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Population dynamics and status of freshwater catfish (*Tandanus tandanus*) in the lower River Murray, South Australia

Qifeng Ye, Luciana Bucater, Brenton Zampatti, Chris Bice, Phillipa Wilson, Lara Suitor, Irene Wegener, David Short and David Fleer

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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

August 2015

Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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EXECUTIVE SUMMARY

Prior to the 1970s, freshwater catfish (*Tandanus tandanus*) was common in the Murray–Darling Basin and supported both commercial and recreational fisheries. Since this time, the species has undergone significant declines in abundance due to a range of anthropogenic impacts such as alteration of the flow regime, barriers to movement, cold water pollution, degradation of habitats, over-harvesting and potential competitive/predatory interactions with non-native species. Consequently, to mitigate further population decline, commercial and recreational harvest of the species ceased in 1997 in South Australia (SA) following protection under the SA *Fisheries Management Act 1982* (now *Fisheries Management Act 2007*). This species is also currently listed as threatened in Victoria and endangered in New South Wales. A national recovery plan was developed for this species in 2001.

Following flood and increased flows during 2010–2012, there were anecdotal reports of increased incidental catches and perceived population recovery of freshwater catfish in the SA River Murray prompting a review of the 'protected' status of the species. Such fisheries management decisions must be informed by knowledge of species life history and understanding of population status. In the absence of a commercial fishery and/or a dedicated fishery-independent monitoring program for freshwater catfish, this project aimed to: 1) consolidate existing biological/ecological knowledge and data on population dynamics of freshwater catfish from the historical fishery records and more recent long-term fishery-independent monitoring programs, 2) engage recreational fishers in collecting data through freshwater catfish fishing events as part of a co-management program, and 3) integrate these data to develop an understanding of the current population status of freshwater catfish relative to the status over the previous decade and in the context of historical declines.

Key findings from this study:

- Historical commercial fisheries data show a substantial reduction in annual catch of freshwater catfish from >20,000 kg in the early 1970s to 6,000 kg in the mid-1970s. Catches remained consistently low throughout the 1980s and 1990s (<550 kg per annum) before this species became a protected species in 1997 under the *Fisheries Management Act 1982* (now *Fisheries Management Act 2007*).
- During a period of prolonged drought over 2002–2009, the relative abundance of freshwater catfish remained low in main channel and anabranch habitats of the SA River Murray. Following high flows and extensive overbank flooding during 2010–2012, there was an

increase in abundance, particularly in 2011/12, compared to the previous drought/low flow years. The increase could be attributed to multiple factors including enhanced recruitment, increased movement, and subsequent elevated catchability (i.e. increased interception rate by drum nets and accumulation of fish below weirs where most electrofishing occurred).

- The peak relative abundance recorded in 2011/12 (drum net catch-per-unit-effort (CPUE), 0.004 kg.net-day^{-1}) remained an order of magnitude lower than the historical commercial CPUE just prior to 1997 (0.06 kg.net-day^{-1}), when freshwater catfish was listed as a protected species in the SA River Murray. Moreover, a general decline in abundance in 2012/13 following the increase in 2011/12 suggested a 'temporary nature' of the recent increase in catch rather than a true 'population recovery' of this threatened species.
- The freshwater catfish population in the SA River Murray remains in low abundance in the context of historical declines.
- The population status of freshwater catfish is **undefined**, based on the definition from the national stock status framework (Flood *et al.* 2014), due to the difficulty in identifying the primary factor (overfishing or environmental impacts) causing the initial declines of the spawning biomass in the lower River Murray.

Long-term monitoring is essential to provide time series data on population dynamics (including abundance and demographics) and assess ongoing status, and potential recovery of freshwater catfish. Ideally, such data would incorporate complementary fishery-dependent and fishery-independent sampling (i.e. vessel electrofishing and drum/fyke netting) and build upon existing long-term datasets. The 2013/14 recreational fishing events established baseline data and collected valuable biological information on this protected species. Ongoing support from recreational fishers through co-management may assist in collecting longer-term data on population trends to inform management.

There remain significant knowledge gaps in the biology and ecology of freshwater catfish in the lower River Murray. These include basic information on life history, population dynamics and the influence of hydrology and habitat on reproduction and movement. Such knowledge is fundamental for assessing ongoing population status and to improve management to facilitate the recovery of freshwater catfish in the lower River Murray.

1. INTRODUCTION

1.1. Background

Freshwater catfish (*Tandanus tandanus* Mitchell, 1838) is a medium-bodied (typically ≤500 mm in length and ≤2 kg in weight) member of the Plotosidae family native to the Murray–Darling Basin (MDB) (Lintermans 2007). The species has been protected under the South Australian (SA) *Fisheries Management Act 1982* (now *Fisheries Management Act 2007*) since 1997, following dramatic declines in commercial fishery catches in the 1970s and the persistence of low catches throughout the 1980s and 1990s. Whilst commercial harvesting likely impacted freshwater catfish populations, other anthropogenic impacts such as altered flow regime, barriers to movement, elevated salinity and potential competitive/predatory interactions with non-native species (e.g. common carp, *Cyprinus carpio*), potentially contributed to declines (Clunie and Koehn 2001a; Lintermans 2007).

Following high flows and widespread flooding in the lower River Murray during 2010–2012, recreational fishers reported increases in the number of freshwater catfish incidentally caught in the SA River Murray. Anecdotal information on increased catches and perceived population recovery prompted suggestions from recreational fishers that freshwater catfish be removed from the protected species list and a personal daily bag limit implemented. Such fisheries management decisions, however, must be informed by knowledge of species life history and empirical data on population status.

After the protection of freshwater catfish in 1997, no specific monitoring or research programs have investigated the ecology of freshwater catfish or assessed the ongoing status of populations in SA. Nonetheless, since early 2000 several long-term (>8 years) fishery-independent monitoring programs have monitored fish assemblages in the main channel, anabranch and wetland habitats of the SA River Murray and these datasets, together with historical fisheries data, represent the best available information to estimate recent trends and current population status of freshwater catfish in the context of historical declines. Furthermore, the current situation provided an opportunity to engage recreational fishers in data collection to inform the co-management of inland fisheries.

Contemporary fisheries management aspires to follow a holistic approach, involving contributions from all stakeholders including recreational fishers (FRDC 2008). As such, Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture have increasingly focused on engaging the recreational sector as a means of fostering relationships with recreational fishers in SA. A project was developed and funded by the Fisheries Research and Development Corporation (FRDC), titled 'Beyond engagement: moving towards a co-management model for recreational fishing in South Australia' (2013/205), with the aim of developing a model for the co-management of recreational fishing through a case study on freshwater catfish in the lower River Murray, SA. Data collected during recreational fishing events in 2013/14, as part of the freshwater catfish case study, complemented the assessment of the current population status of this species in the SA River Murray.

1.2. Objectives

The overall aim of this project was to improve understanding of the ecology, population dynamics and current population status of freshwater catfish in the SA River Murray. Specific objectives were to:

- Collate information on the biology/ecology of freshwater catfish.
- Collate and analyse existing data on freshwater catfish population dynamics (i.e. abundance, recruitment, etc.) from historical fishery and more recent long-term fishery-independent monitoring.
- Develop and undertake a recreational fishing program to foster recreational fisher engagement and generate fishery-dependent data on freshwater catfish including catch rates and size/age compositions.
- Integrate these data to provide an evaluation of the current population status of freshwater catfish relative to the status over the previous decade and in the context of historical declines.

2. BIOLOGY AND ECOLOGY

2.1. Taxonomy

Freshwater catfish (*Tandanus tandanus*) is a member of the family Plotosidae. Two species of *Tandanus* are described; freshwater cobbler (*Tandanus bostocki*), found in south-western Australia, and freshwater catfish (*Tandanus tandanus*), which is distributed across the MDB and eastern drainage system. The taxon may include up to three distinct species and several sub-species; nonetheless, in the MDB the species is represented by one broad panmictic population (Musyl and Keenan 1996; Jerry 2005, 2008; Hardy *et al.* 2011).

2.2. Geographical distribution and habitat preference

Freshwater catfish was historically common and broadly distributed throughout the MDB, as well as in coastal streams in Queensland and New South Wales (NSW) (Lintermans 2009). Currently, it is only considered abundant in Queensland, and is rare in NSW, Victoria and SA (Morris *et al.* 2001; Hammer *et al.* 2010). In SA, freshwater catfish have been stocked and populations established in water-bodies outside the lower River Murray, including farm dams and several streams of the Western Mount Lofty Ranges (i.e. Torrens, Wakefield and Field river catchments) (Hicks and Sheldon 1998; Rowntree and Hammer 2004; Hammer 2005; Hammer *et al.* 2010), as well as the upper Broughton River (Clunie and Koehn 2001a).

Often referred to as a habitat specialist (Rowntree and Hammer 2007), freshwater catfish prefer rivers and wetlands with complex physical structure including snags, undercut banks and aquatic plants (Hammer 2009). Juveniles are found in shallower habitats, whilst adults are more commonly collected in deeper runs and pools (Clunie and Koehn 2001a; Pusey *et al*. 2004). In the present-day SA MDB, freshwater catfish are predominantly found in main channel and anabranch habitats, and intermittently in wetlands (Wedderburn and Suitor 2012; Wilson *et al.* 2012; Thwaites and Fredberg 2014).

2.3. Growth and maturity

Freshwater catfish have been recorded to grow to a maximum length of 900 mm (total length, TL) and 7 kg in weight; however, adults commonly range 300–500 mm and weigh <2 kg (Lake 1967a; Merrick and Schmida 1984). Longevity has been suggested to be at least 8 years (Davis 1975; Davis 1977b). Studies in the upper MDB and south-eastern Queensland suggest both sexes commence gonadal development at two years of age and maturity is reached at between 3 and

5 years of age (Davis 1977b; Clunie and Koehn 2001a) and lengths of 299–355 mm for females and 370–395 mm for males (Davis 1977a; Bluhdorn and Arthington 1994). The smallest mature female freshwater catfish, recorded from the lower River Murray, was 215 mm TL whilst 50% of the females sampled during recent surveys were mature at 252 mm TL (SARDI unpublished data).

2.4. Reproduction and recruitment

Freshwater catfish typically spawn in spring and summer (Lintermans 2007), and larvae are commonly collected in November in the main channel and Chowilla anabranch system of the lower River Murray (Leigh *et al.* 2008; Cheshire 2010; Ye *et al.* 2013). Freshwater catfish are circa-annual spawners; spawning is not associated with increased flow or flooding, but rather rising water temperature is suggested as the primary stimulus, with spawning occurring at temperatures of 20–24˚C (Clunie and Koehn 2001a; Lintermans 2007). The eggs are laid into a nest, which is typically a circular or oval-shaped depression (0.5–2 m diameter) and made of coarse materials (gravel, rocks, sticks, macrophytes) (Merrick and Midgley 1981; Cadwallader and Backhouse 1983; Clunie and Koehn 2001a). Whilst elevated flow is not required to stimulate spawning, it may stimulate productivity, which may facilitate enhanced recruitment of freshwater catfish (Baumgartner, 2011; Cameron *et al*. 2013). It has been suggested that fluctuations in water levels may result in nest exposure and/or abandonment (Clunie and Koehn 2001a), although this is highly unlikely in the lower River Murray where river regulation has resulted in increased stability of river levels.

2.5. Diet

The anatomical features of the freshwater catfish, a broad flattened head, inferior mouth, presence of barbels, vomerine teeth, fleshy gill rakers and a long convoluted intestine, indicate its specialisation for benthic foraging (McMahon 1984). Considered an opportunistic carnivore (Davis 1975, 1977c), key adult prey items include macrocrustaceans, molluscs, aquatic and terrestrial insects, fish and particulate detritus (Pusey *et al.* 2004). Aquatic insects are more important in the diet of juveniles (Pusey *et al.* 2004). There is no published information on the feeding ecology of freshwater catfish larvae, although 27 day old larvae in aquaria were reported to consume cladocerans, copepods and chironomid larvae (Lake 1967b; Pusey *et al.* 2004).

2.6. Movement

Freshwater catfish is believed to be a sedentary and territorial species (Clunie and Koehn 2001a; Pusey *et al.* 2004). Studies in both the northern (Davis 1975) and southern MDB (Reynolds 1983; Koster *et al.* 2014), and coastal NSW (Russell 1991) suggested limited movement of adult fish (typically <5 km). Juveniles may form loose schools, whilst adult fish tend to be solitary except when mating (Cadwallader and Backhouse 1983). Adults are more active at night with peak activity at dusk and early evening (Davis 1975; Koster *et al.* 2014). Having a drifting larval stage, however, means flow and in particular water velocity may play a role in the dispersal of freshwater catfish (Zampatti *et al.* 2011). Indeed, dispersal of both larvae and adults has been shown to increase during periods of high flow (Reynolds 1983; Cheshire *et al.* 2012)

2.7. Threats, population decline and conservation status

A number of anthropogenic impacts have likely contributed to population declines and remain as threats to freshwater catfish populations in the MDB, including altered flow and temperature regimes, habitat degradation, barriers to movement, elevated salinity and potential competitive/predatory interactions with non-native species (e.g. common carp and redfin perch (*Perca fluviatilis*)) (Clunie and Koehn 2001b; Lintermans 2007). In SA, the key threats include river regulation, habitat degradation and impacts of invasive species. As the lower River Murray is a heavily regulated system, significantly reduced flow has led to increased siltation, which may interfere with freshwater catfish feeding behavior and also degrade spawning/nesting habitat (Hammer *et al.* 2010). In addition, invasive species, especially the highly abundant common carp (*Cyprinus carpio*), may have contributed to declines given the potential for competitive interactions with freshwater catfish for food and habitat during both juvenile and adult stages (Hammer *et al.* 2010).

Following a drastic reduction in abundance and distribution in the early to mid-1970s and consistently low abundance from the mid-1980s to mid-1990s, freshwater catfish was listed as a protected species in 1997 under the *SA Fisheries Management* Act *1982* (now *Fisheries Management Act 2007*). Freshwater catfish is also currently listed as threatened in Victoria (*Flora and Fauna Guarantee Act 1988*) and endangered in NSW (*NSW Fisheries Management Act 1994*). A national recovery plan was developed for this species in 2001 (Clunie and Koehn 2001b).

3. STUDY REGION

This study was undertaken in the lower River Murray, downstream of the SA border (Figure 3.1). In this region, the River Murray has no significant tributaries and its hydrology is determined by discharge from the upper Murray and Darling catchments. Flow to SA is largely dictated by the operation of upstream storages (i.e. dams) and irrigation diversions, whilst within SA, a series of six low-level (~3 m) weirs and five tidal barrages regulate flow, fragmenting >600 km of river into a series of contiguous weir pools. Unlike the regulated but free flowing mid-reaches of the River Murray, the weirs in the lower River Murray transform a historically highly dynamic lotic system into a homogenous series of lentic environments under low flows (Walker 2006).

Data on freshwater catfish catch (weight or abundance), effort and length were sourced from commercial and recreational fisheries, as well as fishery-independent studies conducted in main channel and anabranch habitats across four distinct geomorphic regions of the lower River Murray (Walker and Thoms 1993): (i) floodplain (SA border – Lock 3), (ii) gorge (Lock 3 – Mannum) (iii) swamplands (Mannum – Wellington) and (iv) Lower Lakes (Wellington – Murray Barrages) (Figure 3.1). More details about sampling sites are presented in Section 5.

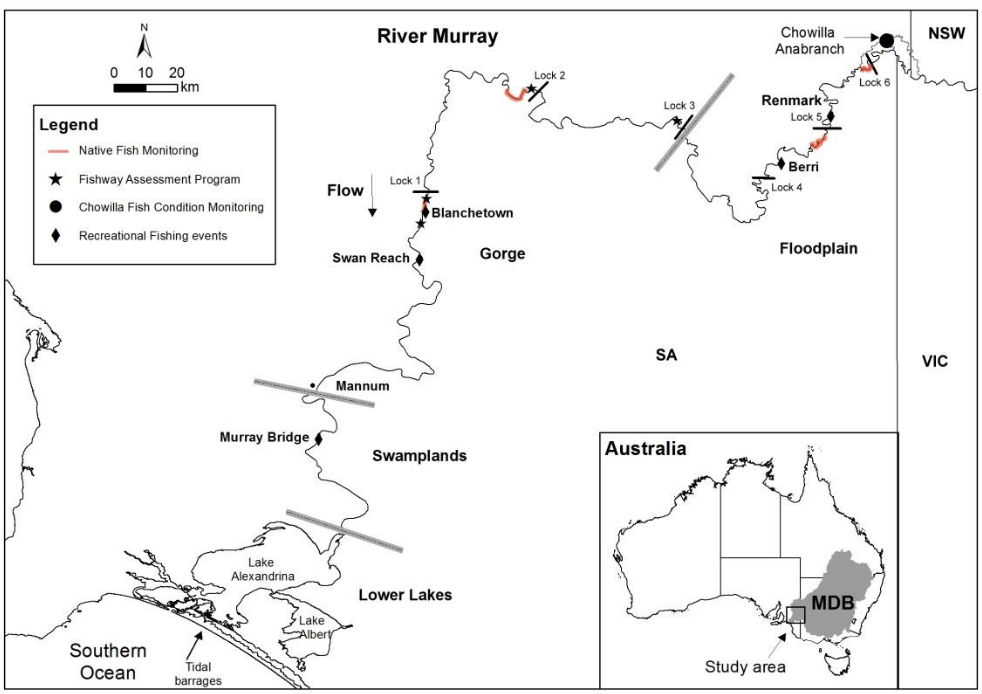

Figure 3.1. Map of lower River Murray, South Australia presenting the main channel and locations of locks, geomorphic regions and fish sampling locations.

4. HYDROLOGY

The period 1990–2014 was characterised by hydrological extremes in the MDB. During the 1990s, the hydrograph of the lower River Murray (flow at the SA border) was characterised by numerous overbank floods (>45,000 $ML.day^{-1}$). In contrast, from 2001–2010, the MDB experienced its most severe drought on record (van Dijk *et al.* 2013) resulting in a prolonged period of highly regulated, low-volume (<15,000 $ML.day^{-1}$) within-channel flows in the lower River Murray (Figure 4.1). Anthropogenically exacerbated hydrological drought resulted in flow to SA reaching a record low of <1,000 $ML.day^{-1}$ in winter 2007 and the River Murray ceased flowing to the sea from March 2007–September 2010.

The drought was broken in late 2010 following a dramatic increase in flow (peak of 93,000 $ML.day^{-1}$) and the largest overbank flood since 1993. The following three years were characterised by high within-channel flows in spring/summer (Figure 4.1).

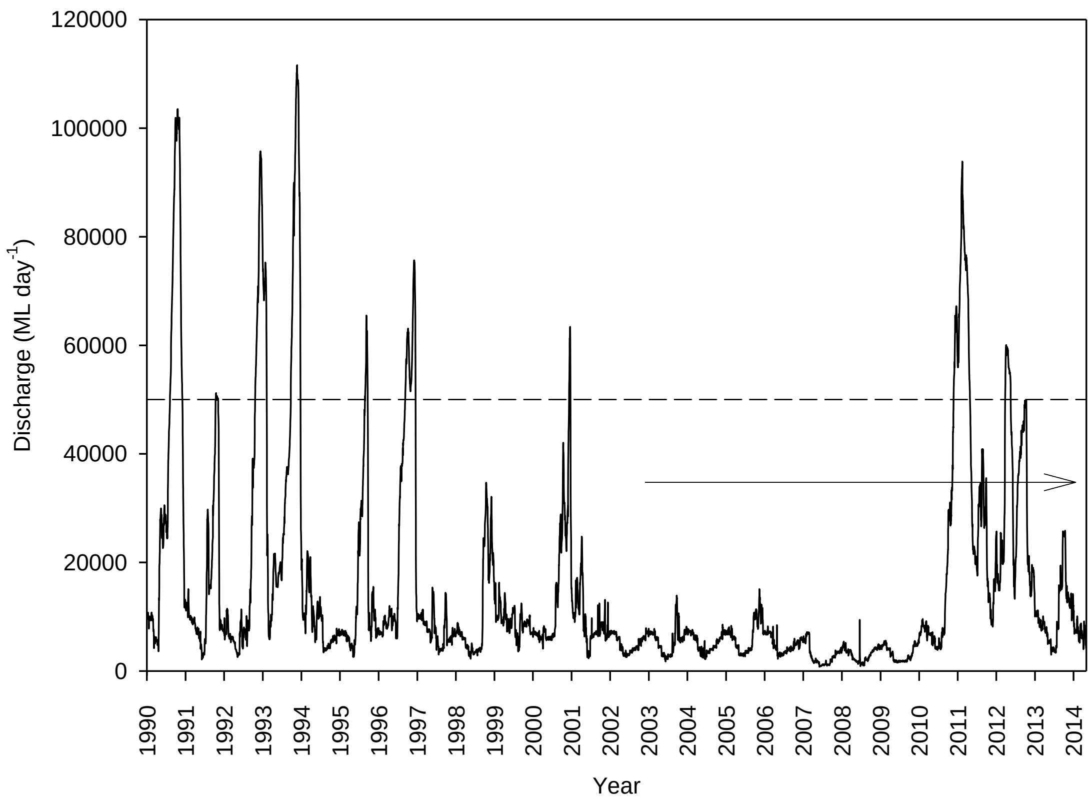

Figure 4.1. River Murray flow (discharge into South Australia, $ML.day^{-1}$) from 1990 to 2014. Black arrow represents the study period and dotted line represents the approximate discharge at which floods occur in the lower River Murray (50,000 $ML.day^{-1}$).

5. METHODS

Data on trends in relative abundance, size and age structures (as estimated from otolith increment count) of freshwater catfish were obtained from three primary sources;

1) historical commercial fishery data,
2) fishery-independent monitoring datasets,
3) recreational fishing events.

5.1. Historical commercial fishery

Historical data of commercial fishery catch (annual total catch from all gears) of freshwater catfish from the SA River Murray and Lower Lakes between 1968/69 and 1975/76 were obtained from Reynolds (1976). There are no effort data for 1968/69–1975/76 and no catch and effort data available for 1976/77–1983/84. Detailed catch and effort data were recorded (Knight *et al.* 2001) between 1984/85 and 1996/97, after which freshwater catfish was listed as a protected species in SA under the *Fisheries Management Act 1982* (now *Fisheries Management Act 2007*).

The trend in annual commercial catch between 1968/69 and 1996/97 was examined to explore potential variation in population abundance of freshwater catfish. These data, however, need to be treated with caution because no effort data were available prior to 1984/85. More detailed analysis on catch, effort and catch-per-unit-effort (CPUE) was conducted for 1984/85–1996/97, based on data from drum nets, which was the primary gear of freshwater catfish catches.

5.2. Fishery-independent data

In the absence of a targeted monitoring program for freshwater catfish in the SA River Murray, we explored various datasets collected by SARDI from large spatio-temporal scale research and monitoring projects of fish populations in this region. Datasets were selected based on the following criteria:

- Fishing methods used would need to effectively target freshwater catfish (i.e. drum/fyke netting or electrofishing);
- Sampling took place in habitats suitable for freshwater catfish (i.e. main channel and off channel habitats of the SA River Murray);
- Monitoring was undertaken annually, using consistent methods, for at least 8 years and comprised sampling in both drought and recent high flow years.

The monitoring programs that met these criteria were considered suitable for further analysis. Further descriptions about these selected programs are provided in Sections 5.2.1–5.2.3.

Additionally wetland fish sampling data collected by the SA MDB Natural Resource Management Board (SA MDB NRMB) were explored, which provided complementary information regarding size compositions of freshwater catfish in the wetlands along the SA River Murray. Details are described in Section 5.2.5.

5.2.1. Native Fish Monitoring Program

A long-term fishery-independent monitoring program (Native Fish Monitoring Program) was implemented in the SA River Murray in 2005 (Ye and Zampatti 2007). Until 2009, the aim of the program was to collect biological information for key native fish species, Murray cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua ambigua*), and to measure biological performance indicators (i.e. relative abundance and size/age structure) for stock assessment. Post 2009, the aims of the monitoring program varied, but the sampling techniques remained consistent. The freshwater catfish data presented in this report are a selected subset of data collected between 2005 and 2012 from four main channel sites in the lower River Murray; two in the gorge (downstream of Locks 1 and 2) and two in the floodplain geomorphic region (downstream of Locks 5 and 6) (Figure 3.1). Sampling was undertaken monthly, by commercial fishers, from September to December in each year. On each occasion, 10 to 15 small mesh drum nets (0.9 m hoop diameter, 3.5 m wings, 50 mm mesh) were set overnight for 2–3 consecutive days for a total of 30 net days sampling effort at each site. Fish from each net were identified, counted and measured for length (± 1 mm, total length, TL).

5.2.2. Murray River Fishway Assessment Program Locks 1–3 Fish Sampling

In order to restore fish passage to over 2000 km of the River Murray, from the sea to Hume Dam, fishways are being constructed on all locks and weirs along the main channel of the river (Barrett and Mallen-Cooper 2006). As part of a long-term (>10 year) assessment program of the effectiveness of newly constructed fishways in decreasing accumulations of fish downstream of the weirs, fish assemblages were sampled annually in the vicinity of Locks 1–3. Fish were sampled monthly (September–February) between 2002 and 2013 at three sites immediately below Lock 1, Lock 2 and Lock 3 and an additional site 5 km downstream of Lock 1 using a vessel mounted 7.5 kW Smith-Root Model GPP 7.5 H/L electrofishing system. Each site was sampled over a diel period with the same method used during the day and night.

Sampling consisted of 18 replicate 90-second (on-time) electrofishing 'shots' with eight shots performed on each bank, downstream of each weir and two shots across the weir face. Electrofishing shots were evenly spaced and commenced approximately 600 m downstream of the weir proceeding in an upstream direction. At the site 5 km downstream of Lock 1, eight shots were done on each side of the river bank. During each shot, fish were collected by dip net and placed into a live well to recover prior to identification and measurement (± 1 mm, caudal fork length, CF or TL).

5.2.3. Chowilla Fish Assemblage Condition Monitoring

Fish assemblage 'condition monitoring' has been undertaken annually from 2005 to 2013 in the Chowilla Anabranch system and adjacent main channel habitats in the floodplain geomorphic region of the lower River Murray (Figure 3.1) (Wilson *et al*. 2012). The Chowilla Anabranch system (hereafter Chowilla) is a complex of anabranches on the northern floodplain of the River Murray that circumvent Lock and Weir No. 6, 620 km from the river mouth. As a result of the head differential created by the weir, flow is diverted through the anabranches and creates permanent lotic habitats in a region where such habitats are now rare in the main river channel.

Fish condition monitoring was conducted annually in March/April in order to maximise the likelihood that young-of-year (age 0+) individuals of all species, from the preceding spring/summer spawning season, were represented in the catch, enabling the recruitment of individual fish species to be assessed. Due to high river levels and extensive floodplain inundation in 2011, surveys were delayed until May when flow had decreased substantially (~45,000 $ML.day^{-1}$), in an effort to ensure that a comparable (standard) area was sampled at each site to previous surveys (2005–2010).

Sampling was 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. Fish from each shot were identified, counted and measured for length (± 1 mm, CF or TL).

5.2.4. Data analysis

Data analyses were undertaken for the above three longer term fishery-independent datasets using the statistical software package PRIMER v.6.12 and PERMANOVA+ (Anderson *et al.* 2008). Temporal variation in freshwater catfish abundance was investigated using single fixed-factor (year) univariate PERMANOVA (permutational multivariate analysis of variance) (Anderson 2001). These analyses were performed on Euclidean distance similarity matrices and prior to all analyses, total numbers of freshwater catfish were standardised as CPUE (fish.minute^{-1} of electrofishing or fish.net-day^{-1}).

5.2.5. SA Wetland Fish Sampling

Regular monitoring of wetland and floodplain habitats is conducted along the lower River Murray by the SA MDB NRMB wetland and floodplain program (Wedderburn and Suitor 2012). The primary objective of the program is to support on-going adaptive management of sites, as well as inform State environmental watering priorities, and evaluate responses of the wetlands and floodplains to management actions such as weir pool manipulation. As part of this program, fish sampling was conducted using single-wing fyke nets (6 mm mesh) in floodplain/wetlands along the SA River Murray. Length data from freshwater catfish sampled in 21 wetlands during October–December 2011 and four wetlands during January–February 2012 were extracted to develop size compositions of wetland populations (see Appendix I).

5.3. Recreational fishing events

In 2013/14, as part of the FRDC project titled ‘Beyond engagement: moving towards a co-management model for recreational fishing in South Australia’ (2013/205), recreational fishers were engaged in fishing events, targeting freshwater catfish between November 2013 and February 2014. Five two-day fishing events were run along the lower River Murray near the townships of Renmark, Blanchetown, Berri, Murray Bridge and Swan Reach (Figure 3.1). At each event day, recreational fishers received an information pack, which contained background information, rationale behind the research, a map of the area to be fished and a catch/effort log sheet. At the end of each fishing day, catch/effort log sheets were collected and information compiled for estimating the catch rates of freshwater catfish (CPUE, fish.rod-hour^{-1}) and analysing size compositions. A subsample of freshwater catfish was retained to facilitate the collection of further biological data.

5.4. Other biological data

A total of 61 freshwater catfish were sampled from the recreational fishing events in 2013/14 and an additional 38 fish were collected opportunistically through SARDI research/monitoring projects in 2012/13 and 2013/14. These fish were measured for length (TL, mm) and weight (g), sex determined and otoliths extracted for increment counts. The data were used to determine a length-weight relationship (Appendix II) and estimate an age-length relationship for freshwater catfish. The age composition of fish sampled from recreational fishing events was also estimated.

5.4.1. Otolith increment count/age estimation

The use of otolith increment counts to estimate age has been validated for some members of the family Plotosidae, e.g. cobbler (*Cnidoglanis macrocephalus*) (Laurenson *et al.* 1994), but not freshwater catfish. Consequently, the increment counts presented in this report provide an estimation of age based on the assumption that increments are formed on an annual basis, but should be viewed with caution. Age determination for freshwater catfish was attempted initially using ground otoliths following the method described for channel catfish (*Ictalurus punctatus*) (Colombo *et al.* 2010), a fork tailed catfish in the same order as freshwater catfish (Siluriformes). After familiarisation with the microstructure of freshwater catfish otoliths, a more efficient transverse sectioning method (Anderson *et al.* 1992) was utilised for all otoliths.

Otolith sections were read by two readers independently to count the number of increments. After about a week, the sections were read a third time by both readers using a consensus approach. This set of agreed increment counts was used in the study. A comparison between the independent readings by two readers and agreed set of readings suggests an average agreement of 60%, although 92% of the readings are within the variation range of ±1 increment count. The overall variations range from -1 to +2 increment counts (see details in Appendix III).

To estimate the age composition of the catch from 2013/14 recreational fishing events, otolith increment counts from 55 out of 61 fish collected were included; whereas the otolith microstructure of the remaining six individuals was unclear and increments could not be discerned. Those 55 fish were also used in estimating an age-length relationship of freshwater catfish, along with an additional 37 of 38 fish opportunistically collected from other SARDI projects in the lower River Murray (noting otolith increments were unclear for one remaining individual).

6. RESULTS

6.1. Historical commercial fishery

6.1.1. Total annual catch

Annual commercial catches of freshwater catfish from the SA River Murray and Lower Lakes were ~20,000 kg.yr^{-1} in the late 1960s and early 1970s (Figure 6.1), but declined drastically to ~6,000 kg in 1975/76. The catch continued to decline from 1975/76 to 1984/85. Between 1984/85 and 1996/97, annual commercial catch remained very low, ranging 183 to 534 kg. From 1984/85 to 1996/97, all records represent non-target catch with most of the fish caught when targeting golden perch (83%) or no specific target species being identified (14%); 73% of the catch came from drum nets and 26% from large-mesh gill nets (stretch mesh ≥70 mm).

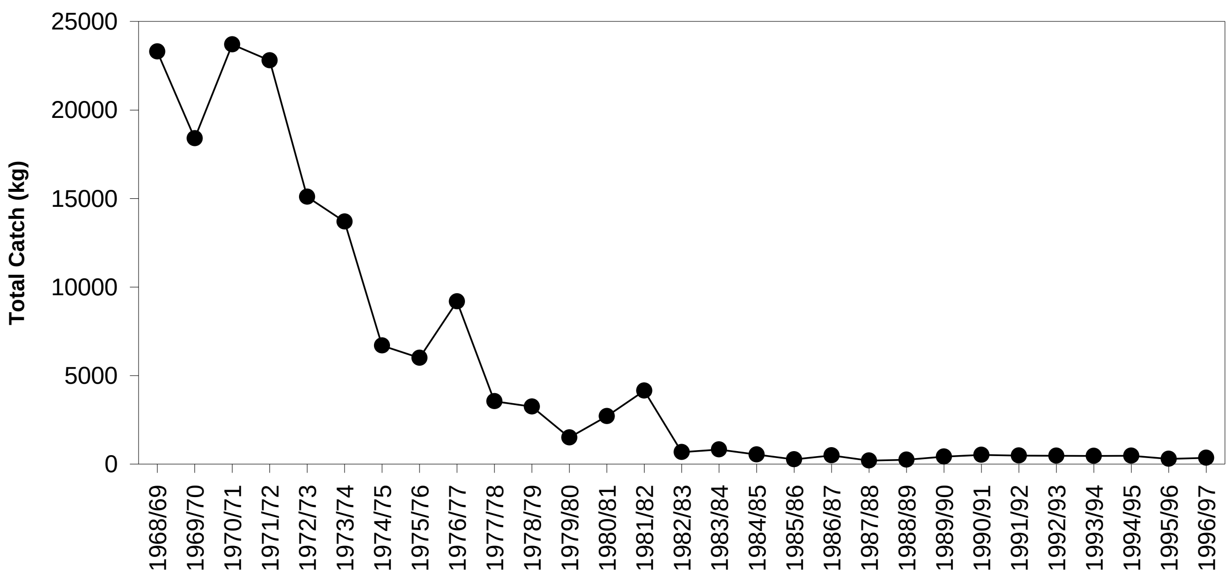

Figure 6.1. Annual commercial catches of freshwater catfish from the South Australian River Murray and Lower Lakes between 1968/69 and 1996/97 (Data source: Reynolds 1976; SAFIC 1982, 1983, 1983, 1985; South Australian Fisheries Statistics).

6.1.2. Catch, effort and CPUE

Annual non-target catch, effort and CPUE for freshwater catfish by drum net operations are shown in Figures 6.2a and 6.2b. Catch and effort fluctuated greatly between 1984/85 and 1988/89, then stabilised in the following six years at around 350 kg and 8,000 net days, respectively (Figure 6.2a). Catch and effort decreased by approximately 30% during the last two years before the fishery was closed in 1997.

The daily average CPUE peaked at 0.12 kg (net.day)$^{-1}$ in 1984/85, then exhibited a 50% decline over the next three years. From 1987/88 to 1996/97, CPUE remained around an average of 0.06 kg (net.day)$^{-1}$ (Figure 6.2b).

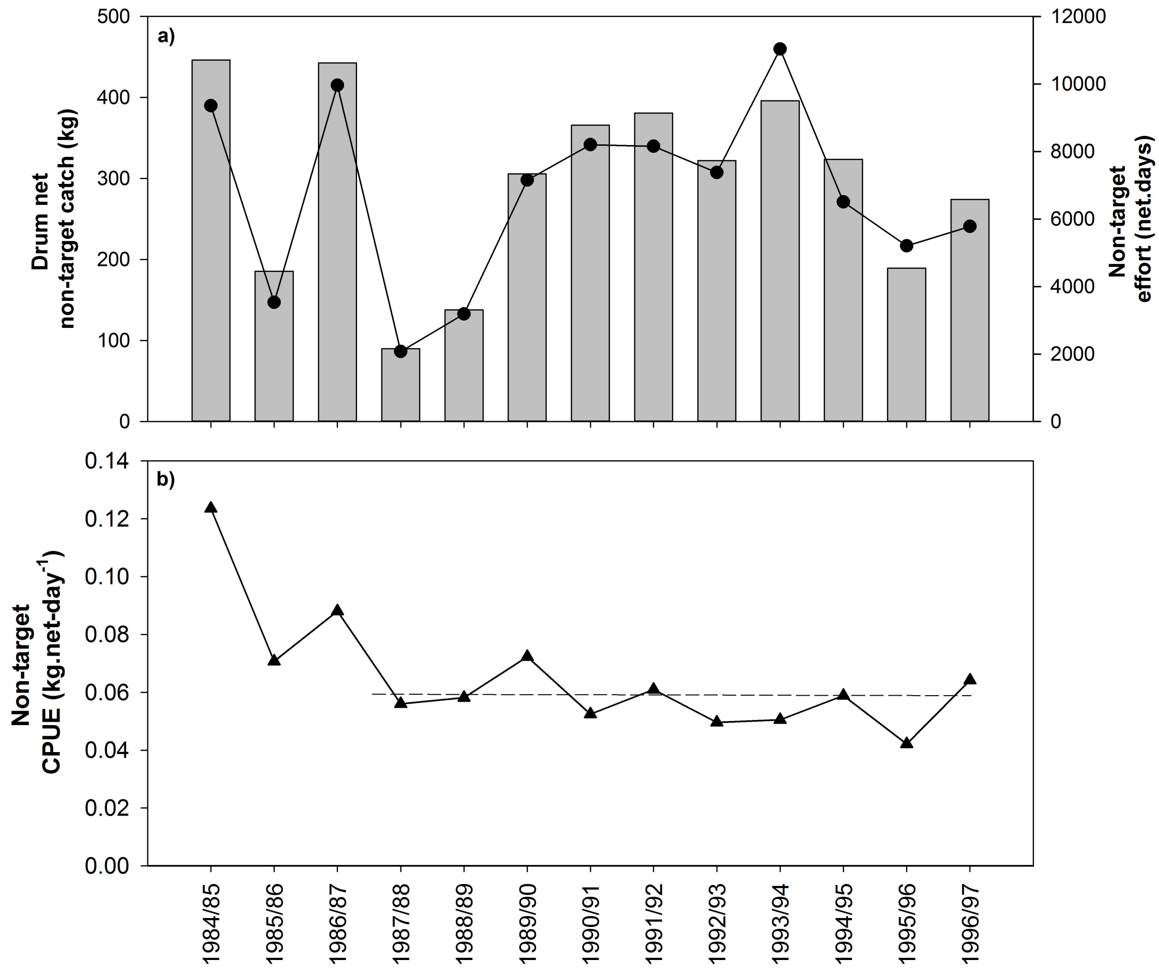

Figure 6.2. Catch, effort and catch-per-unit-effort (CPUE) of freshwater catfish from the South Australian commercial fishery in the River Murray between 1984/85 and 1996/97. (a) Annual non-target catches of freshwater catfish by drum net (kg) (grey bars) and effort (black line) expressed as net-days and (b) non-target CPUE (kg.net-day^{-1}), calculated by averaging daily CPUE. Dashed black line indicates the average CPUE of the last ten years of the fishery 0.06 kg.net-day^{-1}.

6.2. Fisheries-independent data

6.2.1. Relative abundance

<u>*Native Fish Monitoring Program*</u>

Drum netting downstream of Locks 1, 2, 5 and 6 from 2005 to 2010 sampled one freshwater catfish (Table 6.1). The number of freshwater catfish sampled increased in 2011 (n = 67) before decreasing in 2012 (n = 10). Mean relative abundance (mean CPUE) remained consistent at a low level, with the exception of a significant increase in 2011 (PERMANOVA main test $Pseudo\text{-}F_{7,24}$ = 5.53, p = 0.001) (Figure 6.3 and Appendix IV).

Table 6.1. Total numbers of freshwater catfish captured at four sites sampled in the River Murray for the Native Fish Monitoring Program from 2005 to 2012. Sampling occurred monthly from September to December each year.

Site	2005	2006	2007	2008	2009	2010	2011	2012
D/S Lock 1	0	0	0	0	0	0	4	1
D/S Lock 2	0	0	0	0	0	0	11	0
D/S Lock 5	0	0	0	1	0	0	17	4
D/S Lock 6	0	0	0	0	0	0	35	5
Total	0	0	0	1	0	0	67	10

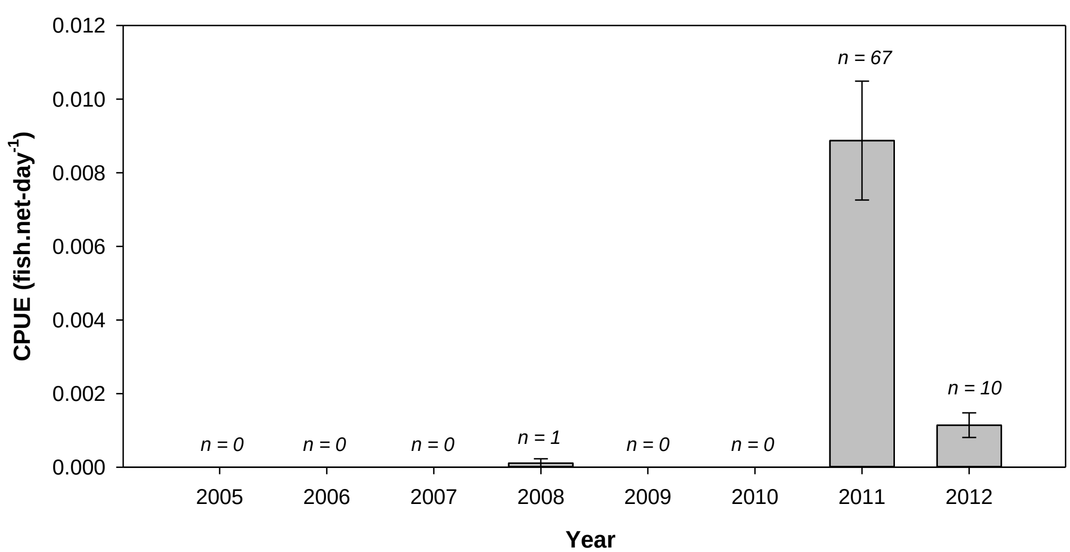

Figure 6.3. Mean (± SE) catch-per-unit-effort (CPUE) (fish.net-day^{-1}) of freshwater catfish collected annually by drum netting from 2005 to 2012 at Lock 1, Lock 2, Lock 5 and Lock 6 on the River Murray (*n* = total number of freshwater catfish collected). Sampling occurred monthly from September to December each year.

Murray River Fishway Assessment Program Locks 1–3 Fish Sampling

No freshwater catfish were sampled at sites in the SA River Murray main channel in the vicinity of Locks 1–3 from 2002/03 to 2007/08, and low numbers (n = 1–4) were sampled from 2008/09 to 2010/11. In contrast, a total of 44 individuals were sampled in 2011/12 and 14 in 2012/13 (Table 6.2). PERMANOVA detected a significant difference in relative abundance between years, with greatest CPUE in 2011/12 (PERMANOVA main test $Pseudo\text{-}F_{9,29} = 4.88$, $p = 0.004$) (Figure 6.4 and Appendix V).

Table 6.2. Total numbers of freshwater catfish captured at sites sampled downstream of Locks 1–3 for the Murray River Fishway Assessment Program from 2002 to 2013 (d/s = downstream). Sampling occurred monthly from September to February each year.

	02/03	03/04	04/05	06/07	07/08	08/09	09/10	10/11	11/12	12/13
Lock 1 0km D/S	0	0	0	0	0	1	0	1	5	2
Lock 1 5km D/S	0	0	0	0	0	0	0	1	15	6
Lock 2 0km D/S	0	0	0	0	0	0	4	1	19	6
Lock 3 0km D/S	0	0	0	0	0	0	0	0	5	0
Total	0	0	0	0	0	1	4	3	44	14

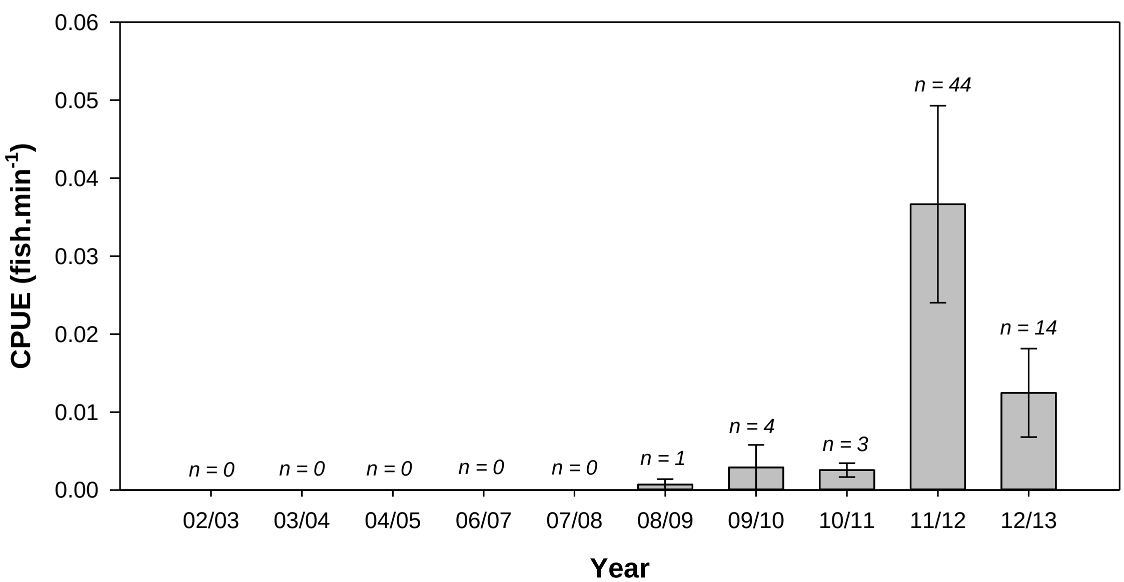

Figure 6.4. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of freshwater catfish collected annually during standardised boat electrofishing surveys from 2002 to 2013 at sites in the River Murray downstream of Locks 1–3 (*n* = total number of freshwater catfish collected). Sampling occurred monthly from September to February each year.

Chowilla Fish Assemblage Condition Monitoring

Freshwater catfish were collected in six out of nine years at sites in the Chowilla region from 2005 to 2013, with numbers sampled ranging 1–20 fish per year (Table 6.3). PERMANOVA detected a significant difference in relative abundance between years ($Pseudo\text{-}F_{8,118} = 4.81$, $p = 0.001$); mean relative abundance remained low from 2005–2010, but appeared to increase after 2011, with peak CPUE in 2012 (Figure 6.5 and Appendix VI).

Table 6.3.Total numbers of freshwater catfish captured at sites sampled as part of fish assemblage condition monitoring in the Chowilla region from 2005 to 2013. (NS = not sampled; US = upstream; DS = downstream). Sampling occurred in March/April each year except for 2011 when it occurred in May.

Site name	2005	2006	2007	2008	2009	2010	2011	2012	2013
Chowilla US Boat Creek Junc.	0	0	0	0	0	0	0	2	0
Chowilla DS Slaney Junc.	0	0	0	0	0	0	0	0	2
Boat Creek US bridge	0	0	0	0	1	1	0	2	3
Swifty's	0	0	0	0	0	0	1	5	4
Pipeclay Creek	0	0	0	0	0	0	0	1	0
Slaney Lower	0	0	1	0	1	0	0	1	1
Slaney Billabong	0	0	NS	0	0	0	1	0	0
Hypurna @ Wilkadene	0	0	0	0	0	0	0	1	0
MR u/s Chowilla junction	0	0	0	0	0	0	1	0	0
Murray DS Lock 6	0	0	0	0	1	0	2	4	2
Isle of Mann	0	0	0	NS	0	0	0	1	0
Monoman Creek Campsite 9	0	0	0	NS	0	0	0	0	1
Murray @ Border Cliffs	0	NS	NS	NS	0	1	1	0	1
Bank K NSW	NS	NS	NS	0	0	0	0	3	0
Salt @ Tareena Billabong	NS	NS	NS	NS	0	0	0	0	1
Pilby Swamp	0	NS	NS	NS	NS	0	3	0	0
Total	0	0	1	0	3	2	9	20	15

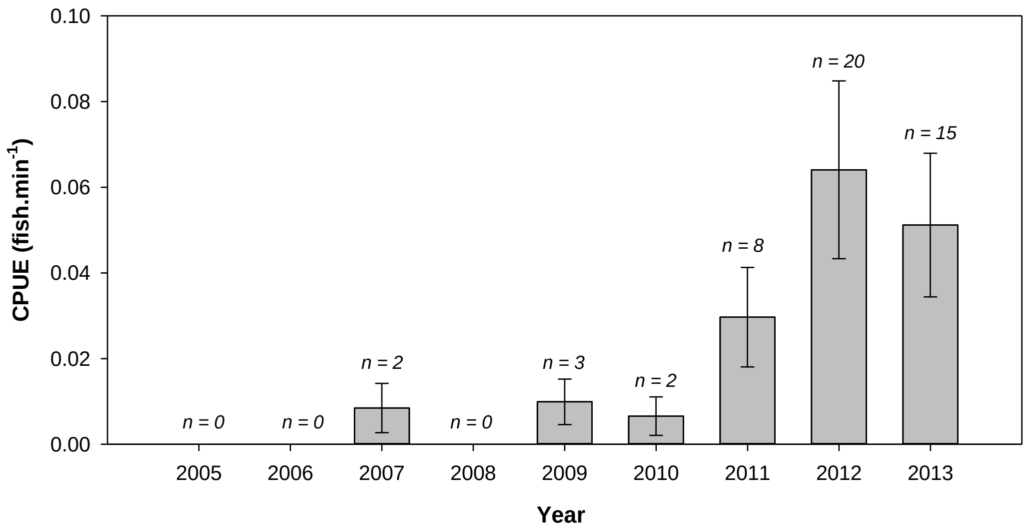

Figure 6.5. Mean (± SE) catch-per-unit-effort (CPUE) (fish.min^{-1}) of freshwater catfish collected annually during boat electrofishing surveys from 2005 to 2013 at 16 sites in the Chowilla Anabranch system and adjacent River Murray (*n* = total number of freshwater catfish collected). Sampling occurred in March/April each year except for 2011 when it occurred in May.

6.2.2. Length-frequency distribution

Native Fish Monitoring Program

Length-frequency data from the Native Fish Monitoring Program are based on very small sample sizes (*n* = 1–2) prior to 2011. In 2011, when a greater number of fish were sampled (*n* = 67), the length-frequency distribution exhibited a broad size range (207–502 mm TL) and a mode at 350–399 mm TL (Figure 6.6). In 2012, the size range was narrower (310–475 mm TL) than the previous year although the sample size was much lower (*n* = 14). There appeared to be a slight progression of the size frequency mode from 2011 to 2012 with an increased proportion of fish 400–449 mm TL.

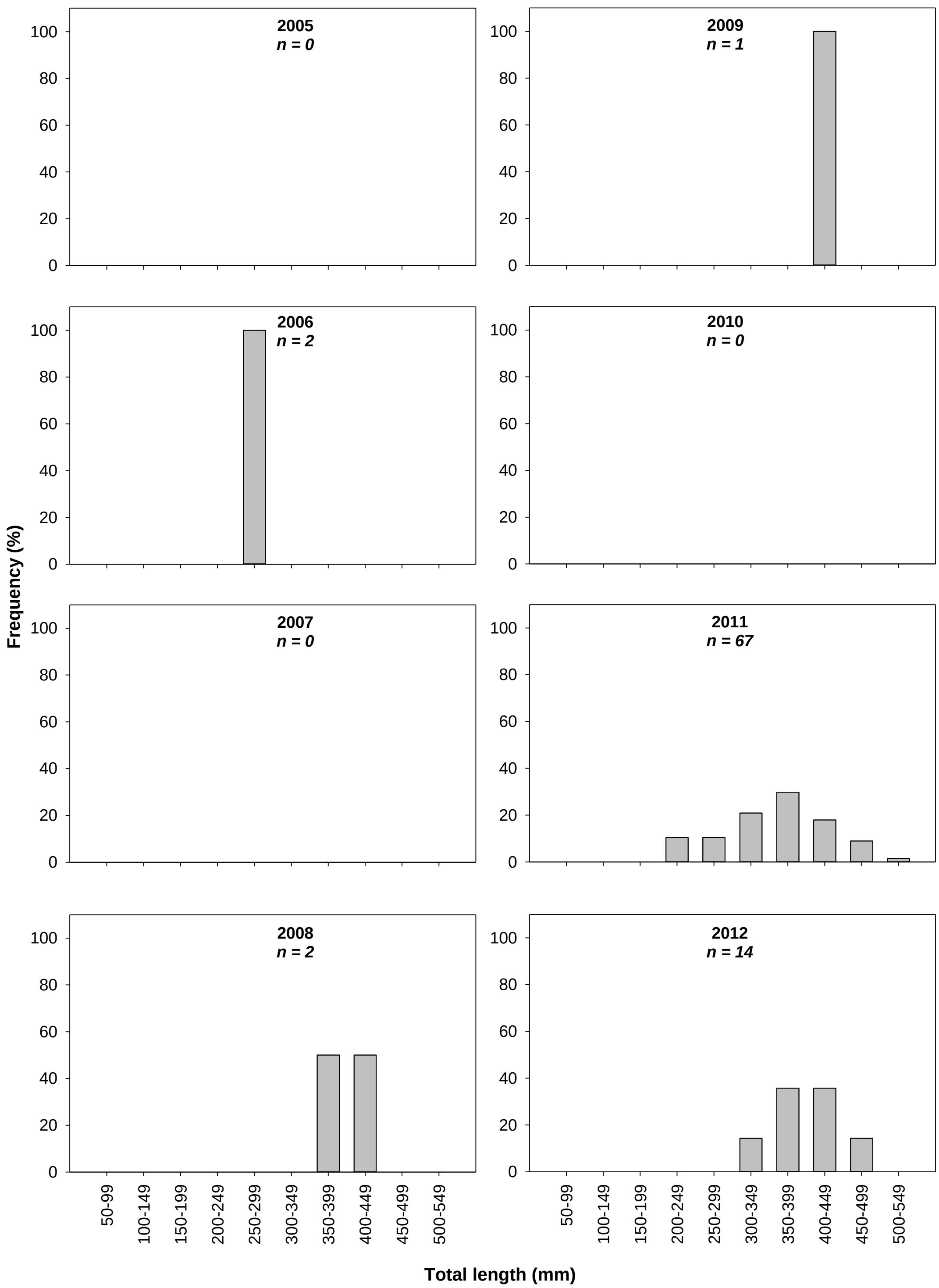

Figure 6.6. Length-frequency distributions of freshwater catfish collected during drum netting surveys at sites directly downstream of Locks 1, 2, 5 and 6 in the River Murray main channel from 2005–2012 (*n* = sample size). Sampling occurred monthly from September to December each year.

Murray River Fishway Assessment Program Locks 1-3 Fish Sampling

Length-frequency data from fish sampled by electrofishing at sites in the main channel of the River Murray in the vicinity of Locks 1–3 are based on small sample sizes (n = 1–12) in all years, except 2011. In this year, freshwater catfish showed a broad size range of 109–460 mm TL (Figure 6.7).

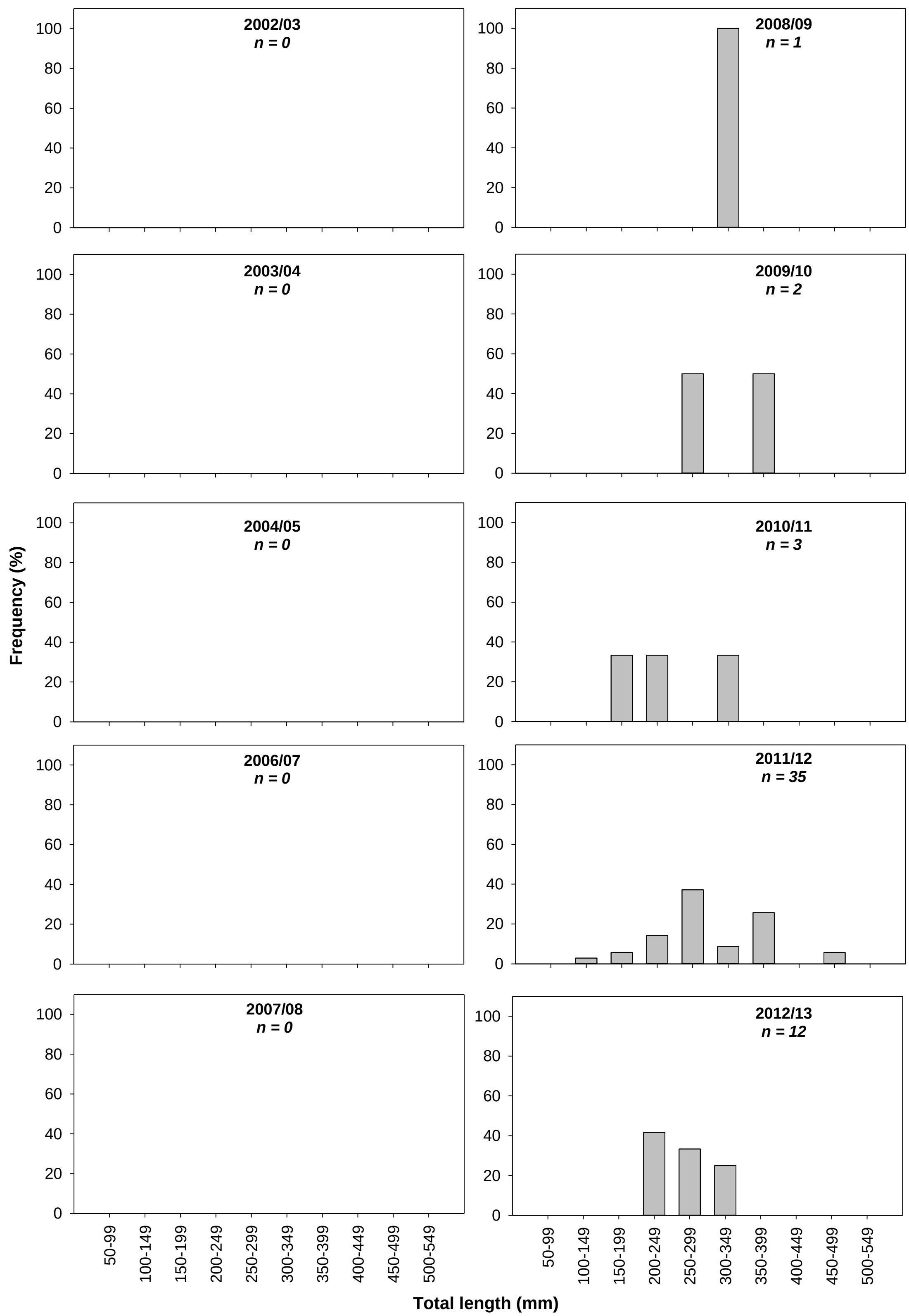

Figure 6.7. Length-frequency distributions of freshwater catfish collected during electrofishing surveys at four sites in the River Murray main channel downstream of Locks 1–3 from 2002/03–2012/13 (*n* = sample size). Sampling occurred monthly from September to February each year.

Chowilla Fish Assemblage Condition Monitoring

Length-frequency data from fish sampled by electrofishing at sites in the Chowilla system and adjacent River Murray main channel are based on small sample sizes ($n \leq 16$). Despite this, fish were typically sampled over a broad range of lengths (84–523 mm TL) and length-frequency distributions appeared to show some yearly size progressions from 2011 to 2013. For example, individuals ranging 50–99 mm TL in 2011 had likely progressed to >150 mm TL in 2013. Furthermore, individuals 300–399 mm TL comprised the majority of the sampled population in 2011 and progression of this cohort was evident, with increasing proportions of individuals >400 mm in subsequent years (Figure 6.8).

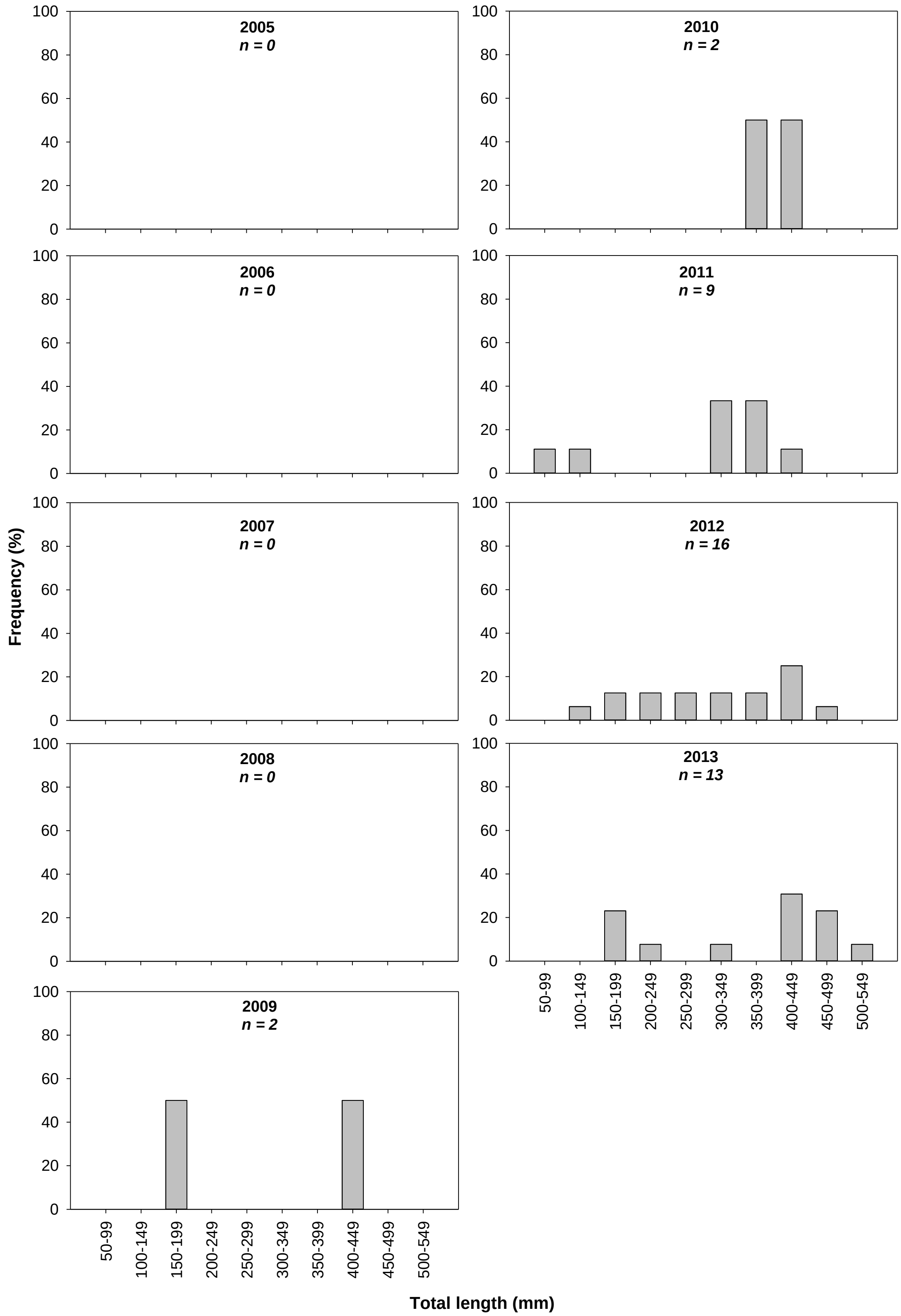

Figure 6.8. Length-frequency distributions of freshwater catfish collected during electrofishing surveys at sites in Chowilla Anabranch system and adjacent River Murray main channel from 2005–2013 (*n* = sample size). Sampling occurred in March/April each year except for 2011 when it occurred in May.

SA Wetland Fish Sampling

The length-frequency distribution of freshwater catfish sampled using single-wing fyke nets in the wetlands along the SA River Murray during 2011/12 is presented in Figure 6.9. Samples showed a broad size range (61–460 mm TL), with 44% of the fish collected being less than 150 mm TL. These fish were likely new recruits from 2010/11 and/or 2011/12 spawning seasons.

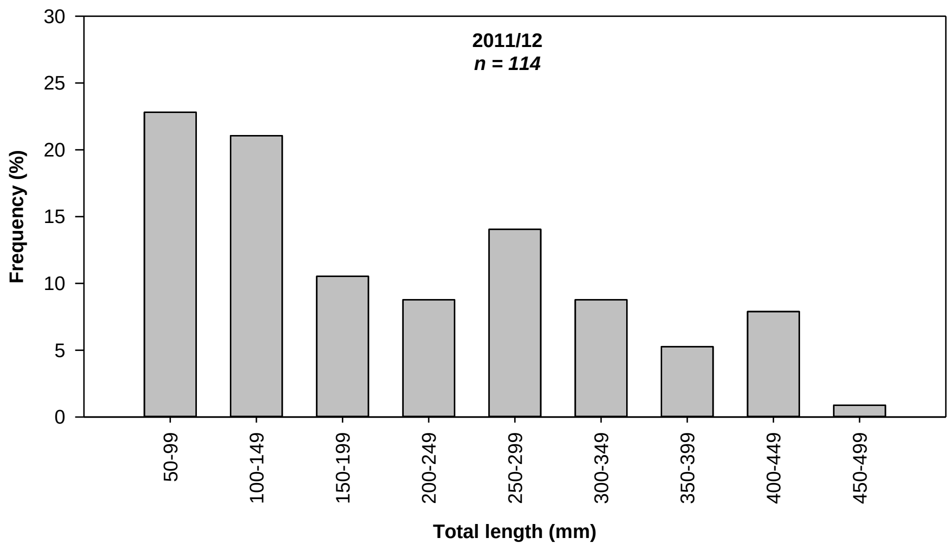

Figure 6.9. Length-frequency distribution of freshwater catfish sampled using fyke nets in the wetlands along the South Australian River Murray during 2011/12 through the Natural Resources SA Murray–Darling Basin wetland and floodplain program (n = sample size).

6.3. Recreational fishing events

6.3.1. Relative abundance

A total of 58 fishers participated in the recreational fishing events in 2013/14, sampling a total of 72 freshwater catfish. A summary of the numbers of fish caught, retained, number of fishers and CPUE (fish.rod-hour^{-1}) at different sites is presented in Table 6.4. The average CPUE from different sites are also presented in a graph (Appendix VII).

Table 6.4. Numbers of freshwater catfish caught, retained for ageing and recreational fishers engaged in the fishing events during 2013/14 and catch-per-unit-effort (CPUE) in the lower River Murray, South Australia.

Region	Sites/reaches	Date	Number caught	Number retained	Number of fishers	CPUE fish.rod-hour^{-1}
Floodplain	Renmark	Dec/13	2	0	5	0.01
Floodplain	Berri	Jan/14	21	21	20	0.11
Gorge/Swamplands	Blanchetown	Dec/13	0	0	5	0.00
Gorge/Swamplands	Swan Reach	Feb/14	1	1	18	0.01
Gorge/Swamplands	Murray Bridge	Jan/14	48	39	10	0.77
Overall			**72**	**61**	**58**	**0.18**

6.3.2. Length-frequency distribution

The freshwater catfish collected from the recreational fishing events during 2013/14 ranged from 190 to 475 mm TL. The length-frequency distribution is bimodal, with the primary and secondary size modes at 200–249 mm and 350–399 mm TL, respectively (Figure 6.10).

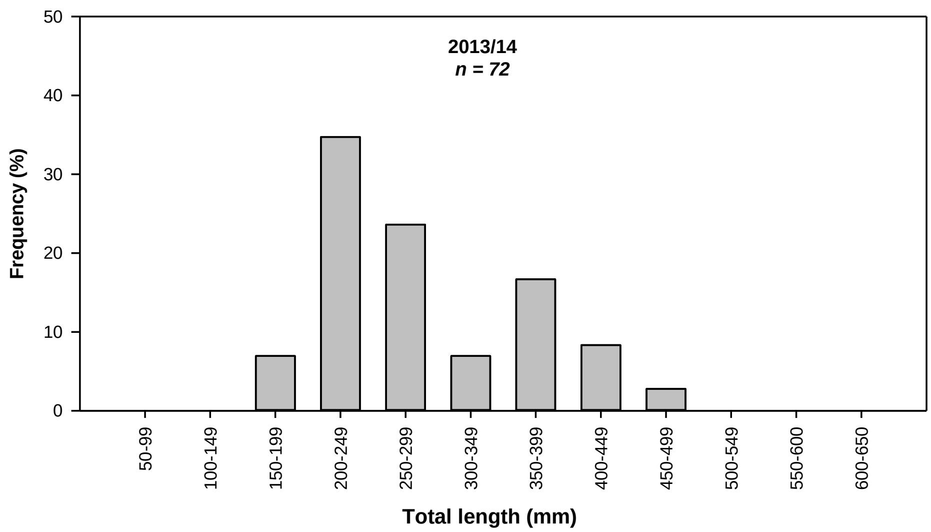

Figure 6.10. Length-frequency distribution of freshwater catfish sampled during the 2013/14 recreational fishing events in the South Australian lower River Murray (*n = sample size*).

6.3.3. Estimated age composition

The number of otolith increments from fish collected during the 2013/14 recreational fishing events ranged 2–12, suggesting a broad age range based on the assumption that otolith increments are deposited annually (Figure 6.11). These fish probably include cohorts spawned in recent high flow years as well as during the drought (2001–2009). Fish with three otolith increments dominate the frequency distribution (Figure 6.11); these fish were potentially spawned during the 2010/11 flood.

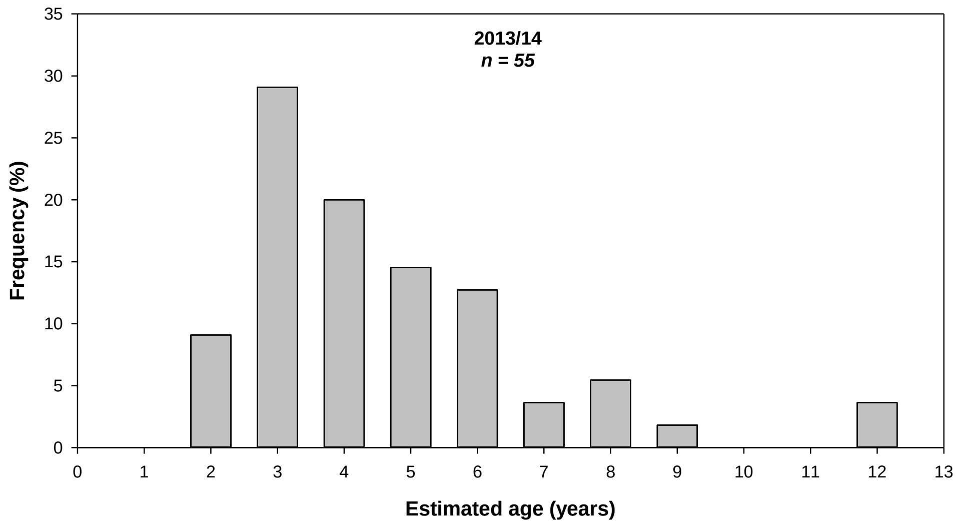

Figure 6.11. Estimated age composition, based on otolith increment/ring counts, of freshwater catfish sampled during the 2013/14 recreational fishing events in the lower River Murray, South Australia (*n* = sample size). Age estimation was based on the assumption that otolith increments are formed on an annual basis.

6.4. Increment counts and an estimated age-length relationship

Freshwater catfish in the SA River Murray show considerable variation in length-at-age for most age classes, estimated based on otolith increment counts (Figure 6.12). For example, 2-year-old fish may range from 190 to 290 mm TL and 8-year-old fish from 257 to 482 mm TL; fish about 200 mm TL may range 2–6 years. The oldest fish aged was 12 years. The von Bertalanffy growth curve for freshwater catfish in the lower River Murray is represented by the equation:

$$L_\infty = 407.1577\ (1 - \exp\ [-0.3475\ \{t + 0\}])$$

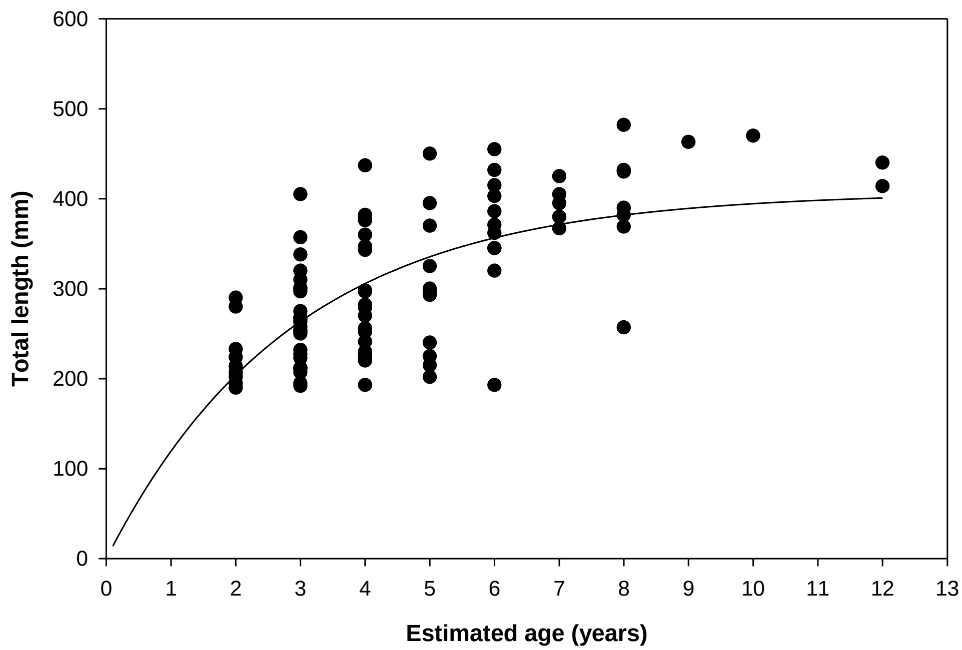

Figure 6.12. Length-at-estimated age data fitted with a von Bertalanffy growth curve for freshwater catfish collected in the main channel of the lower River Murray, South Australia (*n* = 92). Age estimation was based on the assumption that otolith increments are formed on an annual basis.

6.5. Stock Status

The freshwater catfish population experienced substantial declines in the lower River Murray, as shown by historical commercial fishery catch data. The declines were likely due to multi-factorial impacts including river regulation, water extraction, habitat degradation, invasive species and historical over-harvesting. Currently, the population of the SA River Murray continues to represents a depleted stock with recruitment coming from a reduced spawning biomass and constrained by environmental changes. The management response resulted in the species being protected in SA since 1997 (*Fisheries Management Act 2007*). Some major environmental and riverine restoration work (e.g. environmental watering, fishways) have been initiated in the lower River Murray, particularly over the last decade. Nevertheless, the freshwater catfish population has not yet recovered. Given the current population status, freshwater catfish warrants continued protection in the SA River Murray.

In terms of stock status, there was difficulty in identifying the primary factor (i.e. overfishing or environmental impacts) that caused the initial declines of the spawning stock biomass in the lower River Murray. Using the definitions from the National Status of Key Australian Fish Stocks Report (Flood *et al.* 2014), the stock status of freshwater catfish in the SA River Murray is **undefined**.

7. DISCUSSION

Knowledge of species-specific life history, population dynamics and status is critical to underpin fisheries management and conservation. Freshwater catfish was formerly abundant in the lower River Murray (prior to the 1980s) and supported important commercial and recreational fisheries in SA (Ye and Hammer 2009). Similar to many other native fish in the MDB, freshwater catfish has experienced a significant decline in abundance and distribution, likely due to multiple factors; notably over-harvesting, barriers to movement, altered flow regimes, elevated salinity and potential competitive/predatory interactions with non-native species (e.g. common carp and redfin perch) (Clunie and Koehn 2001a; Lintermans 2007). The population decline in SA is best demonstrated by the historical commercial fisheries data (see Section 6.1). The catch showed a drastic decline in early 1970s, followed by persistent low catches (<550 kg annually) for over a decade (1984–1997). Subsequently, freshwater catfish has been protected under the SA *Fisheries Management Act 1982* (now *Fisheries Management Act 2007*) since 1997.

Following broad-scale flooding in the lower River Murray in 2010/11, anecdotal evidence indicated an increase in abundance of freshwater catfish prompting calls from recreational fishers for changes to fisheries regulations. Consequently, to inform fisheries management, there was a need to collate existing data and collect new data on the population dynamics of freshwater catfish to provide insight on the population status of this species in the SA River Murray.

In this study we interrogated historical and contemporary data primarily from three sources: 1) the historical commercial fishery, 2) three long-term (8–11 years) fish monitoring projects (fishery-independent) conducted in the lower River Murray and 3) targeted recreational fishing events in 2013/14. The fishery-independent data were collected over a period of extreme hydrological conditions, including eight years of drought and unprecedented low flow in the lower River Murray (2002/03–2009/10), followed by three years (2010/11–2012/13) of overbank or elevated within-channel flows.

Population dynamics and status

Data from the long-term fish monitoring projects indicated that during the drought (2002–2010), relative abundances of freshwater catfish were low in the main channel and anabranch habitats of the SA River Murray. After the 2010/11 flood, there was a general increase in relative abundance; most pronounced in 2011/12, followed by a decrease in 2012/13. This pattern was consistently reflected in all datasets analysed. These data are also in agreement with anecdotal reports from recreational fishers of increased encounters with freshwater catfish when fishing for other species in the SA River Murray post the 2010/11 flood.

Length data of freshwater catfish from the long-term fish monitoring projects indicate that during 2010–2013, fish collected generally covered a broad size range in both the main channel (109–502 mm TL) and anabranch habitats of the Chowilla region (84–523 mm TL). In particular, increased catches in 2011/12 were comprised of fish from multiple size classes including evidence of recent recruitment (<150 mm TL). Nonetheless, the presence of a high proportion of large fish (>300 mm TL) suggests increased abundance was not driven solely by recent recruitment. Similarly, the size composition of freshwater catfish sampled from recreational fishing events in 2013/14 also demonstrated a broad range of sizes (190–475 mm TL), with estimated ages between 2 and 12 years. This further suggests that the freshwater catfish population in the SA River Murray was comprised of multiple cohorts from recruitment events during both recent high flow years and the drought years. Indeed, some of the freshwater catfish captured in the SA River Murray might have been redistributed from upstream during the flood and subsequent years of increased flow (2010–2012).

Estimated ages of freshwater catfish from recreational catches in 2013/14 showed a strong cohort spawned in 2010/11, coinciding with an extensive flood. New or recent recruitment was also evident in fish sampled in wetlands of the SA River Murray in 2011/12, when a high proportion of fish were less than 150 mm TL. These fish potentially aged 0+ and 1+ years based on the estimated age-length relationship (Figure 6.12), thus were spawned in years of elevated river flow in 2010/11 and 2011/12. Floodplain inundation leads to improved lateral and longitudinal connectivity, allowing fish access to an increased range of habitats, promoting recruitment and ultimately increased abundance (Zeug and Winemiller 2007; Lyon *et al.* 2010; Zampatti and Leigh 2013). Recent studies in the lower River Murray indicated a substantial increase in ecosystem productivity during the 2010/11 flood year compared to the previous drought years (Aldridge *et al.* 2012; Oliver and Lorenz 2013). The increased productivity and improved connectivity may have facilitated the recruitment and movement of freshwater catfish in the lower River Murray.

Overall, there are three possible explanations for the increase in abundance of freshwater catfish in the SA River Murray post-2010 compared to the previous decadal drought: 1) increased flow enhanced connectivity and fish movement, leading to a spatial redistribution of fish. This was observed for numerous native and invasive fishes following extensive flooding in the MDB (Wegener and Suitor 2013; Zampatti *et al.* 2015); 2) there was enhanced recruitment promoted by enhanced productivity during high flows, increasing food resources and potentially improving survival and growth of early life stages; and 3) catchability increased due to increased fish movement and accumulation downstream of weirs during high flows. Drum netting and vessel electrofishing were primary sampling methods for the long-term fish monitoring projects included in this study. The effectiveness (inception rate) of drum nets is considered to be enhanced under high flows and reduced under low flows in the lower River Murray (Ye *et al.* 2000). Accumulation of fish downstream of weirs is a common impact of regulating structures (Lucas and Baras 2001), and some of the electrofishing sites in this study were situated below weirs.

High flows had a positive effect on recruitment and abundance of freshwater catfish in the lower River Murray relative to the previous decade of low flows (2002–2010). Nonetheless, 2002–2010 represented an atypical period of river hydrology (i.e. predominated by very low flow) and recent changes in abundance must be viewed across a broader temporal context to truly reflect current population status. Indeed, peak CPUE in 2011/12 (0.004 kg.net-day^{-1} or 0.01 fish.net-day^{-1} by drum net), based on the fishery-independent drum net data, was an order of magnitude lower compared to the historical CPUE just prior to 1997 (0.06 kg.net-day^{-1} by drum net), when freshwater catfish was listed as a protected species in SA. As such, the perception of a current population increase was negligible in a historical context. Furthermore, there has been a reduction in relative abundance post 2011/12. These data suggest that freshwater catfish population abundance remains low in the context of historical abundances in the SA River Murray.

<u>Otolith increment counts and estimated age-length relationships</u>

Freshwater catfish has previously been aged using dorsal spines, with validation using fish of known ages and tagging information (Davis 1977b). Anderson (1990), however, noted the first year's annuli in the dorsal spine may become difficult to detect or may be lost as the core of the spine hollows over time. A comparison using both otoliths and dorsal spines was conducted by the Central Ageing Facility at Queenscliff in Victoria and suggested that using otoliths may be the most reliable ageing technique for freshwater catfish (Clunie and Koehn 2001a). In this study, we used transverse sectioned otoliths to age freshwater catfish based on increment counts, and estimated age up to 12 years. Although age determination using otoliths has been validated for other Plotosidae species (Laurenson *et al.* 1994), species-specific validation is required for freshwater catfish to provide an accurate estimate of age.

Length is unlikely to be a reliable substitute for age in freshwater catfish. In the lower River Murray freshwater catfish appear to exhibit considerable variability in length-at-age and the same has been reported for other freshwater catfish populations (Sedger 1994). Variability in length-at-age may be due to the combined effects of genetics and environment.

Conservation and restoration of freshwater catfish in the lower River Murray

Low abundances of freshwater catfish remain a concern throughout much of the MDB (Lintermans 2007). Indeed, a basin-wide recovery plan was developed for this species in 2001, recommending a range of recovery actions to address key threats that had likely attributed to the population declines (Clunie and Koehn 2001b). Priority actions included: nomination of freshwater catfish under relevant legislation, assessment and protection of major populations/areas, provision of environmental flows, restoration of natural water temperature regimes, determination of impacts of invasive species and restocking or translocation to establish new populations.

Of these actions only one has been implemented for freshwater catfish in SA; this species has been protected since 1997 (*Fisheries Management Act 2007*). Nonetheless, major initiatives for broader ecosystem restoration and rehabilitation of native fish communities should provide benefit to freshwater catfish in the lower River Murray. For example, the construction of fishways on weirs of the River Murray over the last decade under the 'Murray Fishway Program' has improved biological connectivity (Baumgartner *et al.* 2014) and in recent years, environmental flows have been delivered to the SA River Murray to restore ecologically important facets of the flow regime and facilitate rehabilitation of the riverine ecosystem (Ye *et al.* 2014). Specific ecological objectives and targets have also been established with environmental water requirements identified for freshwater catfish and other key native fish species, to support the development of the Long-Term Watering Plan for the SA River Murray water resource plan (Wallace *et al.* 2014).

The current study suggests that despite increased recruitment and abundance of freshwater catfish post flooding in 2010/11, abundance remains low in the context of a historical level in the SA River Murray. Consequently, specific management actions may be needed to aid in the restoration of freshwater catfish populations. These could potentially include some of the recovery actions currently implemented in Victoria and NSW: 1) identifying significant populations and raising awareness to management agencies and stakeholders to ensure their conservation needs are included in relevant management programs; 2) assessing and managing threats to freshwater catfish including the protection and rehabilitation of instream habitats and riparian zones where significant populations occur; and 3) improving knowledge of the biology and ecology of freshwater catfish (Morris *et al.* 2001; DSE 2005). The third point remains a significant gap in SA.

Among 46 native fish species in the MDB, freshwater catfish is one of the four most popular angling species, along with Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*) (Koehn 2010). Maintaining sustainable native fisheries and engaging recreational fishers and the community are important because they could become key advocates, not only for fishing, but also for the conservation and sound management of aquatic ecosystems (Koehn 2010). As such, restoring freshwater catfish populations in the lower River Murray is a common goal for both conservation and fisheries management. PIRSA's ultimate goal for protected species management is to facilitate the recovery towards sustainably managed recreational fisheries (*Fisheries Management Act 2007*). This requires a long-term commitment and collaborative effort between fisheries, conservation and water management agencies and the community. While some species-specific management actions may be required for the recovery of freshwater catfish, it is important that these are undertaken in a broader context of ecological restoration in the lower River Murray. A holistic approach to restore key ecological processes and functions will ultimately benefit the entire aquatic community including freshwater catfish and other native fishes.

<u>Future research and monitoring</u>

Significant knowledge gaps remain regarding the biology and ecology of freshwater catfish in the lower River Murray. Priority research in this region includes:

- Understanding basic biology (e.g. reproduction, size/age at maturity, life history, age validation/growth rate/longevity, etc.).
- Identifying genetic structure and potential key populations of freshwater catfish in SA.
- Determining the habitat requirements of freshwater catfish at different life stages.
- Understanding the effect of flow on the recruitment of freshwater catfish, including how hydrological/hydraulic variability affects spawning, nesting and nursery habitats, food resources and dispersal.
- Understanding the movement (longitudinal and lateral) of juvenile and adult freshwater catfish and determining potential environmental cues (e.g. flow and water temperature) that stimulate movement, and the species' ability to negotiate existing barriers and use fishways.
- Improved understanding of the interaction between introduced fish species, particularly common carp and redfin perch, and freshwater catfish.
- Understanding the impact of sedimentation/siltation on freshwater catfish populations.

Furthermore, long-term monitoring is essential to provide time series data on population dynamics (e.g. trends in abundance and demographics) to assess population status and recovery of freshwater catfish. Targeted monitoring programs are likely required for freshwater catfish due to their patchiness and low abundance, and the difficulties of sampling them in the lower River Murray. Multiple sampling methods may be required across a range of habitat types, including the main river channel and wetlands. These could be achieved through fishery-independent monitoring programs (e.g. by vessel electrofishing and drum/fyke netting) and fishery-dependent sampling with support from recreational fishers.

8. CONCLUSION

The current study has provided vital information on contemporary population dynamics and status of freshwater catfish in the SA River Murray to inform the management of this protected species. There were substantial declines and subsequently consistent low catch rates in the former commercial fishery in the 1970s, 1980s and 1990s. Over the period 2002–2009, which was characterised by severe drought, the relative abundance of freshwater catfish remained very low in the main channel and anabranch habitats. Following extensive flood and increased in-channel flows during 2010–2012, there was a significant increase in abundance relative to the previous low flow years. Nevertheless, the peak relative abundance in 2011/12 remained an order of magnitude lower than the historical commercial catch rate just prior to 1997, when freshwater catfish was listed as a protected species in SA. Moreover, relative abundance generally declined following the increase immediately post flooding in 2011/12, indicating a temporary rather than a true long-lasting ‘population recovery’. Freshwater catfish abundance in the lower River Murray remains low in the context of historical population levels and warrants continued protection. The freshwater catfish stock in the lower River Murray is classified as **undefined** based on the national stock status framework (Flood *et al.* 2014) because of the complexity and difficulty in identifying the primary cause leading to the initial declines of the spawning stock biomass.

Conservation and fisheries management are best supported by empirical data, and targeted monitoring programs are required for freshwater catfish, particularly due to their rareness and patchiness in the lower River Murray. Long-term monitoring is essential to provide data on population dynamics (e.g. abundance and demographics) and assess population status and recovery. This could include both fishery-independent and recreational fishery-dependent monitoring programs.

The 2013/14 recreational fishing events established baseline data and collected valuable biological information. Ongoing support from recreational fishers through co-management may assist with the collection of long-term data.

Finally, there remain significant knowledge gaps in the biology and ecology of freshwater catfish in the lower River Murray. These include basic information on life history, population dynamics and the effects of flow and habitat on reproduction and movements. Such knowledge is fundamental to inform the assessment of population status and improve management to facilitate the recovery of freshwater catfish in the lower River Murray.

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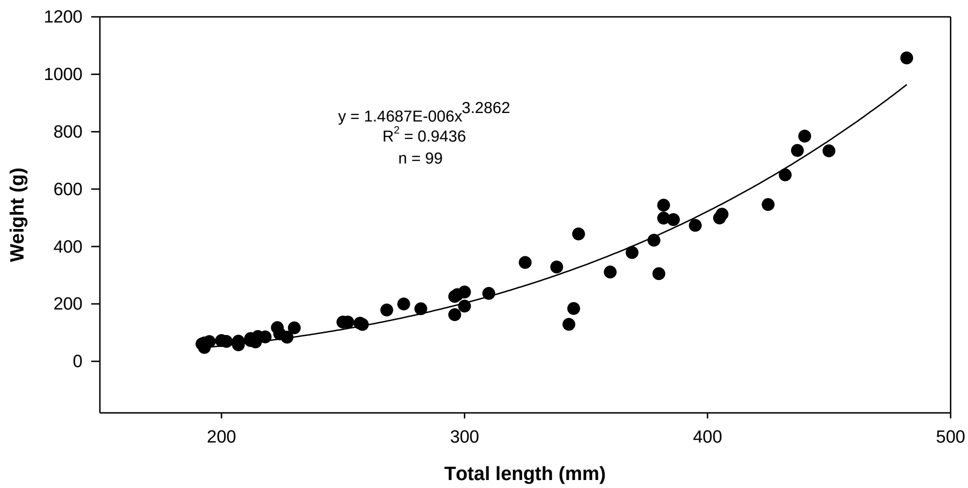
APPENDICES

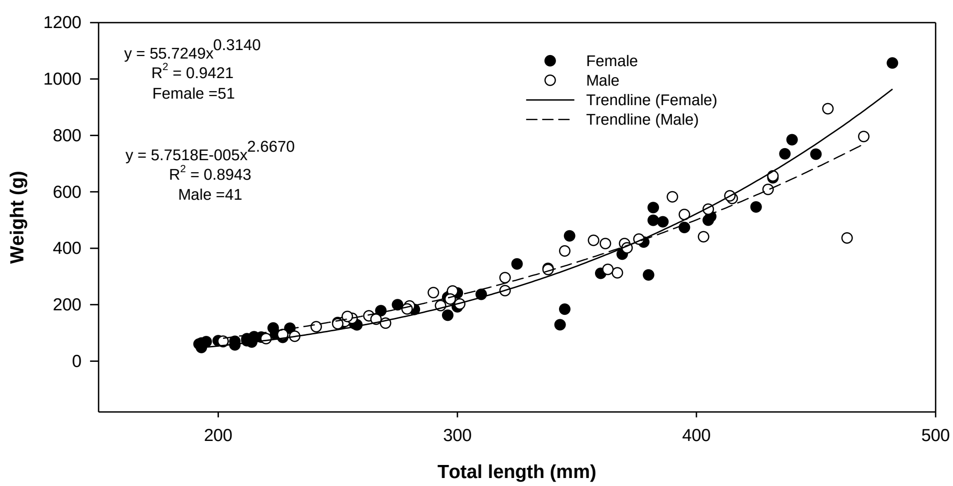
Appendix I. List of SA wetlands with freshwater catfish sampled during 2011/12 through the SA MDB NRMB wetland and floodplain program.

Wetland name	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12
Andersons Creek Floodplain Chowilla		x			
Bookmark Creek	x				
Eckerts Ck Nth Arm		x			
Jury Swamp					x
Katarapko Floodplain		x			
Little Schillers Lagoon	x				
Martins Bend		x			
Morgan CP		x			
Murbpook lagoon	x				
Nelbuck Creek		x	x		
Nigra Creek	x				
Nigra Creek Creek	x				
Noonawirra			x		
Paiwalla			x	x	
Pilby Lagoon		x			
Portee Creek			x		
Riverglades				x	
Rocky Gully				x	x
S0000392		x			
Sawmill Creek		x			
Schillers Lagoon	x				
Scotts Creek		x			
Slaney Billabong		x			
Yatco Lagoon	x				

a)



b)



Appendix II. Length and weight relationship for freshwater catfish collected in the lower River Murray, South Australia. a) All fish grouped; b) Males and females (*n* = sample size).

Appendix III. Percentage of difference in increment counts of freshwater catfish otolith sections assessed by two SARDI readers.

	Difference in otolith increment counts				
Increment numbers	-2	-1	0	1	2
1		25%	75.0%		
2		18.8%	81.3%		
3		8.9%	64.3%	21.4%	5.4%
4			66.7%	23.8%	9.5%
5			62.5%	12.5%	50.0%
6		8.3%	33.3%	45.8%	12.5%
7			30.0%	60.0%	10.0%
8			40.0%	40.0%	20.0%
9			25%	50%	25%
10					
11					
12			100%		

Appendix IV. PERMANOVA pair-wise test factor level year, results for mean CPUE of freshwater catfish collected in the Native Fish Monitoring Program.

	t	P(perm)	perms
2005 x 2006	Denominator is 0		
2005 x 2007	Denominator is 0		
2005 x 2008	1	1	1
2005 x 2009	Denominator is 0		
2005 x 2010	Denominator is 0		
2005 x 2011	2.4061	**0.034**	8
2005 x 2012	2.154	0.139	4
2006 x 2007	Denominator is 0		
2006 x 2008	1	1	1
2006 x 2009	Denominator is 0		
2006 x 2010	Denominator is 0		
2006 x 2011	2.4061	**0.023**	8
2006 x 2012	2.154	0.145	4
2007 x 2008	1	1	1
2007 x 2009	Denominator is 0		
2007 x 2010	Denominator is 0		
2007 x 2011	2.4061	**0.031**	8
2007 x 2012	2.154	0.165	4
2008 x 2009	1	1	1
2008 x 2010	1	1	1
2008 x 2011	2.3736	**0.024**	15
2008 x 2012	1.8862	0.15	8

2009 x 2010	Denominator is 0		
2009 x 2011	2.4061	**0.029**	8
2009 x 2012	2.154	0.152	4
2010 x 2011	2.4061	**0.024**	8
2010 x 2012	2.154	0.121	4
2011 x 2012	2.0808	**0.039**	35

Appendix V. PERMANOVA pair-wise test factor level year, results for mean CPUE of freshwater catfish collected through the Murray River Fishway Assessment Program Locks 1–3 Fish Sampling.

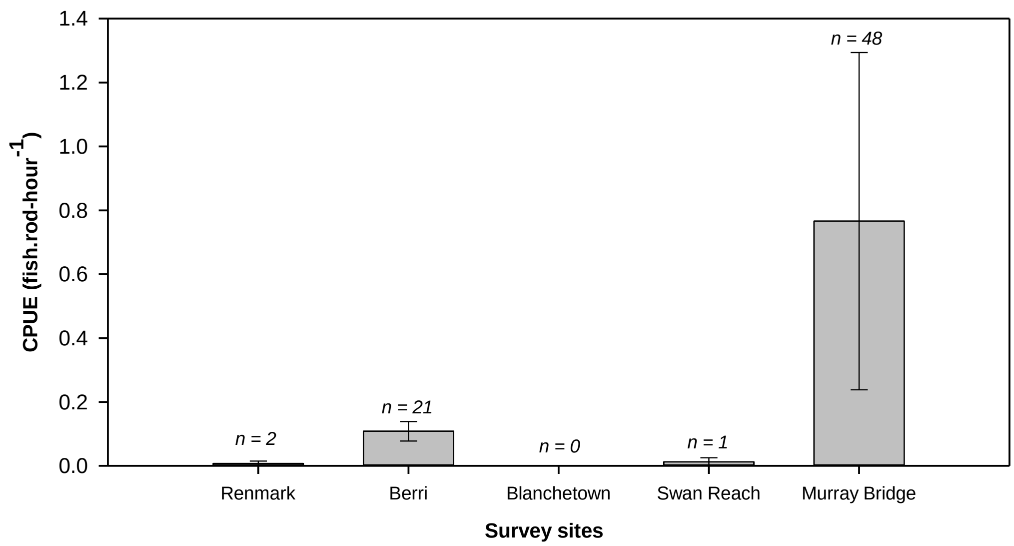
	t	P(perm)	perms
2002/03 x 2003/04	Denominator is 0		
2002/03 x 2004/05	Denominator is 0		
2002/03 x 2006/07	Denominator is 0		
2002/03 x 2007/08	1	1	1
2002/03 x 2008/09	Denominator is 0		
2002/03 x 2009/10	1.3324	0.436	2
2002/03 x 2010/11	1.7353	0.126	4
2002/03 x 2011/12	2.4861	**0.037**	8
2002/03 x 2012/13	2.3379	0.145	4
2003/04 x 2004/05	Denominator is 0		
2003/04 x 2006/07	Denominator is 0		
2003/04 x 2007/08	1	1	1
2003/04 x 2008/09	Denominator is 0		
2003/04 x 2009/10	1.3324	0.469	2
2003/04 x 2010/11	1.7353	0.153	4
2003/04 x 2011/12	2.4861	**0.028**	8
2003/04 x 2012/13	2.3379	0.137	4
2004/05 x 2006/07	Denominator is 0		
2004/05 x 2007/08	1	1	1
2004/05 x 2008/09	Denominator is 0		
2004/05 x 2009/10	1.3324	0.437	2
2004/05 x 2010/11	1.7353	0.134	4
2004/05 x 2011/12	2.4861	**0.039**	8
2004/05 x 2012/13	2.3379	0.154	4
2006/07 x 2007/08	1	1	1
2006/07 x 2008/09	Denominator is 0		
2006/07 x 2009/10	1.3324	0.453	2
2006/07 x 2010/11	1.7353	0.149	4
2006/07 x 2011/12	2.4861	**0.026**	8
2006/07 x 2012/13	2.3379	0.132	4
2007/08 x 2008/09	1	1	1
2007/08 x 2009/10	1.0412	0.428	4
2007/08 x 2010/11	1.4692	0.127	8

2007/08 x 2011/12	2.4323	**0.026**	15
2007/08 x 2012/13	2.205	0.14	8
2008/09 x 2009/10	1.3324	0.406	2
2008/09 x 2010/11	1.7353	0.136	4
2008/09 x 2011/12	2.4861	**0.035**	8
2008/09 x 2012/13	2.3379	0.151	4
2009/10 x 2010/11	0.41357	0.58	15
2009/10 x 2011/12	2.1818	0.054	25
2009/10 x 2012/13	1.5542	0.286	15
2010/11 x 2011/12	2.0512	0.055	35
2010/11 x 2012/13	1.275	**0.27**	25
2011/12 x 2012/13	1.1377	0.367	35

Appendix VI. PERMANOVA pair-wise test factor level year, results for mean CPUE of freshwater catfish collected through the Chowilla Fish Assemblage Condition Monitoring Program.

	t	P(perm)	perms
2005 x 2006	Denominator is 0		
2005 x 2007	1.1349	0.46	2
2005 x 2008	Denominator is 0		
2005 x 2009	1.803	0.207	8
2005 x 2010	1.3662	0.489	4
2005 x 2011	2.3856	**0.019**	64
2005 x 2012	2.8823	**0.002**	421
2005 x 2013	2.8513	**0.004**	246
2006 x 2007	1.0467	0.498	2
2006 x 2008	Denominator is 0		
2006 x 2009	1.6647	0.258	8
2006 x 2010	1.2616	0.495	4
2006 x 2011	2.203	0.051	64
2006 x 2012	2.6616	**0.011**	407
2006 x 2013	2.6331	**0.021**	231
2007 x 2008	1	1	1
2007 x 2009	0.89442	0.367	16
2007 x 2010	0.46477	0.694	8
2007 x 2011	1.8036	0.065	124
2007 x 2012	2.3812	**0.019**	566
2007 x 2013	2.3106	**0.025**	393
2008 x 2009	1.5914	0.225	8
2008 x 2010	1.2062	0.507	4
2008 x 2011	2.1062	0.051	63
2008 x 2012	2.5447	**0.011**	398
2008 x 2013	2.5174	**0.013**	215
2009 x 2010	0.48211	0.652	32
2009 x 2011	1.5125	0.158	434
2009 x 2012	2.4546	**0.013**	870

2009 x 2013	2.2831	**0.029**	778
2010 x 2011	1.8545	**0.04**	96
2010 x 2012	2.7077	**0.007**	627
2010 x 2013	2.5706	**0.006**	410
2011 x 2012	1.4463	0.166	964
2011 x 2013	1.0544	0.276	888
2012 x 2013	0.48362	0.636	987



Appendix VII. Mean (± SE) catch-per-unit-effort (CPUE) (fish.rod-hour^{-1}) of freshwater catfish collected as target species at five sites during the recreational fishing events in 2013/14 in the lower River Murray, South Australia (*n* = total number of freshwater catfish caught).