abundant during low flow periods.

Golden perch recruitment was episodic from 2005–2016. Young-of-year (YOY) golden perch were only collected in 2006 and 2010–2014 following increased discharge (within-channel and overbank) in the River Murray and/or Darling River. No YOY golden perch were collected in 2016, following generally low flows in the Murray and Darling rivers in spring–summer 2015–16. 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). In 2014, a strong cohort (>50% of the sampled population) of 4 year old golden perch was detected in the lower River Murray, including Chowilla, and analysis of natal origin using otolith microchemistry revealed these fish were spawned in the Darling River in 2009 in association with a substantial summer flow (~10,000 ML day^{-1}) (Zampatti *et al.* 2015). During this period, flows in the lower River Murray were generally low. In 2016, these 2009 spawned fish continued to compromise a large proportion (~46%) of the sampled population, along with distinct cohorts of fish spawned in 2010/11 (age 5+) and 2011/12 (age 4+). Post 2010, golden perch recruitment was more consistent, with consecutive year-classes from 2010–2014 spawned in association with within-channel and overbank increases in flow in the lower Murray and Darling rivers (SARDI unpublished data).

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). The number of Murray cod collected during fish condition monitoring surveys at Chowilla is generally low and, using condition monitoring methods, young fish are difficult to detect until ~400 mm TL (Zampatti *et al*. 2011). Additional targeted sampling in 2013–2016 has augmented the catch of Murray cod and enabled the detection of Murray cod recruits as small as 81 mm TL in Chowilla and the adjacent River Murray.

Small Murray cod (<200 mm) were present in low abundance (i.e. 0–4 individuals) in 2013–2015. In 2016, 19 individuals under 200 mm were captured, the highest out of all years. Prior to this, and in the absence of targeted surveys, small individuals were also detected in all years from 2006–2014 with the exception of 2011 and 2012. Despite no YOY recruits being detected in May 2011, otolith microstructure analyses revealed that the strong cohort of 300–400 mm Murray cod collected in 2013 were spawned in association with overbank flows in spring 2010 (SARDI unpublished data). Using available length-at-age data, Murray cod <200 mm are likely to represent YOY fish (Zampatti *et al.* 2014) and therefore the consistent presence of these fish in most years indicates that recruitment has occurred within Chowilla on a regular basis.

Freshwater catfish recruitment to YOY was only detected in 2011. From 2005–2010 and in 2016, sample sizes of catfish were too low ($n \leq 3$) to assess recruitment. Following 2011, all freshwater catfish sampled were greater than 140 mm TL, a size at which catfish are potentially >1 year old (Davis 1977). The smallest freshwater catfish sampled in 2014 was 308 mm TL. Freshwater catfish in the Goulburn River catchment (a tributary of the mid-upper River Murray) have been found to strongly select habitats containing wood and aquatic macrophytes (Koster *et al.* 2014). Consequently, to more accurately assess recruitment for this species the adoption of a targeted survey approach (similar to that used for Murray cod) may be required, potentially using a combination of methods (e.g. electrofishing and fyke netting).

Recruitment of non-native species

Increased recruitment of YOY common carp and goldfish corresponded with increased discharge and water levels that occurred at the catchment scale (i.e. 100s – 1000 km) in 2005–06, 2010–11 and 2013–14, and at the local scale (i.e. 10s km) during the Slaney Creek flow manipulation in 2009 (Leigh and Zampatti 2011) and following operation of the Chowilla regulator in spring–summer 2014. 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

Condition monitoring of fish assemblages at Chowilla from 2005–2016 indicates Ecological Objectives 10 and 11 (as defined in the Chowilla Environmental Water Management Plan) are being met. Over the 12 year sampling period, the diversity and distribution of native species has been maintained. Native species were largely detected in fast-flowing mesohabitats and non-native species in backwater mesohabitats. Fast-flowing mesohabitats also consistently exhibited the highest species richness.

Comparisons of relative abundance and recruitment data highlight that ecological responses to flow are complex and species specific, reflecting the diversity of life history strategies of fish in the MDB. Substantial recruitment of YOY and 1+ golden perch, common carp and goldfish followed significant overbank flows in 2010–11, whereas standard condition monitoring, in association with targeted sampling, indicates annual recruitment of YOY Murray cod (~10–32% of the sampled population) at Chowilla. Freshwater catfish recruitment to YOY was not evident in 2016 and to more accurately assess the demographics of this species the adoption of a targeted survey approach (similar to that used for Murray cod) may be required.

High flows and overbank flooding from 2010–2014 led to decreased recruitment and abundance of the small- to medium-bodied native species, bony herring, Australian smelt, Murray rainbowfish and unspecked hardyhead, compared to the drought years of 2005–2009, primarily due to the loss of submerged aquatic macrophytes in the main river channel. In 2016, these small- to medium-bodied native fishes again increased in abundance as low flows promoted hydraulically benign main channel habitats, and re-establishment of submerged aquatic macrophyte. The range of ecological responses to hydrological variability indicates that environmental flow management strategies in the lower River Murray may not elicit a consistent response from all fish species and that consideration of the individual life histories of native and non-native fish, including hydraulic habitat requirements, is required to successfully manage fish populations in the lower River Murray.

Twelve 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).

Some research questions in order of priority include:

- Survival and diet of larvae of circa-annual (e.g. Murray cod, freshwater catfish and common carp) and flow cued (e.g. golden perch and silver perch) spawners in lotic, lentic and floodplain habitats, under within-channel flows and ‘natural’ and engineered artificial floodplain inundation.
- 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.
- Freshwater catfish ecology (including recruitment and movement) in Chowilla and the adjacent River Murray.

- Fish-habitat (mesohabitat and microhabitat) associations during 'natural' within-channel and overbank flows, and artificial floodplain inundation events.

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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**