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Coorong Fish Condition Monitoring 2008-2013: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations

Qifeng Ye, Luciana Bucater and David Short

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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

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EXECUTIVE SUMMARY

The Lower Lakes, Coorong and Murray Mouth (LLCMM) region is recognised as a wetland of international importance under the Ramsar Convention. It is also an 'icon site' under the Murray–Darling Basin Authority's (MDBA) The Living Murray (TLM) program. Over the recent decadal drought in the Murray–Darling Basin (MDB), the Coorong ecosystem has become increasingly degraded as a consequence of diminished freshwater inflows and subsequent increases in salinity. In order to restore and enhance the environmental values of the LLCMM region, an Icon Site Environmental Management Plan was developed by the Murray–Darling Basin Commission (MDBC, now MDBA), within which preliminary targets were set for fish in the Coorong. A Condition Monitoring Plan was implemented to evaluate whether these targets are achieved. This report presents the findings of the first five years (2008/09-2012/13) of a monitoring program for smallmouthed hardyhead (*Atherinosoma microstoma*), black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) in the Murray Estuary, North Lagoon and South Lagoon of the Coorong. This monitoring allows evaluation of two targets within the Icon Site Environmental Management Plan: (1) Target F3: to provide optimum conditions to improve recruitment success of smallmouthed hardyhead in the South Lagoon; and (2) Target F4: to maintain or improve recruitment of black bream and greenback flounder in the Murray Mouth Estuary and North Lagoon.

Monitoring of the smallmouthed hardyhead population indicated that management Target F3 was met following the barrage releases from 2010 to 2013, with significant increases in recruitment, abundance and distribution relative to the drought years (2008/09 and 2009/10). Although this species is highly tolerant of elevated salinity, in 2008/09, extreme hypersaline conditions (salinity up to 166 psu) restricted its southerly distribution. There were some improvements in abundance and recruitment in 2009/10, with a localised recovery in the southern end of the Coorong following small volumes of freshwater inflows (~100 ML d^{-1}) from Salt Creek. Since 2010/11, broadly decreased salinities after barrage releases, coupled with other freshwater induced environment changes, have led to a substantial increase in population abundance, distributional range and recruitment in this species, especially in the southern part of the Coorong when salinities reduced to <100 psu. This is of particular ecological significance, given the important role this keystone species plays in the trophic ecology of the region. In 2012/13, although there was some reduction in smallmouthed hardyhead in the North Lagoon, the abundance in the South Lagoon was maintained or showed a further increase. Overall, the response of smallmouthed hardyhead to flows provides insight into population recovery when favourable conditions (i.e. salinity <100 psu) are restored and shows the resilience of the population in the Coorong.

In contrast, for black bream and greenback flounder, condition monitoring in the Murray Estuary and North Lagoon prior to 2012/13 showed no indication that management Target F4 was met. Nevertheless, the results of 2012/13 monitoring indicated some improvements in the populations of these two species, suggesting that management Target F4 was partially met. This was reflected in the following changes:

For black bream:

- a gradual increase in abundance, as indicated by the increasing commercial fishery catch from a historical low of 1.1 t in 2009/10 to 2.3 t and 3 t in 2010/11 and 2011/12, respectively, although these remained below the average of the previous ten years (5.5 t y^{-1});
- an increase in targeted CPUE from 2010/11 to 2011/12 (5.8 to 8 kg.fisher day^{-1});
- expansion of distributional range of fishery catch from the Estuary during the drought years into the North Lagoon post 2010 flows;
- a significant increase of new recruit abundance in 2012/13 compared to the previous two years.

For greenback flounder:

- a substantial increase in population abundance as indicated by a significant increase in commercial fishery catch from 0.1 t in 2010/11 to 30 t in 2011/12, the 4th highest since 1984/85;
- a significant increase in targeted CPUE, reaching a historic high of 23.8 kg.fisher day^{-1} in 2011/12;
- a substantial range expansion with the majority of the catch coming from the North Lagoon in 2011/12, whilst in the previous years (2008-2010) catches were mainly from the Estuary;
- an increased abundance of new recruits in the North Lagoon, despite a reduction in the Estuary.

Despite the above positive signs in these two species detected following 2-3 years of high flows, it should be noted that the population level of black bream still remained low in the Coorong considering the substantial decline in abundance since the mid-1980s. A heavily truncated age structure of this long-lived species suggested reduced population resilience in the Coorong.

The recent barrage releases are ecologically significant given the critical role of freshwater flows in facilitating successful spawning and recruitment in key estuarine fish species, and restoring/maintaining estuarine habitat with a favourable salinity gradient. Ongoing monitoring will be required in subsequent years to: 1) continue investigations of population dynamics and recruitment of large-bodied estuarine species; 2) evaluate the benefit/impact of various flow scenarios (both natural and managed flows) for these populations; and 3) assess population recovery (abundance and demography). Importantly, environmental water management should take into account flow regimes of small to moderate freshwater releases which could be linked to the strong recruitment of black bream (as per the releases in 2003/04 and 2006/07). In addition, fisheries and conservation management should seek to protect the remnant populations of these species and rebuild their age structures to improve population resilience. Further research/monitoring will be required to improve our understanding of primary environmental factors, including flow regime and habitat requirements, that influence recruitment success of key estuarine species.

The first five years of fish condition monitoring has provided valuable information on the abundance, distribution, population age/size structures and recruitment ecology of black bream, greenback flounder and smallmouthed hardyhead populations in the Coorong. The study occurred during an extreme drought period (2008/09 and 2009/10), followed by three significant flow years, which allows quantitative assessment of biological responses to flows and an investigation of population recovery. The results of this study form an important basis for the delivery of environmental flows and adaptive management to ensure the ecological sustainability of iconic estuarine fish species in the LLCMM region.

1 INTRODUCTION

The Lower Lakes, Coorong and Murray Mouth (LLCMM) region is located at the terminus of Australia's largest River, the Murray–Darling. It is recognised internationally as a Ramsar Wetland, providing an important breeding and feeding ground for waterbirds, and supporting significant populations of several species of fish and invertebrates (Phillips and Muller 2006; Bice and Ye 2009). The region is classified as an 'icon site' under the Murray–Darling Basin Authority's The Living Murray (TLM) program, based on its unique ecological qualities, hydrological significance, and economic and cultural values (Murray–Darling Basin Commission 2006).

The Coorong is a long (about 110 km) and narrow (<4 km) estuarine lagoon system with a strong north-south salinity gradient, generally ranging from brackish/marine near the Murray Mouth to hypersaline in the North and South Lagoons (Geddes and Butler 1984; Geddes 1987). Salinities are spatiotemporally variable and highly dependent on the freshwater inflows from the River Murray, with varied salinities supporting different ecological communities (Brookes *et al.* 2009). In addition, the southern end of the South Lagoon receives small volumes of fresh/brackish water (about 10.2 GL y^{-1}) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek.

As the terminal system of the Murray–Darling Basin (MDB), the Coorong region has been heavily impacted by river regulation and water extraction since European settlement. The average annual flow at the Murray Mouth has declined by 61% (from 12333 GL y^{-1} to 4733 GL y^{-1}; CSIRO 2008). The construction of five tidal barrages in the 1940s significantly reduced the area of the original Murray Estuary, establishing an abrupt physical and ecological barrier between marine and freshwater systems. During the protracted drought from 2001 to early 2010 in the MDB, there were very low or no flow releases through the barrages between 2002 and 2009 (DFW 2010). The Murray Mouth closed in 2002 due to siltation and regular dredging was required to maintain its opening (DWLBC 2008) until December 2010. During the drought period, the Coorong was transformed into a marine/hypersaline environment (Brookes *et al.* 2009). Many native fish species that resided in the Coorong estuary and depended on its habitat for breeding, nursery and feeding grounds were negatively affected (Noell *et al.* 2009; Ye *et al.* 2012a), and recruitment of diadromous fish failed due to a lack of connectivity between freshwater and marine environments (Zampatti *et al.* 2010).

Since late 2010, continued high flows in the River Murray have led to substantial barrage releases to the Coorong, and the restoration of connectivity between the freshwater and marine environment (with barrages and fishways opening). Fish assemblages in the Coorong have shown significant responses to freshwater inflows and the changing environmental conditions with signs of recovery in a number of species (Ye *et al.*

2012a). These include a general increase in species richness and diversity, enhanced recruitment and abundance of estuarine species (e.g. smallmouthed hardyhead and sandy sprat) and catadromous species (congolli), and a southward range expansion for several species (e.g. black bream, congolli and yelloweye mullet) (Ye *et al.* 2012a). With the continued high flows in 2012/13, further physico-chemical and ecological changes were expected in the Coorong.

Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma)* are target species in the LLCMM Icon Site Environmental Water Management Plan (EWMP). A scientifically robust monitoring program was designed in 2008/09 and condition monitoring has been implemented since then for these species in the Coorong (Maunsell Australia Pty Ltd. 2009) to assess whether the following targets have been achieved:

Target F3: Provide optimum conditions to improve recruitment success of smallmouthed hardyhead in the South Lagoon.

Target F4: Maintain or improve recruitment of black bream and greenback flounder in the Murray Estuary and North Lagoon.

In relation to these targets, this project aimed to assess the population and recruitment status of black bream, greenback flounder and smallmouthed hardyhead in the Coorong. Specific objectives relative to each of the key species were to:

- determine the relative abundance and distribution of these species;
- determine the population size and/or age structures; and
- assess the level of recruitment in the Coorong.

The current report presents the findings of the fish condition monitoring over the last five years (2008-2013) in the Coorong using both commercial fishery and fishery-independent data.

2 METHODS

2.1 Fishery catch, effort, CPUE and freshwater inflows

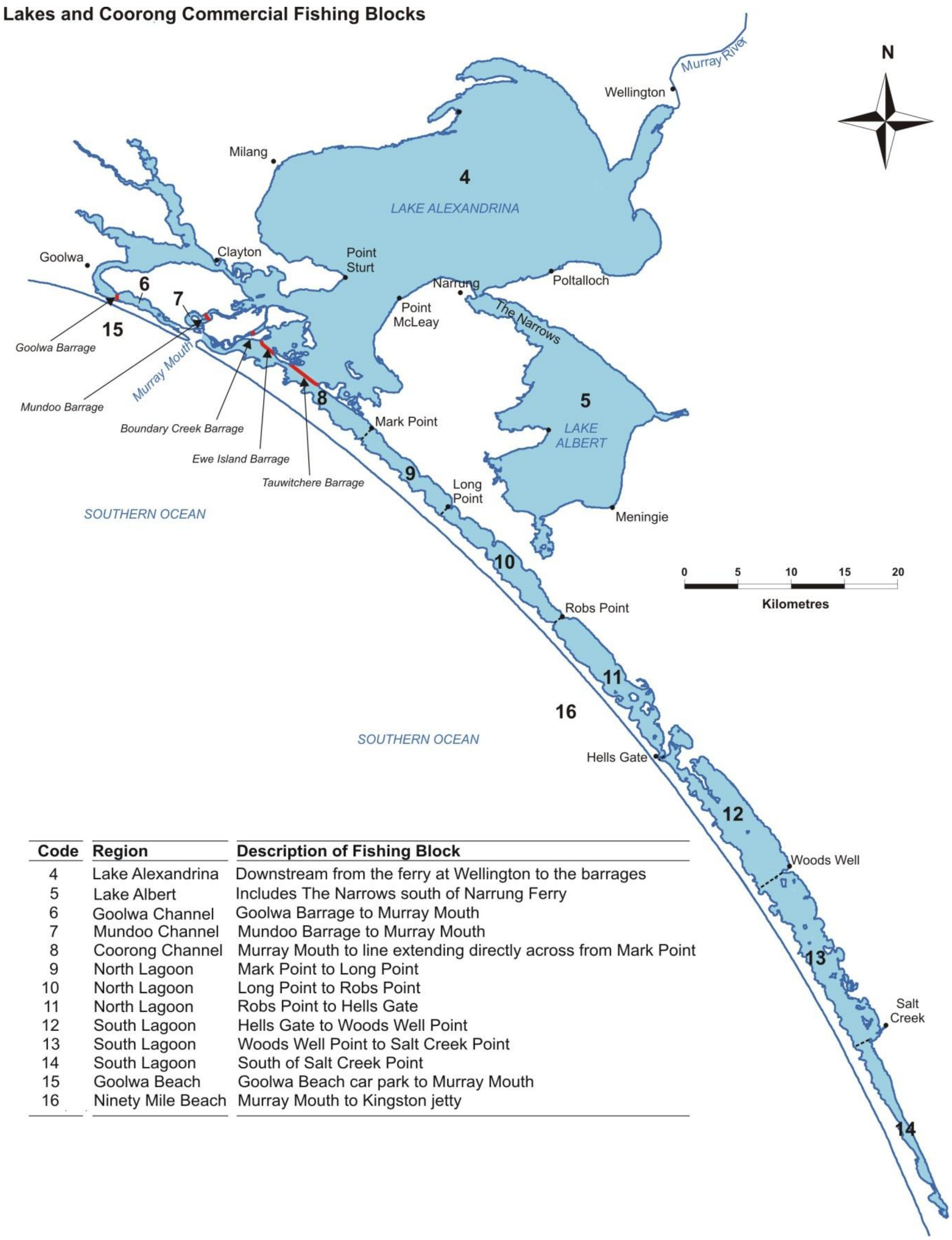
2.1.1 Data

Commercial catch and effort data for black bream and greenback flounder from the Lakes and Coorong Fishery were available from 1984/85 to 2011/12. Data include catch (kg), effort (fisher days and net days), and spatial reporting fishing block (Figure 2.1). Targeted catch, as specified in logbook, is defined as the catch of a species when it is targeted by fishers. The Coorong region involves fishing blocks 6 to 14.

Annual and monthly freshwater discharge across the barrages was available for the period from July 1984 to March 2012 from the estimates of the regression-based Murray hydrological model (MDM, BIGMOD, MDBA). The SA Water discharge dataset from September 2010 to May 2013, which was based on the number of gates opened in all five barrages of the Coorong, was also used. In addition, estimates of daily salinity and freshwater discharge from the Salt Creek inlet to the South Lagoon of the Coorong (Station A2390568) were obtained from the Water Connect website of the Department of Environment, Water and Natural Resources (DEWNR) (2013).

2.1.2 Analysis

Historical catch and effort data were analysed to assess temporal trends in catch, effort, and catch per unit effort (CPUE), and their ability to provide biological indicators of relative abundance of each large-bodied species. A comparison of the available effort measures was done using linear regression in SPSS 14. A linear regression was used to investigate the relationship between freshwater inflow and both black bream and greenback flounder catch from the area south of Mark Point.



Code	Region	Description of Fishing Block
4	Lake Alexandrina	Downstream from the ferry at Wellington to the barrages
5	Lake Albert	Includes The Narrows south of Narrung Ferry
6	Goolwa Channel	Goolwa Barrage to Murray Mouth
7	Mundoo Channel	Mundoo Barrage to Murray Mouth
8	Coorong Channel	Murray Mouth to line extending directly across from Mark Point
9	North Lagoon	Mark Point to Long Point
10	North Lagoon	Long Point to Robs Point
11	North Lagoon	Robs Point to Hells Gate
12	South Lagoon	Hells Gate to Woods Well Point
13	South Lagoon	Woods Well Point to Salt Creek Point
14	South Lagoon	South of Salt Creek Point
15	Goolwa Beach	Goolwa Beach car park to Murray Mouth
16	Ninety Mile Beach	Murray Mouth to Kingston jetty

Figure 2.1. Spatial reporting blocks for the Lakes and Coorong Fishery.

2.2 Age/Size structures

2.2.1 Samples

Sampling of black bream and greenback flounder from commercial catches was conducted in the Murray Estuary and North Lagoon of the Coorong between 2008/09 and 2012/13 to establish the population age/size structures for these species. Population age structure of both species was only determined in the first four years of this study (2008-2012). Adult black bream were collected during spring/early summer each year, mainly from Goolwa channel, Newells and Seven Mile (Figure 2.2) and adult greenback flounder were collected during winter each year from the Goolwa channel, Sam Island and Seven Mile (Figure 2.3). In addition, fishery-independent samples of both black bream and greenback flounder were collected opportunistically from multiple sites in the Murray Estuary and North Lagoon predominantly using seine nets (Appendices A and B). Sample sizes for adult black bream and greenback flounder are shown in Table 2.1 and Table 2.2, respectively.

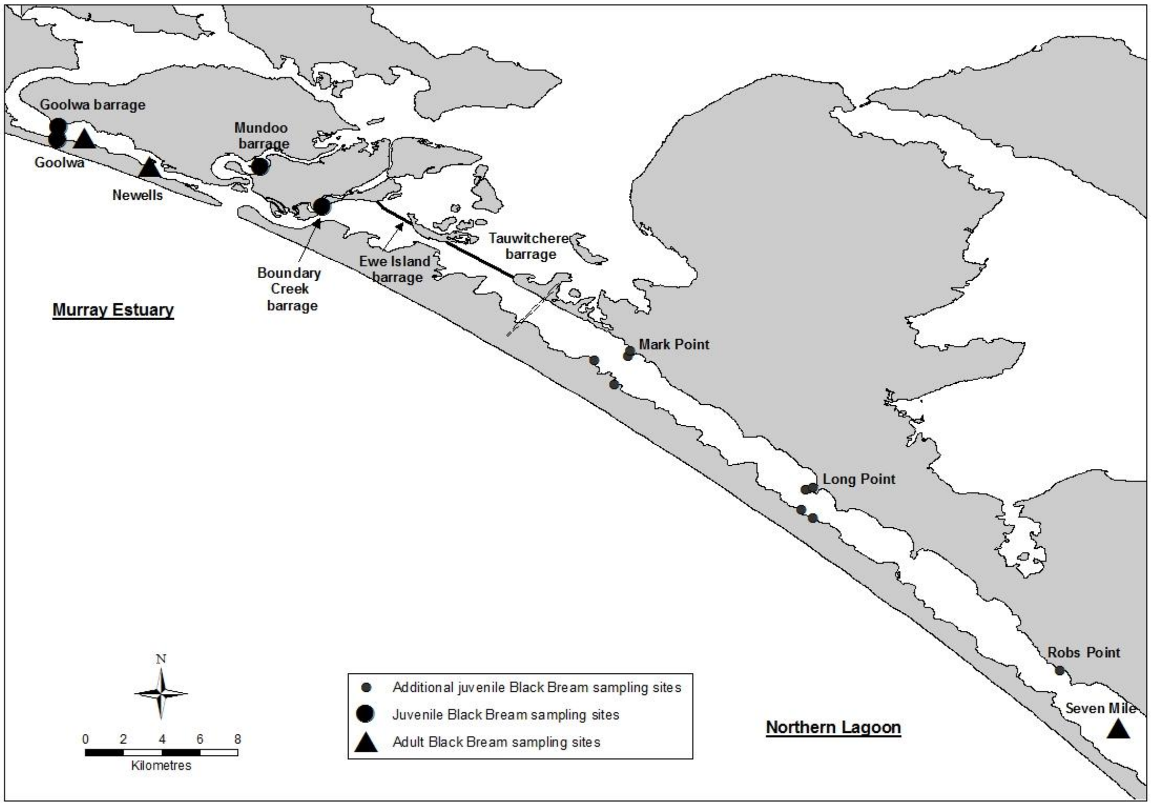


Figure 2.2. Condition monitoring sampling sites for adult and juvenile black bream at the Coorong. Adult black bream sampling sites represent commercial fishery sampling sites.

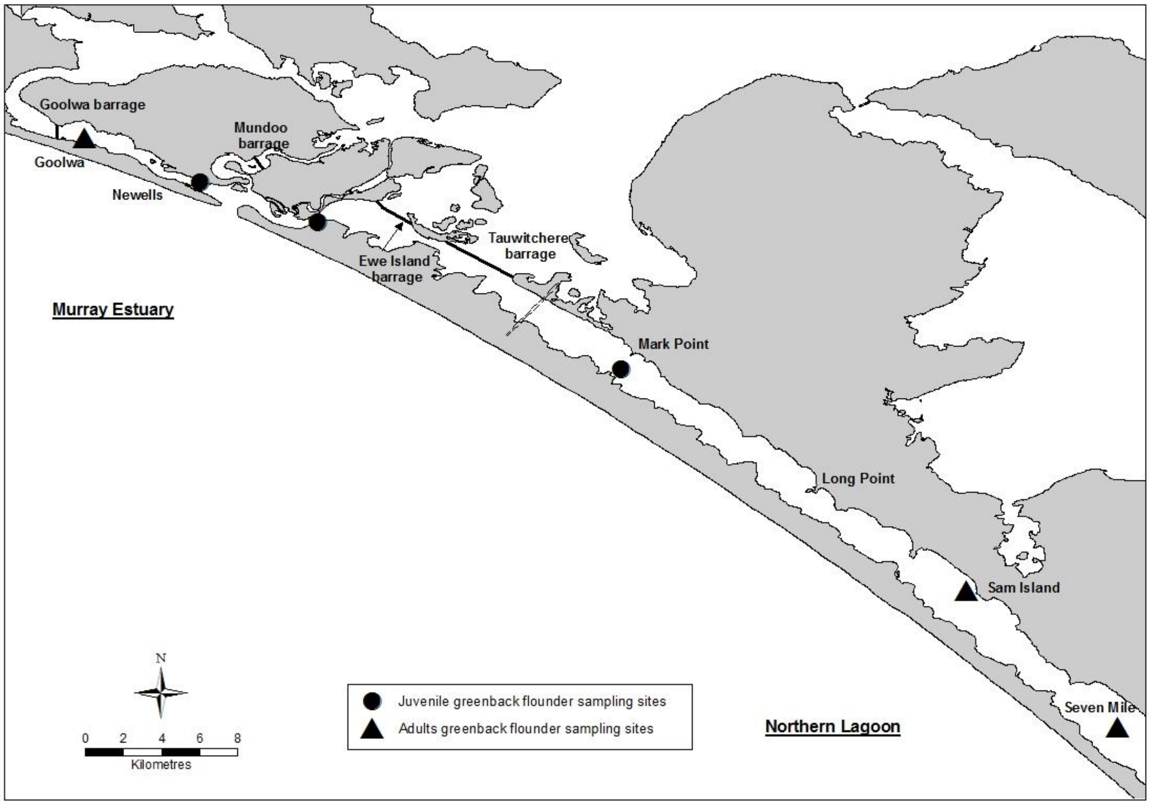


Figure 2.3. Condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong. Adult flounder sampling sites represent commercial fishery sampling sites.

Table 2.1. Numbers of adult black bream collected from commercial fishery and fishery-independent sampling and number of fish aged from 2008/09 - 2012/13.

	2008/09			2009/10			2010/11			2011/12			2012/13		
Month	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total
July								9	9						
August													43		43
September				50		50	37	30	67	37		37	8		8
October	15		15	46		46	27		27	39		39	24		24
November				37		37		1	1	9		9	13		13
December	20		20	25	1	26		5	5	21	3	24	14	4	18
January	46	1	47	6		6				6	1	7	2		2
February	2		2		23	23		2	2	14		14			
March	18	1	19		1	1					1	1		1	1
April														2	2
May					14	14									
June		3	3		9	9									
Overall	101	5	106	164	48	212	64	47	111	126	5	131	104	7	111
Aged			102			212			111			124			0

Table 2.2. Numbers of adult greenback flounder collected from commercial fishery and fishery-independent sampling and number of fish aged from 2009 - 2012.

	2009			2010			2011			2012		
Month	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total
January					1	1		3	3		1	1
February		18	18							33	9	42
March								1	1			
April												
May	14		14	37	58	95						
June	24	9	33		52	52						
July	38		38		47	47						
August	29		29	14	33	47				17		17
September										15		15
October							1		1			
November					5	5	31		31	73	2	75
December							35	4	39	29	5	34
Overall	105	27	132	51	196	247	67	8	72	167	17	184
Aged			108			245			67			0

2.2.2 Laboratory processing and analysis

To assess the presence/absence of strong year classes that recruit to the fishery, age structures were generated from annual bands in sagittae, i.e. the largest pair of otoliths. Otoliths were extracted from black bream and greenback flounder in the laboratory. For black bream, otoliths were prepared using the 'break and burn' method, as described in Ye *et al.* 2002. For greenback flounder transverse sections were made from the otoliths (Ye *et al.* 2002). Numbers of fish aged for each species by year are presented in Tables 2.1 and 2.2. For 2012/13, otoliths were extracted and stored for future ageing.

2.3 Recruitment

2.3.1 Sampling

Additional sampling was carried out to quantify the abundance of juvenile (young-of-the-year, YOY) black bream and greenback flounder, in order to establish annual recruitment indices. For black bream, juvenile sampling was conducted at four regular sites (i.e. two below the Goolwa Barrage, one in Boundary Creek and one below Mundoo Barrage) using single-wing fyke nets (*n*=4 trips per year) (Figure 2.2). The Mundoo Barrage site was added in 2010/11. Exploratory sampling was also conducted at other sites (e.g. upstream of Goolwa Barrage, Mundoo and Tauwitchere Barrages, Pelican Point, Mark Point, Long Point and Noonameena) aiming to collect juveniles of black bream. The single-wing fyke nets were 8.6 m long (3 m leader plus 5.6 m funnel) with a mesh size of 8 mm and a hoop diameter of 0.6 m. On most sampling occasions, eight fyke nets were set overnight at each site. A summary of effort for juvenile black bream is presented in Table 2.3.

For greenback flounder, juvenile sampling was conducted at Sugars Beach, Godfrey's Landing and Mark Point (Figure 2.3) using standard seine net hauls during spring/early summer each year (*n*=3 trips per year). The seine net was 61 m long and consisted of two 29 m-long wings (22 mm mesh) and a 3 m-long bunt (8 mm mesh). It was deployed in a semi-circle, which sampled to a maximum depth of 2 m and swept an area of about 592 m^2 per haul. A standardised sampling regime comprising 3 shots was replicated at each site. A summary of effort for juvenile greenback flounder is presented in Table 2.4.

Table 2.3. Sampling effort for collecting juvenile black bream using single-wing fyke nets at regular and additional sites in the Coorong from 2008/09 - 2012/13. Sw= saltwater, fw=freshwater, HI=Hindmarsh Insland, SRP=Sir Richard Peninsula, YHP=Young Husband Peninsula, Phrag. Opp= Phragmites opposite.

Number of fyke net.night per year	2008/09	2009/10	2010/11	2011/12	2012/13
Location					
Regular sampling sites					
Goolwa Barrage sw side HI	21	24	28	15	24
Goolwa Barrage sw side SRP	31	24	20	22	32
Boundary Creek	31	24		16	32
Mundoo Barrage	4		24	24	32
Additional sampling sites					
Boundary Creek Barrage	4				
Cattle Point			4	12	4
Ewe Island Causeway	4	16			
Godfrey's Landing				4	
Goolwa Barrage fw side HI	4				
Goolwa Barrage fw side SRP	2	4			
Goolwa channel HI side				4	
Long Point			8	4	4
Long Point beach				4	4
Long Point reef				4	4
Long Point sand dune			4		
Long Point YHP side				4	4
Mark Point	8		8	12	4
Mark Point beach				4	4
Mundoo Channel	8				
Mundoo Channel in front of house				4	
Noonameena			4		
Opposite Mark Point YHP				4	
Pelican Point	4				
Pelican Point YHP	8				
Pelican Point YHP Phrag. Opp Rumbolow Shack				4	
Robs Point			4		
South Cattle point				4	4
Tauwitchere Barrage	3	4			
Overall	132	96	104	145	152

Table 2.4. Sampling effort used to collect juvenile greenback flounder using standard seine net at the Coorong from 2008/09 - 2012/13.

Number of seine net shots per year	2008/09	2009/10	2010/11	2011/12	2012/13
Location					
Godfrey's Landing	9	9	9	9	9
Sugars Beach	9	9	9	9	9
Mark Point	9	9	9	9	9
Overall	**27**	**27**	**27**	**27**	**27**

Standardised seine netting, as described above, was also used for quantitative sampling of smallmouthed hardyhead at six sites along the North and South Lagoons of the Coorong (Figure 2.4). Sampling was conducted at each site during spring/summer over five years (2008-2013) (*n*=4 trips per year), targeting the main spawning and recruitment season. A small seine net has also been used since February 2009 to more effectively target new recruits. The small seine net was 8 m long with a 2 m drop and a mesh size of 2 mm. It was hauled through water less than 0.5 m deep over a distance of 20 m by two people walking 5 m apart, thus sampling an area of about 100 m^2. Sampling was replicated (i.e. 3 standard shots) at each site for each seine net type. A summary of sampling effort for smallmouthed hardyhead is presented in Table 2.5.

The number of juvenile black bream, greenback flounder and smallmouthed hardyhead from each net were counted and a random subsample of up to 50 individuals per species per net measured for total length (TL mm). During the first two years of condition monitoring, age determination (in days) was conducted by counting otolith daily rings using a sub-sample of 50 otoliths per species in order to confirm if fish collected were young-of-the-year (YOY) (Ye *et al.* 2011a).

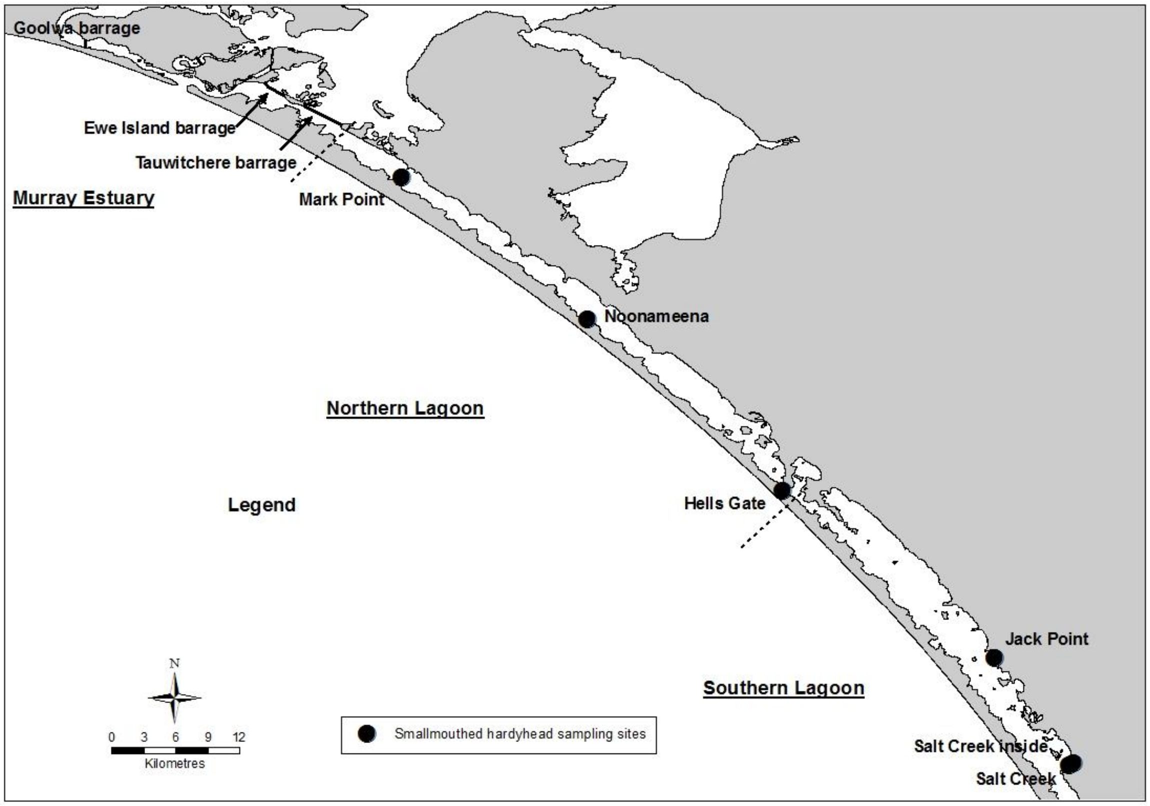


Figure 2.4. Condition monitoring sampling sites for smallmouthed hardyhead in the Coorong.

Table 2.5. Sampling effort for juvenile and adult smallmouthed hardyhead using large and small seine nets in the Coorong from 2008/09 - 2012/13.

(number of seine net shots per year)	2008/09	2009/2010	2010/11	2011/12	2012/13
Large seine net					
Mark Point	12	12	12	12	12
Noonameena	12	12	12	12	12
Salt Creek	12	12	12	12	12
Hells Gate	12	12	12	12	12
Jack Point	12	12	12	12	12
Salt Creek inside creek	3	12	12	12	12
Overall	**63**	**72**	**72**	**72**	**72**
Small seine net					
Mark Point	3	9	12	12	12
Noonameena	3	9	12	12	12
Hells Gate	0	12	12	12	12
Jack Point	0	12	12	12	12
Salt Creek	0	12	12	12	12
Salt Creek inside creek	3	12	12	12	6*
Overall	**9**	**66**	**72**	**72**	**72**

*Note: 12 net shots were conducted; however data from six shots during January and February 2013 were excluded. During this period, very low water level and dense *Ruppia* bed within Salt Creek made the operation of small seine net ineffective.

Water quality parameters (i.e. salinity, temperature, pH) were recorded using a TPS water quality meter and water transparency was measured using a Secchi disc at each site on each fish sampling occasion. The extreme salinities encountered during the sampling period were beyond the range (150 psu) in which the water quality meter is reliable for dissolved oxygen (DO) readings. Therefore, an equation of state that incorporates temperature and salinity (Sherwood *et al.* 1992) was used to estimate DO for all sites in all sampling events. This estimate provides maximum DO at equilibrium and does not account for potential biological use of oxygen at the time of sampling. See Table 2.6 for a list of sites, gear types used and fish targeted at each location.

Table 2.6. List of sites sampled, species targeted and sampling gear used for fishery-independent sampling during the Coorong fish condition monitoring from 2008/09-2012/13.

Sites	**Site code**	Species targeted	Sampling gear
Goolwa Barrage saltwater side Hindmarsh Island end	E1	Black Bream	Fyke net
Goolwa Barrage saltwater side Sir Richard Peninsula end	E2	Black Bream	Fyke net
Mundoo Barrage	E3	Black Bream	Fyke net
Boundary Creek	E4	Black Bream	Fyke net
Sugars Beach	E5	Greenback Flounder	Standard seine net
Godfrey's Landing	E6	Greenback Flounder	Standard seine net
Mark Point	N1	Greenback Flounder/Smallmouthed Hardyhead	Standard and small seine nets
Noonameena	N2	Smallmouthed Hardyhead	Standard and small seine nets
Hells Gate	N3	Smallmouthed Hardyhead	Standard and small seine nets
Jack Point	S1	Smallmouthed Hardyhead	Standard and small seine nets
Salt Creek	S2	Smallmouthed Hardyhead	Standard and small seine nets
Salt Creek inside creek	S3	Smallmouthed Hardyhead	Standard and small seine nets

2.3.2 Analysis

Estimates of catch per unit effort (CPUE) of juveniles were used to compare recruitment between years at key sites for each species. Fyke net data for black bream, standard seine net data for greenback flounder and small seine net data for smallmouthed hardyhead were used. Similarly, CPUE data for smallmouthed hardyhead from the standard seine net were used to compare relative population abundance between years at key sites. Box plots and Cochran's test were used to test for normality and homogeneity of variance and because the data did not meet either assumption, analysis was done using permutational analysis of variance (PERMANOVA) (Anderson 2001). CPUE data were examined using Euclidean distance similarity measures. A two-way design was used, with Year and Site as fixed factors, to determine whether spatiotemporal differences between years and sites could be detected. Unrestricted permutations of data were performed for all analyses, with 999 permutations for the test, to detect differences at $\alpha=0.05$ (Anderson 2001). Where significant interactions occurred, pairwise analyses were also performed to detect differences at p level after a modified false discovery rate (FDR) by Benjamin and Yekutieli (B-Y) correction was applied (see Narum 2006).

For both black bream and greenback flounder, recruitment success could also be corroborated using year class strength in the population age structure for 2008-2012. For smallmouthed hardyhead, length frequency distributions of both standard and small seine samples were analysed to investigate recruitment success. Using length data to estimate the presence of new recruits (evidence of recent reproduction) was considered an appropriate method for smallmouthed hardyhead given the one-year life cycle of this species (Molsher *et al*. 1994).

For graphical visualisation of the abundance and distribution of the three species in all years (2008-2013), CPUE data were mapped using Arc Map 10.1 – ArcGIS/ESRI, which complemented the results of the PERMANOVA analyses. The Geocentric Datum of Australia 1994 (GDA94) was used as the standard geographical coordinate system.

3 RESULTS

3.1 Freshwater inflow

From 1984-2013, the Murray Estuary and Coorong experienced substantial fluctuations in freshwater inflows. Annual discharges were consistently high during the late 1980s and early 1990s, ranging between 10500 and 12000 GL y^{-1}, with the exception of 1991/92 when it was just over 3000 GL y^{-1} (Figure 3.1). After 1993/94, inflows to the Coorong generally declined until 2007/08, after when there was no freshwater discharged to the Coorong for three years. Since September 2010, significant flow increases in the MDB have led to substantial barrage releases, with annual discharge of ~13000 GL in 2010/11 and ~6500 GL in 2011/12. In 2012/13, freshwater inflows to the Coorong decreased to ~4500 GL. A peak monthly inflow of ~1500 GL was recorded in August 2012 (Figure 3.1). It is important to note that the barrage flow data for 2012/13 came from a different dataset (SA Water), as the MDBA modelled data were not of a sufficient standard to be included in the report at the time of publication.

Freshwater inflows from Salt Creek into the South Lagoon were highly variable between years for 2001 to 2013 (Figure 3.2). Inflows were highly seasonal in most years. Overall, peak flow rates were lowest in 2006, failing to exceed 25 ML d^{-1}. In contrast, discharge rates were highest in September 2010 and July 2011, reaching peaks in excess of 450 and 500 ML d^{-1}, respectively. In 2012, discharge was similar to 2010, and peaked in August (approximately 440 ML d^{-1}). Salinity in Salt Creek was also variable and seasonal, ranging between 5 and 25 psu since 2010. No salinity data were available in 2012/13.

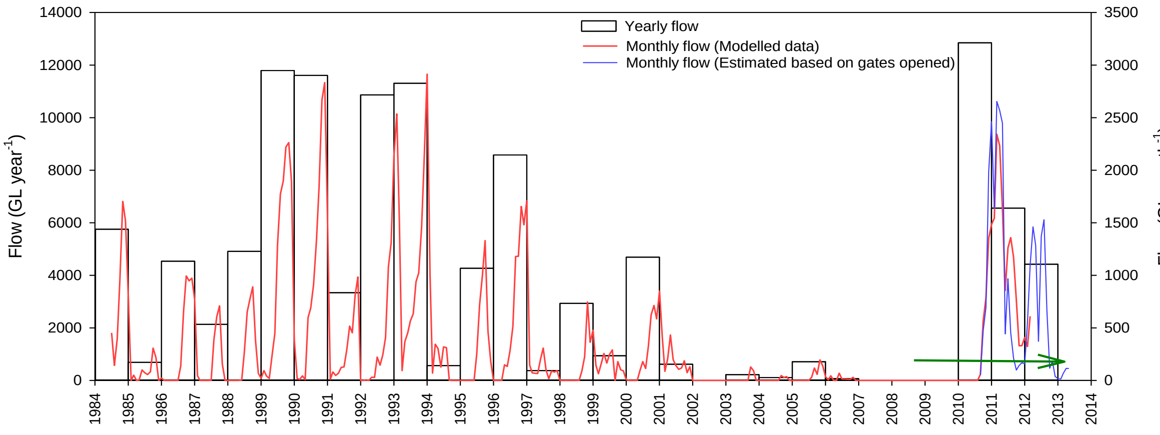


Figure 3.1. Average annual and monthly freshwater inflows across the barrages from July 1984 to May 2013 (source: MDBA, 2013) Green arrow indicates time period of fish condition monitoring.

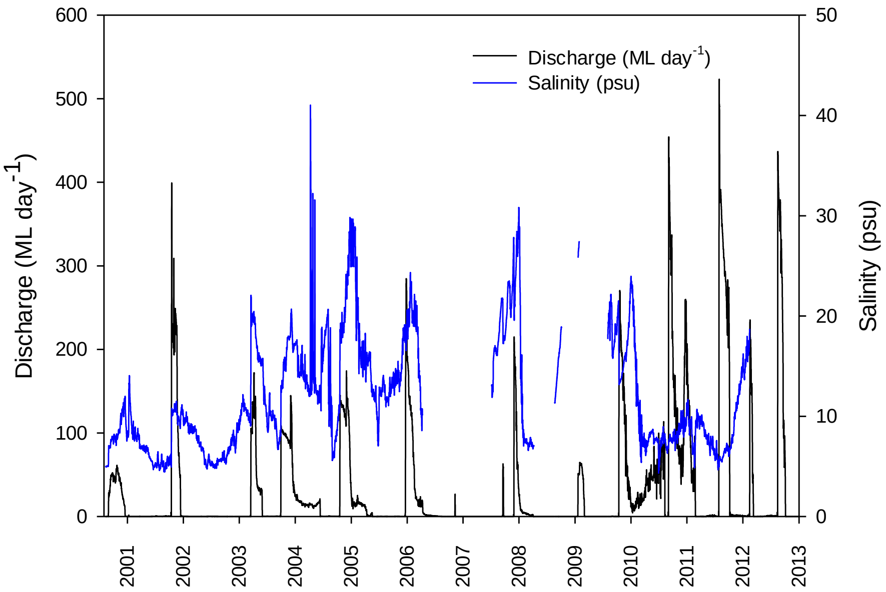


Figure 3.2. Daily flow discharge through Salt Creek, with salinity levels (DEWNR 2013, Water Connect website, Station A2390568).

3.2 Water Quality

Mean values of temperature, salinity, DO, pH and water transparency (Secchi disk depth) for the sampled period at each sampling site are presented in Figure 3.3. A north-south gradient of increasing salinity was present in all years; however, there were substantial reductions in mean salinity at all sampling sites during the barrage releases from 2010 to 2013. In 2008/09 and 2009/10, mean salinities ranged from 36-44 psu in the Murray Estuary, 49-139 psu in the North Lagoon, and 95-134 psu in the South Lagoon. In contrast, from 2010/11 to 2012/2013, salinities decreased to 0-26 psu in the Murray Estuary, 5-77 psu in the North Lagoon, and 59-99 psu in the South Lagoon. Salinity ranges in the South Lagoon don't take into consideration measurements inside Salt Creek. Notably, in 2012/13, salinity showed an increase in the Murray Estuary, whilst salinity in the North and South Lagoons generally maintained similar levels to the previous two years. A decline in transparency was observed in the Estuary following high flows, particularly in 2010/11. There was no substantial change in other environmental parameters.

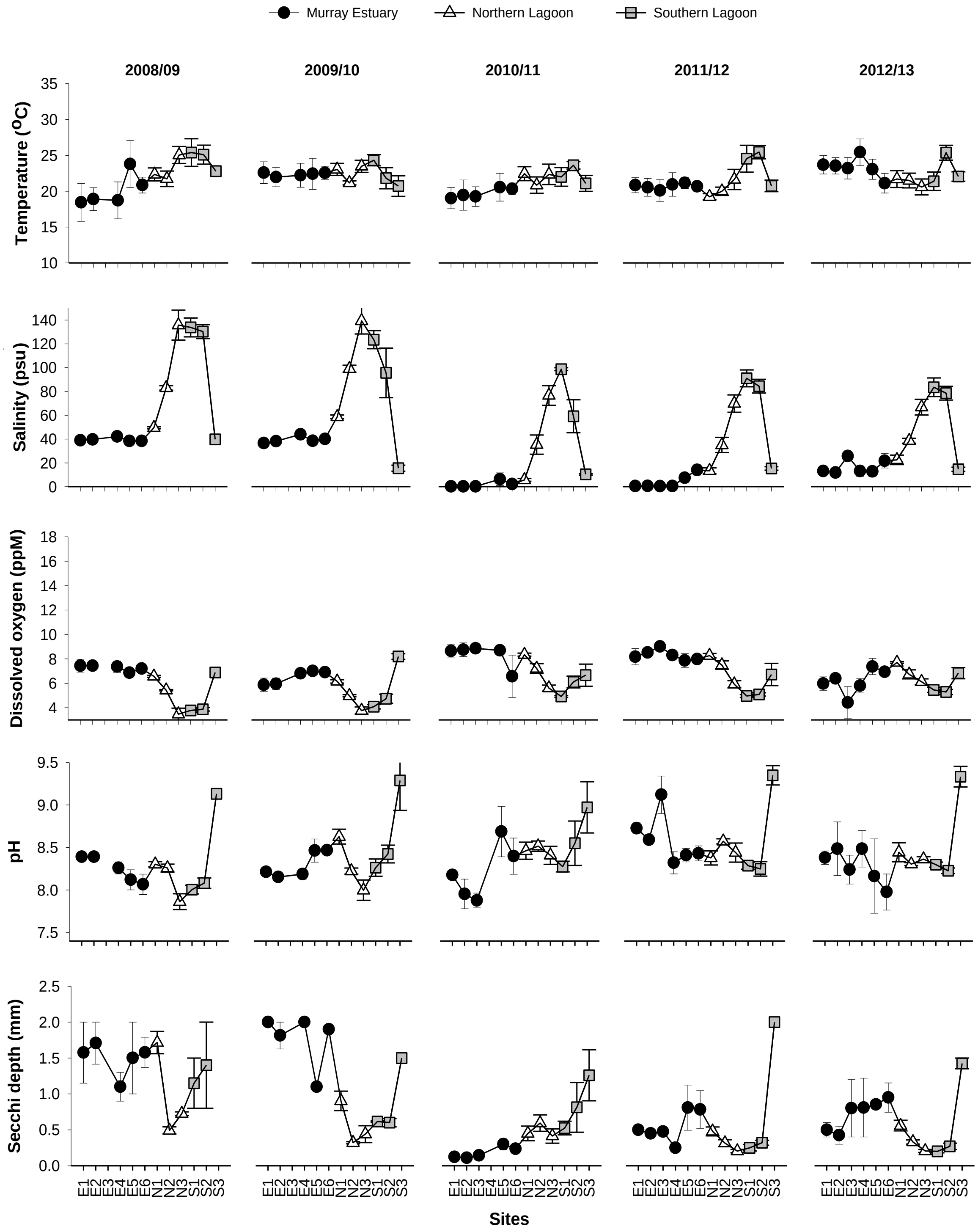


Figure 3.3. Mean values ± S.E. of water temperature, salinity, dissolved oxygen, pH and Secchi depth for the sampled period at each sampling site (sampling occasions pooled) within the Murray Estuary and Coorong regions between 2008/09 and 2012/13. Note S3 is a sampling site within the Salt Creek.

3.3 Black Bream

3.3.1 Fishery catch, effort and CPUE

Since 1984/85, 93% of the Lakes and Coorong Fishery's total commercial catch of black bream has come from the Coorong. In 2010/11-2011/12, Coorong catch accounted for 99% of the total harvest. The total annual catch from the Coorong was the highest on record in 1984/85, with 46.7 t harvested (Figure 3.4). Annual catch declined steeply to 2.6 t by 1992/93, and remained <5 t y^{-1} until 1999/00. Annual catches increased to 11.6 t in 2002/03, before declining to a historical low of 1.1 t in 2009/10. Following significant barrage releases since 2010/11, there was an increase in annual catch to 2.3 t and 3 t in 2010/11 and 2011/12, respectively. However, these levels remain below the average of the previous ten years (5 t y^{-1}). The dominant gear in all years was the large mesh gill net, accounting for approximately 90% of annual catches of black bream (Figure 3.4).

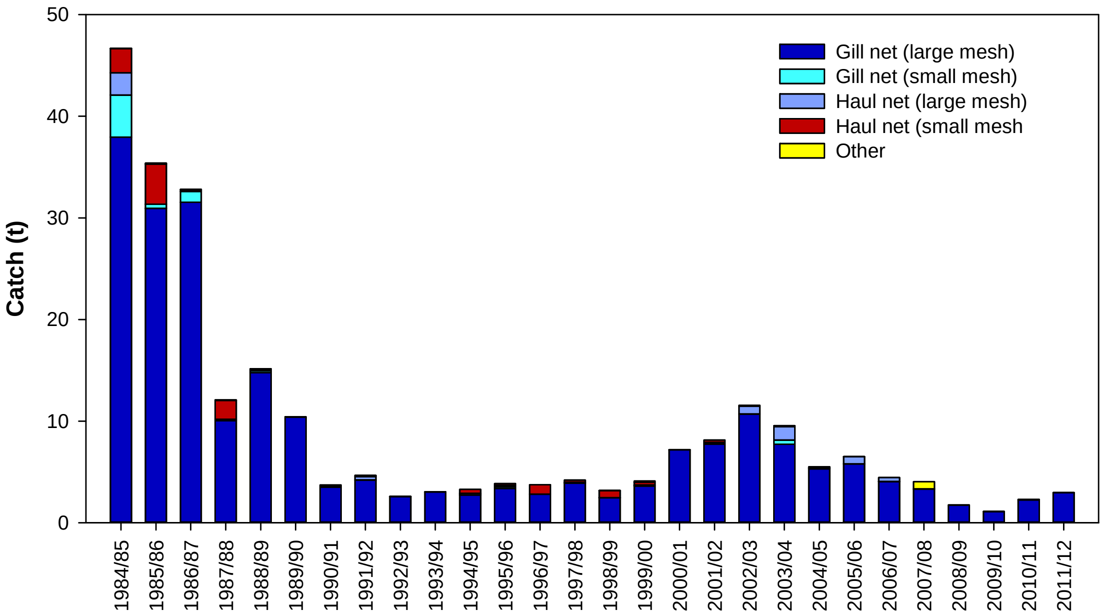


Figure 3.4. Annual catches of black bream taken by gear type in the Coorong.

Catches of black bream have been highly seasonal, with 47% of the annual catch taken between August and October over the last 28 years. In the last 5 years, however, the highest catch has been between July and September, with 48% of the annual harvest from these months. In most years, the peak monthly catch occurred in September (Figure 3.5).

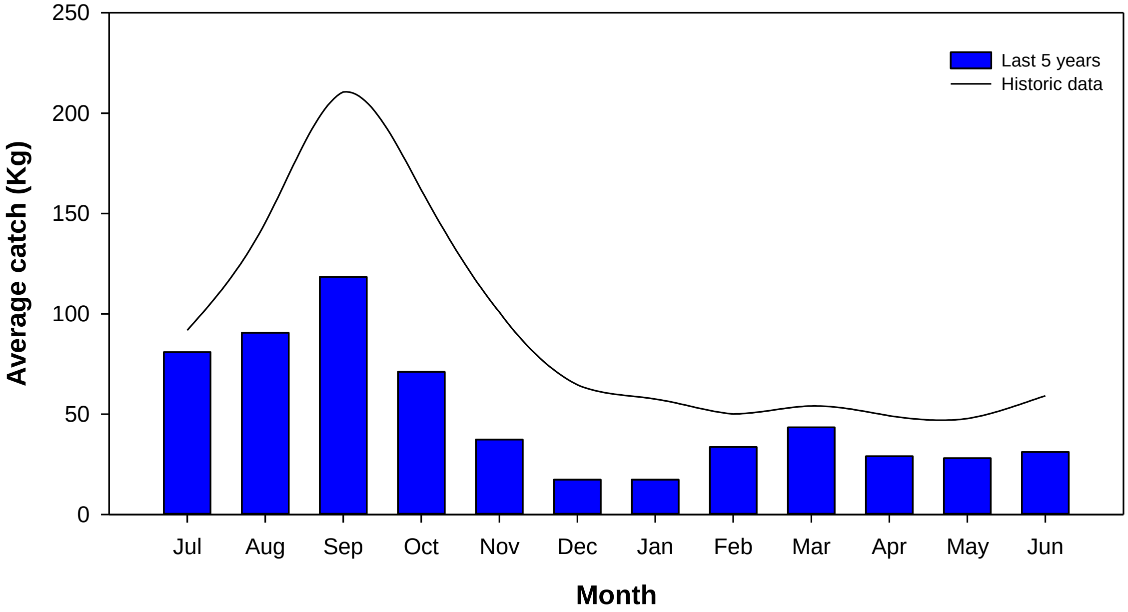


Figure 3.5. Long-term average monthly catches of black bream from the Coorong Fishery (1984/85 to 2011/12) and average monthly catches from the last five years (2008/09 to 2012/13).

Annual targeted catch, effort, and CPUE for black bream caught in large mesh gill nets are shown in Figure 3.6. The highest targeted catch of black bream was 30.6 t in 1984/85, following which it declined dramatically to 0.2 t in 1991/92. It remained low until 2002/03, when it increased to 5.9 t, before a gradual decline to <1 t in 2008/09 (Figure 3.6 A). There was no catch reported in 2009/10, whilst the targeted catch was 0.5 t in 2010/11 and 0.6 t in 2011/12, which comprised 23% and 20% of the total catch, respectively. The contribution of targeted catch to total catch varied greatly between years (0%-83%) (Figure 3.6 A).

Trends in targeted effort (fisher days) were similar to those for targeted catch. Effort was highest in 1985/86 (3365 fisher days and 81995 net days) and 1988/89 (2236 fisher days and 36583 net days) (Figure 3.6 B). Effort then declined steeply to a historic low of 50 fisher days in 1991/92, and it has remained <150 fisher days in the last five years. There was no targeted effort in 2009/10, whereas targeted effort in 2010/11 and 2011/12 were 93 and 73 fisher days, respectively, which were associated with 1329 and 1352 net days.

Trends in targeted effort measured as both fisher days and net days were similar and linearly related (LR: $R^2=0.95$, $F_{1,26}=515.7$, $p<0.001$) (Figure 3.6 B). Variability in targeted effort (fisher days) explained 87% of the variability in targeted catch (LR: $R^2=0.87$, $F_{1,26}=170.54$, $p<0.001$), while effort measured as net days explained 86% of the variability in targeted catch (LR: $R^2=0.86$, $F_{1,26}=162.87$, $p<0.001$).

Targeted CPUE fluctuated greatly between 1984/85 and 1990/91 with a general trend of decline to a historical low in 1990/91 (2.9 kg.fisher day^{-1}) (Figure 3.6 C). It then showed a general increase with some fluctuations and a historical peak (15.2 kg.fisher day^{-1}) in 2007/08, followed by a substantial drop in 2008/09 (4.9 kg.fisher day^{-1}). There was no targeted catch for black bream in 2009/10, whilst CPUE in 2010/11 and 2011/12 were 5.8 to 8.0 kg.fisher day^{-1}, respectively. Trends in CPUE (kg.net day^{-1}) generally followed those of CPUE (kg.fisher day^{-1}).

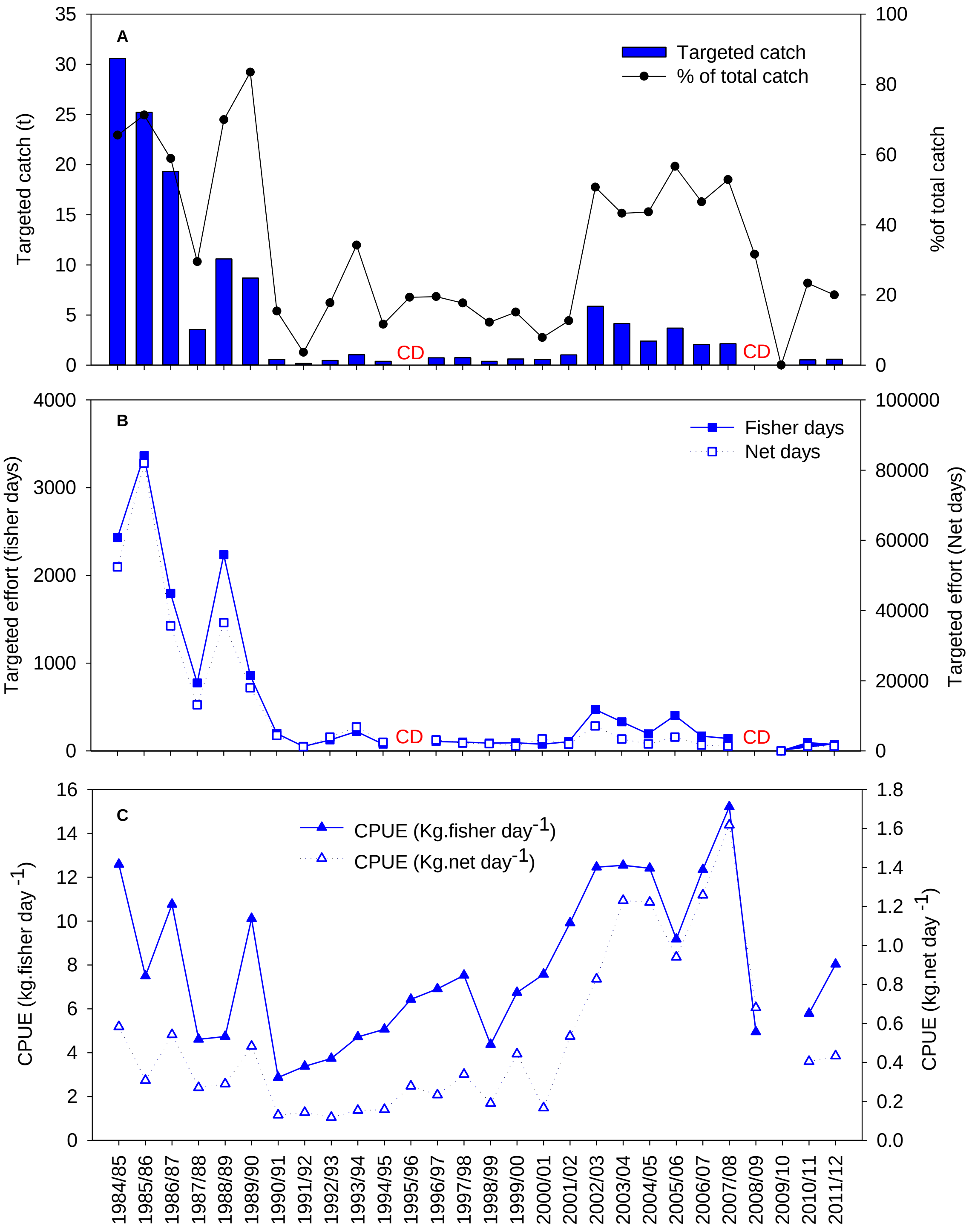


Figure 3.6. Annual targeted catch and effort of black bream caught in the large mesh gill nets. (A) Targeted catch shown in tonnes, and as percentage of total catch (both targeted and non-targeted catch), (B) Comparison of two measures of effort, and (C) Comparison of two estimates of CPUE. CD: confidential data, as these involved fewer than five fishers.

3.3.2 Spatial distribution of catches, and influence of freshwater inflow

Fishery catch and effort from the Murray Estuary and Coorong lagoons are reported for nine spatial blocks (Figure 2.1). Prior to 1994/95, catches of black bream were dominated by contributions from the North Lagoon (Blocks 9, 10, 11), accounting for more than 60% of total annual catches (Figure 3.7). After 1997/98, the catch of black bream from the North Lagoon declined to less than 30% of the total catch, while catches from the Murray Estuary (Blocks 6, 7, 8) increased (Figure 3.7 B). Between 2001/02 and 2009/10, almost all catches (98%) were from the Estuary (Block 6, 7, 8). Interestingly, with the barrage discharges in 2010/11, there was an increase in proportional catch of black bream to 31% in 2010/11 and 37% in 2011/12, in the North Lagoon.

Catches from the South Lagoon (Blocks 12, 13, 14) comprised 14% and 13% of the total catch in 1984/85 and 1986/87, respectively (Figure 3.7 B). However, catches from the South Lagoon in all other years totalled <2%. Since 1997/98, there have been no recorded catches of black bream from the South Lagoon except for 2001/02 when a small catch (0.9% of the total) was reported.

Reduction in the number of spatial reporting blocks fished during the decadal drought period (2001-2009) suggests contraction of the spatial range of black bream toward the Murray Estuary, particularly the area below Goolwa Barrage (Block 6) and Tauwitchere Barrage (Block 8). With the flow restoration since 2010/11, the catches of black bream have extended throughout the North Lagoon (Blocks 9, 10, 11) and showed a slight increase from 2010/11 to 2011/12 (Figure 3.7 A).

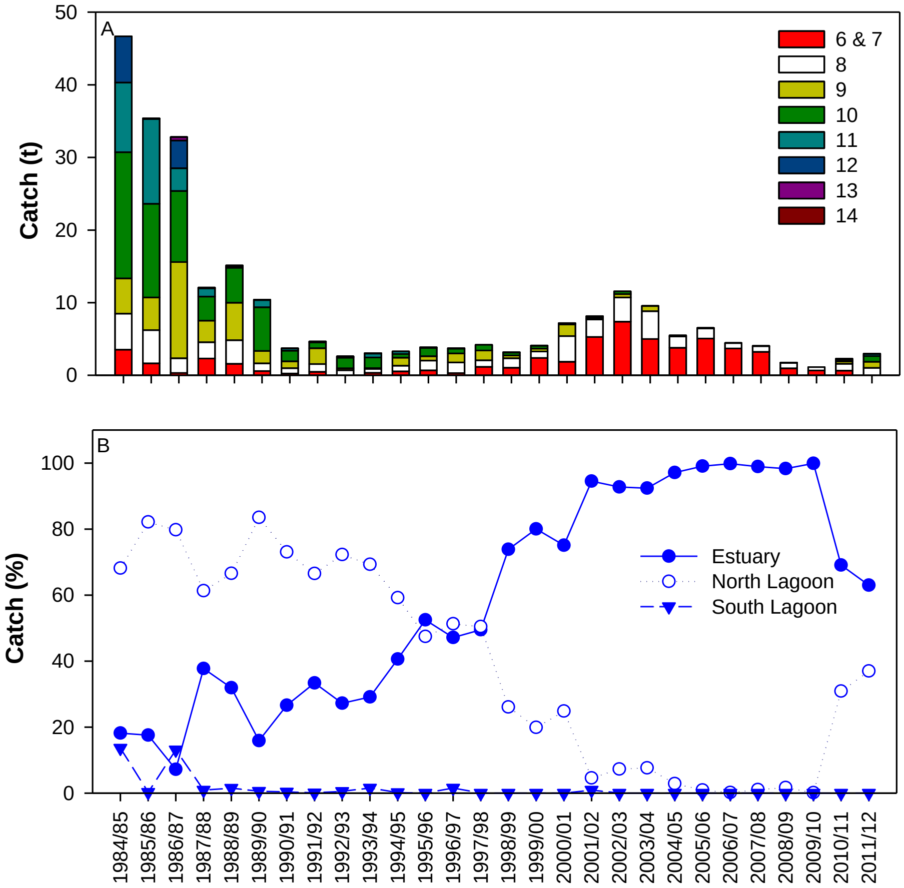


Figure 3.7. Black bream catches from (A) reporting blocks within the Coorong lagoons, and (B) contribution to total catch by areas in the Estuary, North and South lagoons.

3.3.3 Size and age structures

Age and/or size structures for female and male black bream in the last six years are shown in Figure 3.8. In general, ages ranged from 2 to 26 years for females and 2 to 32 years for males. In most years, there was a bimodal distribution in age structure for both sexes, with the exception of 2008/09 and 2011/12, when the distribution was unimodal.

Overall, the strongest cohort was the 2003/04 year class. This cohort was present as 4 year olds in 2007/08, and persisted as 5, 6 and 7 year olds in 2008/09, 2009/10 and 2010/11, respectively. In 2011/12, this cohort was sampled again as 8 year olds but only with males. The second strongest cohort originated in 1997/98, and persisted as 10, 12 and 13 year olds in 2007/08, 2009/10 and 2010/11, respectively. In 2011/12, a new strong cohort (i.e. 5 years old) appeared, representing the 2006/07 year class. Fish otoliths were collected in 2012/13 and stored for age determination in the future.

Size structures for black bream did not reflect the distinct modal progression in age structures (Figure 3.9). All size structures were unimodal with a modal size of 321-360 mm TL for both females and males in all years, except that in 2011/12 the modal size for males was 281-320 mm TL.

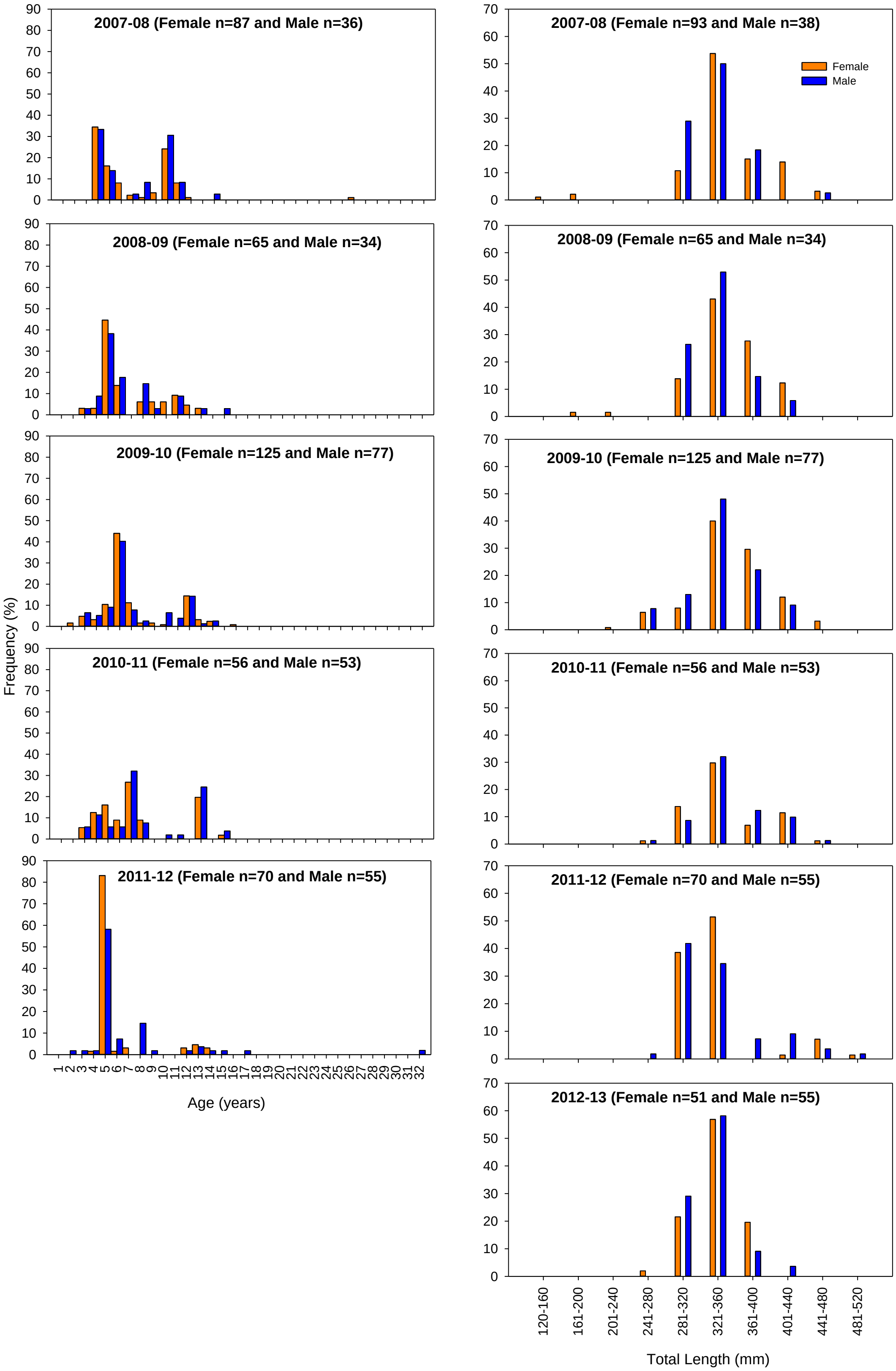


Figure 3.8. Age (left) and size (right) structures of black bream from the Murray Estuary and Coorong from 2007/08 to 2012/13.

3.3.4 Recruitment

Abundance of juvenile black bream exhibited a general decline from 2008/09 to 2011/12 and an increase in 2012/13 (Table 3.1, Figure 3.9). PERMANOVA detected a significant interaction (*p*=0.001) when comparing CPUE of juveniles amongst five years (2008/09-2012/13) across four regular sites (Boundary Creek, downstream of Goolwa Barrage (Hindmarsh Island end and Sir Richard Peninsula end) and Mundoo Barrage) (Table 3.2), indicating that the spatiotemporal pattern was not consistent in all years and sites.

Pairwise comparisons revealed significant changes in juvenile CPUE between years at both Goolwa Barrage sites (Table 3.3), but not at Mundoo Barrage and Boundary Creek. There was a significant decrease (*p*<0.001) in abundance at both Goolwa Barrage sites from 2008/09 to 2010/11. No juvenile black bream were sampled at any sites in 2010/11. In 2011/12, a small number of juveniles were collected at one regular site (Mundoo Barrage) although the increase was not statistically significant, and one additional sampling site (Godfrey's landing). In 2012/13, juvenile black bream were found at three of the four regular sampling sites; at Mundoo Barrage and a Goolwa site the abundance was the highest recorded at the site in the last five years.

The analysis also revealed significant spatial differences in all years except 2010/11 and 2011/12, when there was nil or very low catch of juvenile black bream at all sites. In both 2008/09 and 2009/10, CPUE was significantly higher at the two Goolwa Barrage sites than at Boundary Creek (*p*≤0.001), whereas in 2012/13 CPUE was significantly higher at Mundoo Barrage and the two Goolwa Barrage sites than at Boundary Creek (Table 3.1, Table 3.4).

Length frequency distributions of juvenile black bream from all sites combined are presented for each year (Figure 3.10). In both 2008/09 and 2009/10, a modal progression from March to April was identified, no juvenile black bream were collected in 2010/11 and only four were present in the March 2011/12 samples, despite extra sampling effort in these two years compared to 2008/09 and 2009/10. In 2012/13, 41 juvenile black bream were collected. A modal progression from February to April was evident with a size class progressing from 80-99 mm to 120-139 mm.

Table 3.1. Catch per unit effort (CPUE) for juvenile black bream using single-wing fyke nets in the Murray Estuary and Coorong from 2008/09 to 2012/13. (Regular sampling sites are in bold. SE= standard error).

CPUE (fish per net.night)	**2008/09**		**2009/10**		**2010/11**		**2011/12**		**2012/13**	
Regular and additional sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Goolwa Barrage saltwater side Hindmarsh Island end	**6.6**	**2.1**	**0.5**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**2.8**	**0.5**
Goolwa Barrage saltwater side Sir Richard Peninsula end	**2.1**	**0.4**	**1.0**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**2.4**	**0.6**
Mundoo Barrage	**0.3**	**0.3**			**0.0**	**0.0**	**0.1**	**0.1**	**5.9**	**2.9**
Boundary Creek	**0.1**	**0.1**	**0.0**	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**
Boundary Creek Barrage	0.8	0.3								
Cattle Point					0.0	0.0	0.0	0.0	0.0	0.0
Ewe Island Causeway	0.0	0.0	0.0	0.0						
Godfrey's Landing							0.3	0.3		
Goolwa Barrage freshwater side Hindmarsh Island end	0.0	0.0								
Goolwa Barrage freshwater side Sir Richard Peninsula end	0.0	0.0	0.0	0.0						
Goolwa Channel Hindmarsh Island side							0.0	0.0		
Long Point					0.0	0.0	0.0	0.0	0.0	0.0
Long Point beach							0.0	0.0	0.0	0.0
Long Point reef							0.0	0.0	0.0	0.0
Long Point sand dune					0.0	0.0				
Long Point Young Husband Pen. Side; opp. Jetty							0.0	0.0	0.0	0.0
Mark Point	0.1	0.1			0.0	0.0	0.0	0.0	0.0	0.0
Mark Point beach							0.0	0.0	0.0	0.0
Mundoo Channel	0.0	0.0								
Mundoo Channel in front of house							0.0	0.0		
Noonameena					0.0	0.0				
Opposite Mark Point Young Husband Penisula							0.0	0.0		
Pelican Point	0.0	0.0								
Pelican Point Young Husband Peninsula	0.1	0.1								
Pelican Pt. Young Husband side Phrag. Opposite Rumbolow Shack							0.0	0.0		
Robs Point					0.0	0.0				
South Cattle Point							0.0	0.0	0.0	0.0
Tauwitchere Barrage	1.3	1.3	0.0	0.0						
Average across sites	**1.6**	**0.4**	**0.4**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**3.4**	**0.8**

Table 3.2. PERMANOVA results for CPUE of juvenile black bream, comparison amongst years and sites in the Murray Estuary and Coorong. Bold *p* values are significant.

Source	df	MS	P(perm)
Year	4	50.875	**0.001**
Site	3	55.731	**0.007**
Year x Sie	10	40.342	**0.002**

Table 3.3. PERMANOVA pair-wise test factor level year, results for CPUE of juvenile black bream, comparison amongst years for each site in the Murray Estuary and Coorong. Bold *p* values are significant (FDR B-Y corrected *p*=0.01082 for 56 pairs).

Boundary Creek	Groups	t	P(perm)
	2008/09 x 2009/10	0.87801	1
	2008/09 x 2011/12	0.71459	1
	2008/09 x 2012/13	1.0163	0.493
	2009/10 x 2011/12	N/A	
	2009/10 x 2012/13	N/A	
	2011/12 x 2012/13	N/A	
Goolwa Barrage saltwater side HI end	Groups	t	P(perm)
	2008/09 x 2009/10	3.1243	**0.001**
	2008/09 x 2011/12	2.6316	**0.006**
	2008/09 x 2010/11	3.6234	**0.001**
	2008/09 x 2012/13	2.8388	**0.001**
	2009/10 x 2011/12	2.0704	0.05
	2009/10 x 2010/11	2.8477	**0.002**
	2009/10 x 2012/13	1.4074	0.214
	2011/12 x 2010/11	N/A	
	2011/12 x 2012/13	2.2672	0.038
	2010/11 x 2012/13	3.1184	**0.002**
Goolwa Barrage saltwater side SRP end	Groups	t	P(perm)
	2008/09 x 2009/10	1.5453	0.154
	2008/09 x 2011/12	4.0647	**0.001**
	2008/09 x 2010/11	3.9681	**0.001**
	2008/09 x 2012/13	1.9431	0.054
	2009/10 x 2011/12	3.4531	**0.001**
	2009/10 x 2010/11	3.4399	**0.001**
	2009/10 x 2012/13	0.38205	0.728
	2011/12 x 2010/11	0.95238	1
	2011/12 x 2012/13	2.4292	**0.009**
	2010/11 x 2012/13	2.4277	**0.007**
Mundoo Barrage	Groups	t	P(perm)
	2008/09 x 2011/12	0.97904	0.395
	2008/09 x 2010/11	2.7255	0.146
	2008/09 x 2012/13	0.51741	0.7000
	2011/12 x 2010/11	1.4460	0.517
	2011/12 x 2012/13	1.4546	0.128
	2010/11 x 2012/13	1.5442	0.053

Table 3.4. PERMANOVA pair-wise test factor level site, results for CPUE of juvenile black bream, comparison amongst sites for each year in the Murray Estuary and Coorong. Bold *p* values are significant (FDRB-Y corrected *p*=0.01082 for 56 pairs).

2008/09	Groups	t	P(perm)
	Boundary Creek x Goolwa Barrage Saltwater side HI	3.7758	**0.001**
	Boundary Creek x Goolwa Barrage Saltwater side SRP	4.7545	**0.001**
	Boundary Creek x Mundoo Barrage	0.93298	0.259
	Goolwa Barrage Saltwater side HI x Goolwa Barrage Saltwater side SRP	2.4689	0.014
	Goolwa Barrage Saltwater side HI x Mundoo Barrage	1.2899	0.137
	Goolwa Barrage Saltwater side SRP x Mundoo Barrage	1.5481	0.118
2009/10	Groups	t	P(perm)
	Boundary Creek x Goolwa Barrage Saltwater side HI	2.6321	0.01
	Boundary Creek x Goolwa Barrage Saltwater side SRP	3.7757	**0.001**
	Goolwa Barrage Saltwater side HI x Goolwa Barrage Saltwater side SRP	2.2709	0.029
2010/11	Groups	t	P(perm)
	Goolwa Barrage saltwater side HI x Goolwa Barrage saltwater side SRP	Denominator is 0	
	Goolwa Barrage saltwater side HI end x Mundoo Barrage	Denominator is 0	
	Goolwa Barrage saltwater side SRP end x Mundoo Barrage	Denominator is 0	
2011/12	Groups	t	P(perm)
	Boundary Creek x Goolwa Barrage Saltwater side HI	Denominator is 0	
	Boundary Creek x Goolwa Barrage Saltwater side SRP	0.84959	1
	Boundary Creek x Mundoo Barrage	1.1755	0.483
	Goolwa Barrage Saltwater side HI x Goolwa Barrage Saltwater side SRP	0.82199	1
	Goolwa Barrage Saltwater side HI x Mundoo Barrage	1.1374	0.513
	Goolwa Barrage Saltwater side SRP x Mundoo Barrage	0.50983	1
2012/13	Groups	t	P(perm)
	Boundary Creek x Goolwa Barrage Saltwater side HI	3.3385	**0.001**
	Boundary Creek x Goolwa Barrage Saltwater side SRP	3.0823	**0.001**
	Boundary Creek x Mundoo Barrage	1.7872	**0.007**
	Goolwa Barrage Saltwater side HI x Goolwa Barrage Saltwater side SRP	0.30111	0.823
	Goolwa Barrage Saltwater side HI x Mundoo Barrage	0.55767	0.766
	Goolwa Barrage Saltwater side SRP x Mundoo Barrage	0.45586	0.799

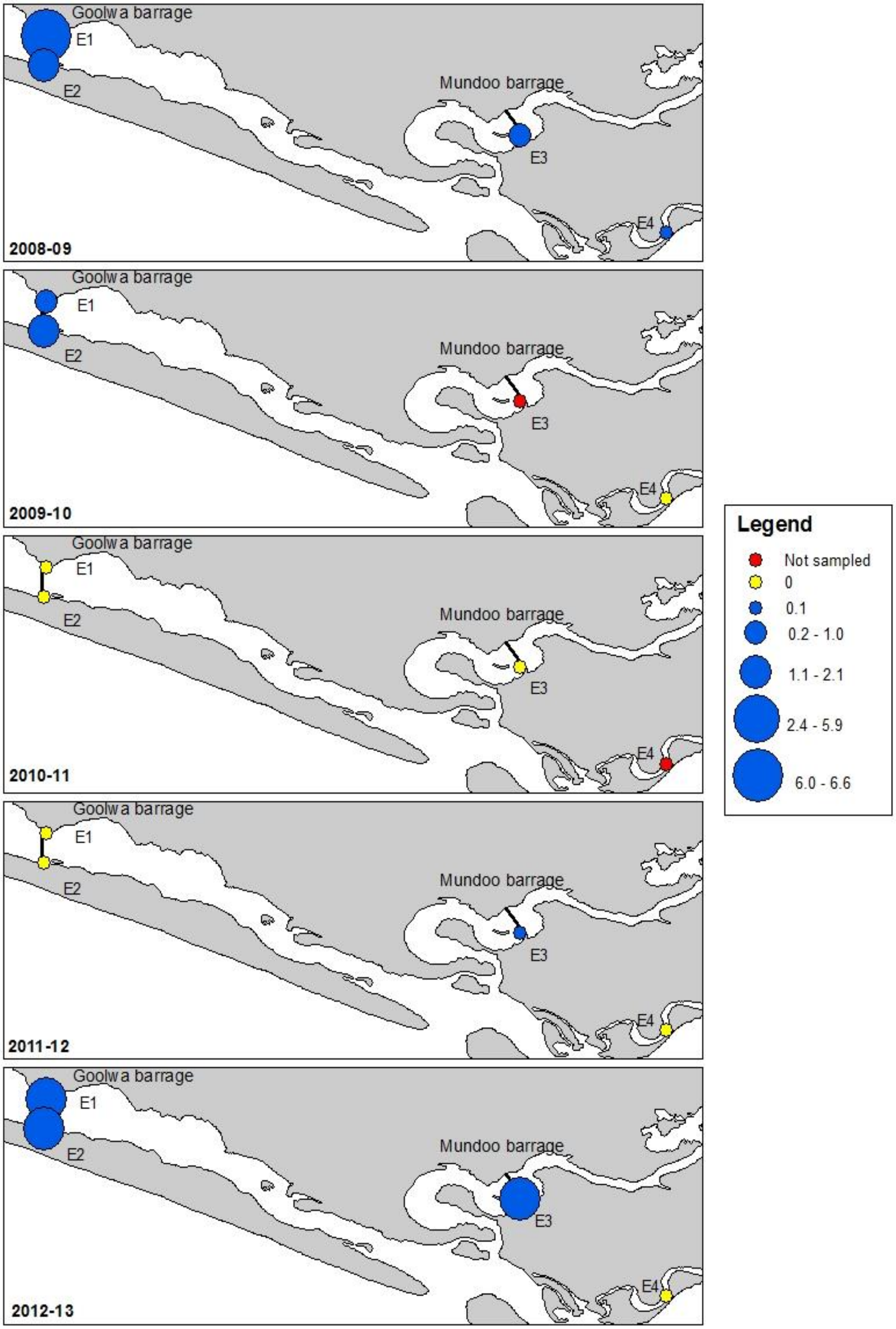


Figure 3.9. Murray Estuary map showing relative abundance and distribution of juvenile black bream from 2008/09 to 2012/13 (top to bottom).

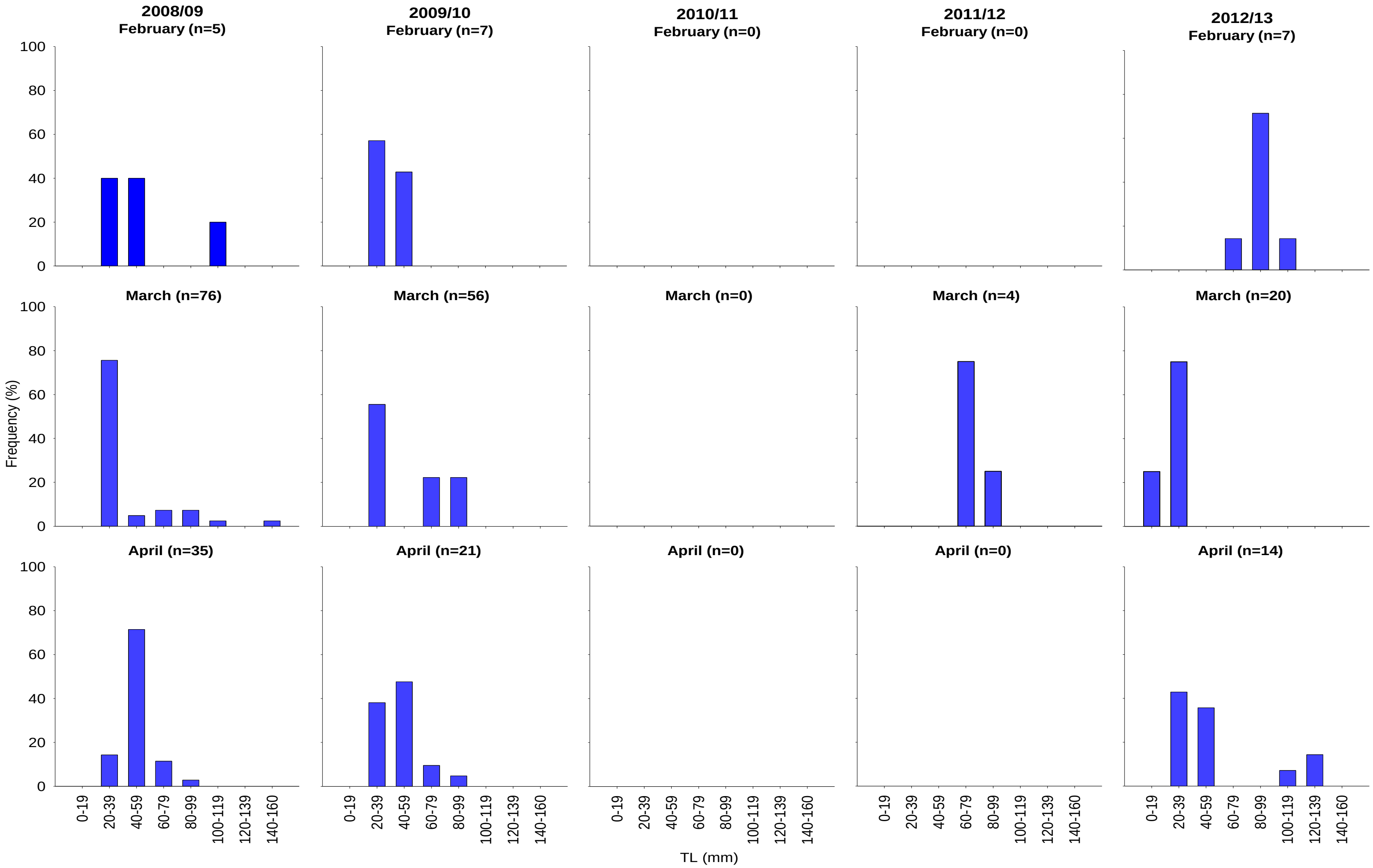


Figure 3.10. Length frequency distributions of juvenile black bream from fyke net samples in the Murray Estuary and Coorong from February to April between 2008/09 and 2012/13.

3.4 Greenback flounder

3.4.1 Fishery catch, effort and CPUE

Over the past 28 years, 99% of the Lakes and Coorong Fishery catch of greenback flounder came from the Coorong. In 2010/11-2011/12, the Coorong catch comprised 95% of the total harvest of this species. The total annual catch from the Coorong was highest in 1990/91 (65.3 t), then declined steeply to 3.0 t in 1994/95. In the following seven years, catches fluctuated between 11 and 40 t. There was a further reduction in catch to less than 9 t from 2002/03 to 2010/11, when the annual catch reached a historical low of 0.1 t in 2010/11 (Figure 3.11). In 2011/12, the catch increased to 29.6 t, a level similar to 1995/96 (30 t). The dominant gear was the large mesh gill net, accounting for more than 95% of the catch from the Coorong over 28 years (Figure 3.11).

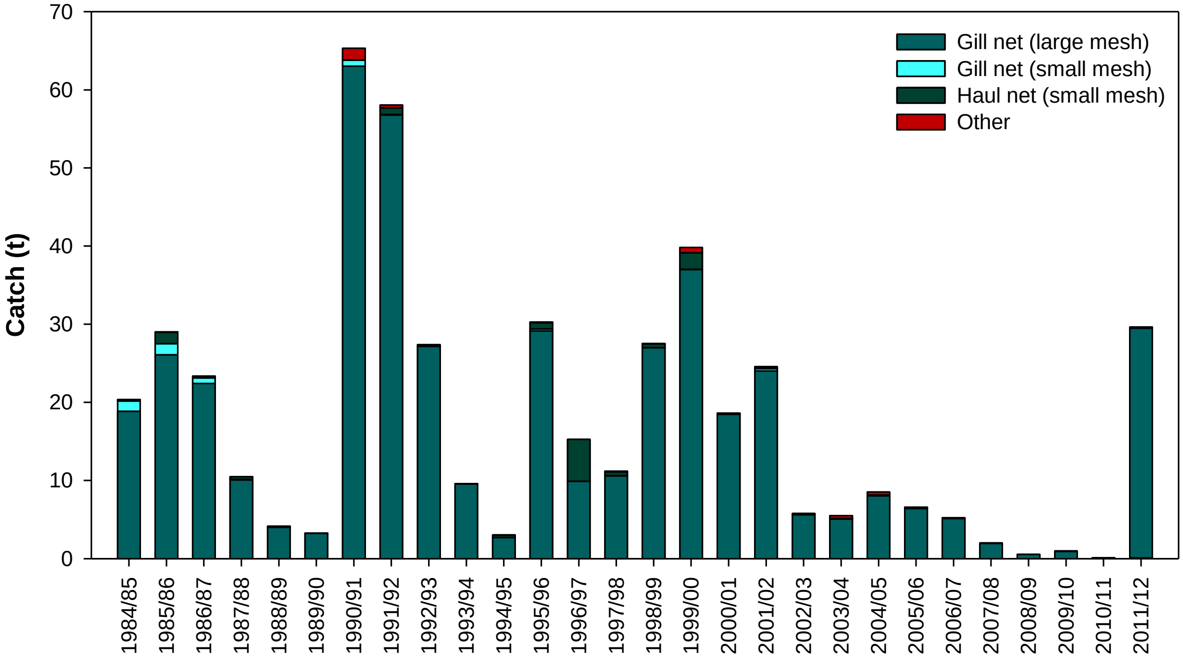


Figure 3.11. Annual catches of greenback flounder taken by gear type in the Coorong.

Historically, catches of greenback flounder were highly seasonal, with 78% of the annual catch taken between October and April since 1984/85 (Figure 3.12). However, the seasonality of catches was less defined from 2007/08 to 2011/12.

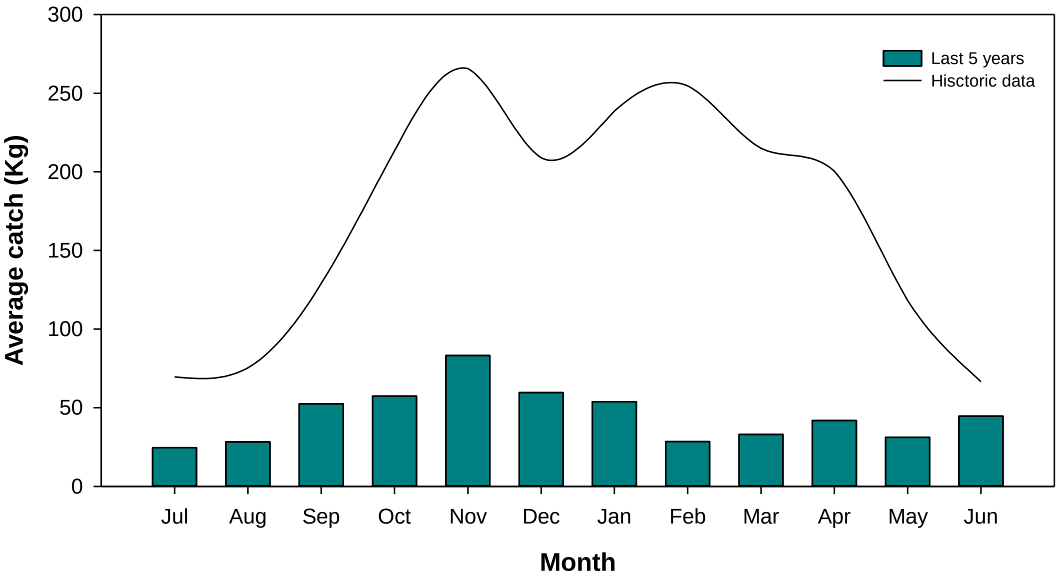


Figure 3.12. Long-term average monthly catches of greenback flounder from the Coorong Fishery (1984/85 to 2012/13) and average monthly catches from the last five years (2008/09 to 2012/13).

Annual targeted catch, effort, and CPUE for greenback flounder in large mesh gill nets are shown in Figure 3.13. The highest targeted catch was 45.8 t in 1990/91, before declining to 0.5 t in 1994/95 and then increasing to 29.2 t in 1999/2000 (Figure 3.13 A). Since then, targeted annual catches have declined to a historically low level (~0.1 t in 2009/10). In 2010/11, the flood year, there was no targeted catch for greenback flounder. In 2011/12, following the flood year, targeted annual catch had a sharp increase to 19.7 t, which was well above the average annual catch (~10 t) over the last 28 years, and was the sixth highest recorded since 1984/85. The contribution of targeted catch to total catch varied greatly between years, from 0% to 81% (Figure 3.13 A). Following a continuing decline in the proportion of targeted catch from 2005/06 (58%) to 2010/11 (0%), there was an increase in targeted catch to 66% in 2011/12.

Trends in annual targeted effort (fisher days) were similar to those of targeted catch. Highest effort occurred in the early 1990s (> 2000 fisher days per year) (Figure 3.13 B). Targeted effort declined in 1994/95 (79 fisher days) before rising again in 1999/2000 (1248 fisher days). In the following years, a general trend of declining effort was evident, reaching a historical low level in 2008/09 and 2009/10 (<20 fisher days). There was no targeted effort of greenback flounder in 2010/11. In 2011/12, targeted effort increased to 830 fisher days.

Trends in effort defined as fisher days and net days were similar, with both measures linearly related (LR: $R^2=0.95$, $F_{1,26}=496.75$, $p<0.001$). Variability in targeted effort (fisher day) explained 78% of the variability in targeted catch (LR: $R^2=0.78$, $F_{1,26}=90.7$, $p<0.001$), whilst targeted effort as net days explained 80% of the catch (LR: $R^2=0.80$, $F_{1,26}=105.66$, $p<0.001$).

CPUE (kg.fisher day^{-1}) varied greatly between 1984/85 and 1999/2000 with a peak of 23.4 kg.fisher day^{-1} in 1999/2000 (Figure 3.13 C). After that, CPUE exhibited a general decline. It remained around 7 kg.fisher day^{-1} between 2005/06 and 2009/10, except for 2008/09 (21.9 kg.fisher day^{-1}). However, CPUE estimates for 2008/09 and 2009/10 should be interpreted with caution because these were based on low levels of fishing effort and may not provide a good estimate of relative abundance for these years. CPUE in 2011/12 was the highest recorded since 1984/85 (23.8 kg.fisher day^{-1}), slighter higher than that in 1999/2000 (23.4 kg.fisher day^{-1}). Trends in net day-based CPUE (kg.net day^{-1}) were generally similar to those for fisher day-based CPUE (kg.fisher day^{-1}).

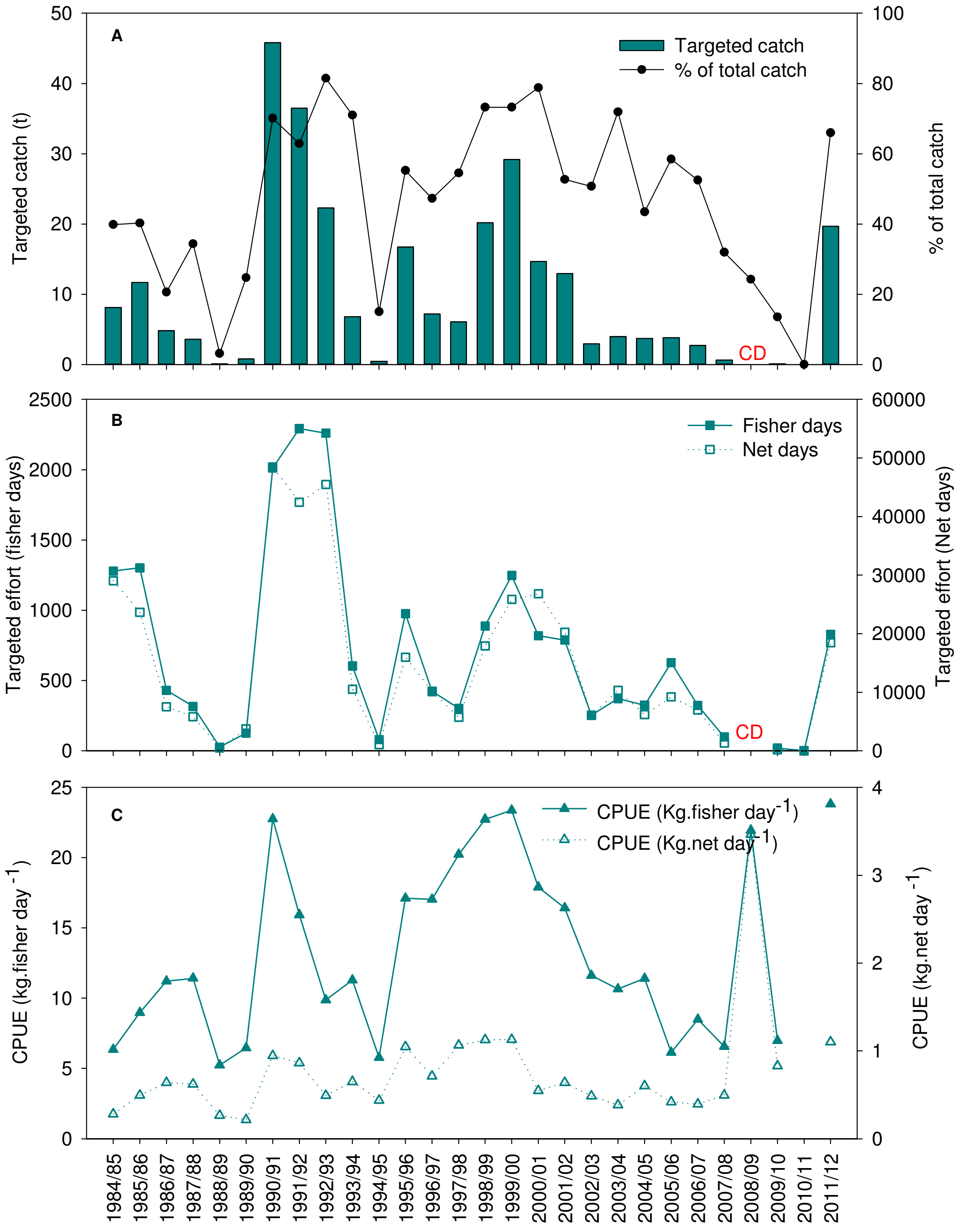


Figure 3.13. Annual targeted catch and effort for greenback flounder caught in the large mesh gill nets. (A) Targeted catch shown in tonnes, and as percentage of total catch (both targeted and non-targeted effort), (B) Comparison of two measures of effort, and (C) Comparison of two estimates of CPUE. CD: confidential data, as these involved fewer than five fishers.

3.4.2 Spatial distribution of catches, and influence of freshwater inflow

Based on fishery catch and effort reports by fishing blocks (Figure 2.1), most of the Coorong catches of greenback flounder (averaging 75%) came from the North Lagoon (Blocks 9, 10, 11) prior to 2005/06 (Figure 3.14). After 2006/07, the proportional catch from the North Lagoon declined significantly such that by 2009/10 and 2010/11, 100% of catches were from the Estuary (Blocks 6, 7, 8). In 2011/12, there was a distinct increase in the percentage catch from the North Lagoon to 99% (Figure 3.14 B).

Annual catches of flounder from the South Lagoon (Blocks 12, 13, 14) were low, contributing <0.3% to the total annual catches, except for 1993/94, when 4.2% of the catch came from this subregion (Figure 3.14 B). There were no catch records of greenback flounder from the South Lagoon between 2002/03 and 2010/11, but 0.2% of the catch was from this subregion in 2011/12.

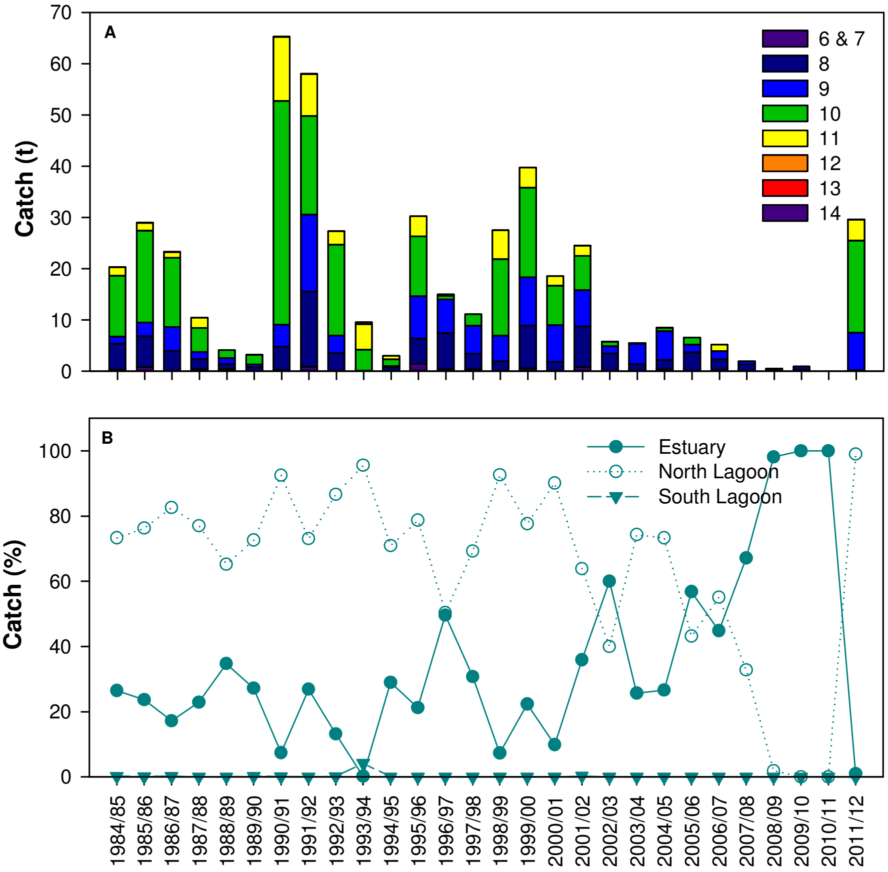


Figure 3.14. Greenback flounder catches from (A) reporting blocks within the Coorong lagoons, and (B) contribution to total catch by areas in the Estuary, North and South lagoons.

3.4.3 Size and age structures

Age structures of female and male greenback flounder are shown in Figure 3.15. In 2007, fish were mainly 2 and 3 year old females, comprising 87.3% of the total catch. Age of females ranged from 1 to 3 years, and of the three males collected, two were 2 years old and the other was 4 years old. In 2009, all fish collected were females, ranging from 1 to 3 years, with 37% and 53% being 1 and 2 year old, respectively. In 2010 and 2011, females of 1 and 2 year olds continued to dominate the catch; however, the majority (>60%) were 1 year olds. Age ranged from 1 to 3 years for both sexes in 2010 and for females in 2011; only two males were collected in 2011 both of which were 1 year old. It should be noted that most of the 2010 samples were derived from fishery-independent sampling, whilst for other sampling years, fish were mainly from commercial fishery catches.

Length frequency distributions (size structure) of female greenback flounder were bimodal in 2007 and 2010 whereas they were unimodal in 2009, 2011 and 2012. The length distributions of females in 2011 and 2012 were much narrower than in previous years, with the majority (>90%) ranging from 260 to 320 mm TL. There was a shift in size mode from 260-279 mm TL in 2011 to 280-299 mm TL in 2012. Throughout the study period, only a few male fish were collected (0-5) each year, with sizes ranging from 220 to 359 mm.

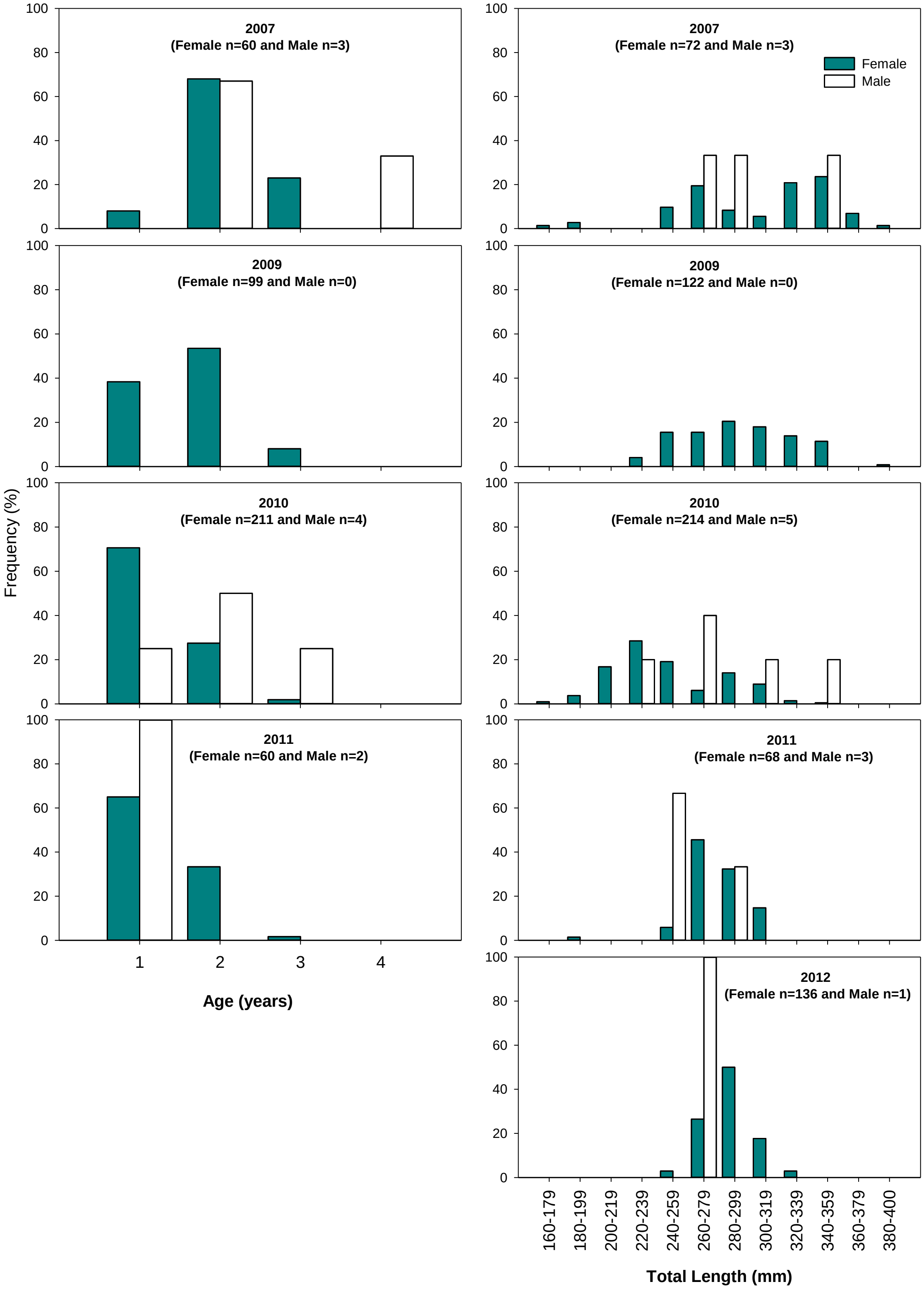


Figure 3.15. Age (left) and size (right) structures of greenback flounder from the Murray Estuary and Coorong from 2007 to 2012 (most of the samples were from commercial catches in 2007 and 2009, 2011 and 2012 whilst 2010 samples were mainly from fishery-independent sampling).

3.4.4 Recruitment

The relative abundance of juvenile greenback flounder varied greatly across sites and amongst years (2008/09-2012/13) in the Murray Estuary and Coorong (Table 3.5, Figure 3.18). PERMANOVA detected a significant interaction (*p*=0.001) amongst the five years across the three sites (Sugars Beach, Godfrey's Landing and Mark Point) (Table 3.6), indicating that the spatiotemporal pattern was not consistent across all years and sites.

Pairwise comparisons revealed significant temporal variation at each site (Table 3.7). At Sugars Beach, the abundance of juvenile flounder was similar in 2008/09 and 2009/10, then decreased significantly in 2010/11 following substantial barrage releases; although there appeared to be an increase in 2011/12 in juvenile CPUE, it was not statistically significant (Tables 3.5 and 3.7). The CPUEs in the three post-flood years were not statistically different. At Godfrey's Landing, CPUE showed a significant reduction from 2008/09 to 2009/10 with no increase post flood. In contrast, at Mark Point, there appeared to be a steady increase in juvenile abundance after 2010/11 (i.e. the flood year); CPUE in 2012/13 was the highest recorded among the five study years and significantly greater than during the drought years (i.e. 2008/09 and 2009/10). Pairwise comparisons also identified spatial variation in each year except 2011/12 (Table 3.8).

Table 3.5. Catch per unit effort (CPUE) for juvenile greenback flounder using seine net in the Murray Estuary and Coorong from 2008/09 to 2012/13.

CPUE (fish per net.shot)	**2008/09**		**2009/10**		**2010/11**		**2011/12**		**2012/13**	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Sugars Beach	10.8	3.1	27.7	8.8	0.7	0.4	4.2	1.7	0.4	0.2
Godfrey's Landing	17.4	3.2	4.3	1.1	8.9	2.7	1.3	0.8	0.8	0.4
Mark Point	0.4	0.2	0.4	0.2	1.8	0.5	2.2	1.7	5.1	1.5
Average across sites	9.6	2.0	10.8	3.7	3.8	1.1	2.6	0.9	2.1	0.7

Table 3.6. PERMANOVA results for CPUE of juvenile greenback flounder, comparison amongst years and sites in the Murray Estuary and Coorong. Bold *p* values are significant.

Source	df	MS	P(perm)
Year	4	453.82	**0.001**
Site	2	534.23	**0.001**
YearxSite	8	584.21	**0.001**

Table 3.7. PERMANOVA pair-wise test factor level year, results for CPUE of juvenile greenback flounder, comparison amongst years for each site in the Murray Estuary and Coorong. Bold *p* values are significant (FDR B-Y corrected *p*=0.01138 for 45 pairs).

Sugars beach	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	1.8079	0.083
	2008/09 x 2010/11	3.2625	**0.002**
	2008/09 x 2011/12	1.8697	0.085
	2008/09 x 2012/13	3.3482	**0.001**
	2009/10 x 2010/11	3.0582	**0.001**
	2009/10 x 2011/12	2.6109	**0.003**
	2009/10 x 2012/13	3.085	**0.001**
	2010/11 x 2011/12	2.0645	0.047
	2010/11 x 2012/13	0.5	0.822
	2011/12 x 2012/13	2.2238	0.02
Godfrey's landing	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	3.9036	**0.005**
	2008/09 x 2010/11	2.0524	0.059
	2008/09 x 2011/12	4.9005	**0.002**
	2008/09 x 2012/13	5.1995	**0.001**
	2009/10 x 2010/11	1.564	0.142
	2009/10 x 2011/12	2.1669	0.063
	2009/10 x 2012/13	3.0237	**0.009**
	2010/11 x 2011/12	2.6692	**0.01**
	2010/11 x 2012/13	2.966	**0.006**
	2011/12 x 2012/13	0.58222	0.769
Mark Point	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	8.30E-09	1
	2008/09 x 2010/11	2.2283	0.064
	2008/09 x 2011/12	1.0129	0.583
	2008/09 x 2012/13	2.9924	**0.002**
	2009/10 x 2010/11	2.3202	0.056
	2009/10 x 2011/12	1.0175	0.555
	2009/10 x 2012/13	3.0096	**0.001**
	2010/11 x 2011/12	0.24388	0.983
	2010/11 x 2012/13	2.0389	0.048
	2011/12 x 2012/13	1.2437	0.291

Table 3.8. PERMANOVA pair-wise test factor level site, results for CPUE of juvenile greenback flounder, comparison amongst sites for each year in the Murray Estuary and Coorong. Bold *p* values are significant (FDRB-Y corrected *p*=0.01138 for 45 pairs).

2008/09	**Groups**	**t**	**P(perm)**
	Sugars beach x Godfrey's landing	1.5077	0.166
	Sugars beach x Mark Point	3.3482	**0.001**
	Godfrey's landing x Mark Point	5.3373	**0.002**
2009/10	**Groups**	**t**	**P(perm)**
	Sugars beach x Godfrey's landing	2.6252	**0.003**
	Sugars beach x Mark Point	3.0855	**0.001**
	Godfrey's landing x Mark Point	3.5132	**0.01**
2010/11	**Groups**	**t**	**P(perm)**
	Sugars beach x Godfrey's landing	3.0166	**0.002**
	Sugars beach x Mark Point	1.6784	0.146
	Godfrey's landing x Mark Point	2.5813	0.016
2011/12	**Groups**	**t**	**P(perm)**
	Sugars beach x Godfrey's landing	1.5334	0.172
	Sugars beach x Mark Point	0.82699	0.438
	Godfrey's landing x Mark Point	0.4594	0.805
2012/13	**Groups**	**t**	**P(perm)**
	Sugars beach x Godfrey's landing	0.67082	0.67
	Sugars beach x Mark Point	2.9924	**0.001**
	Godfrey's landing x Mark Point	2.7074	**0.003**

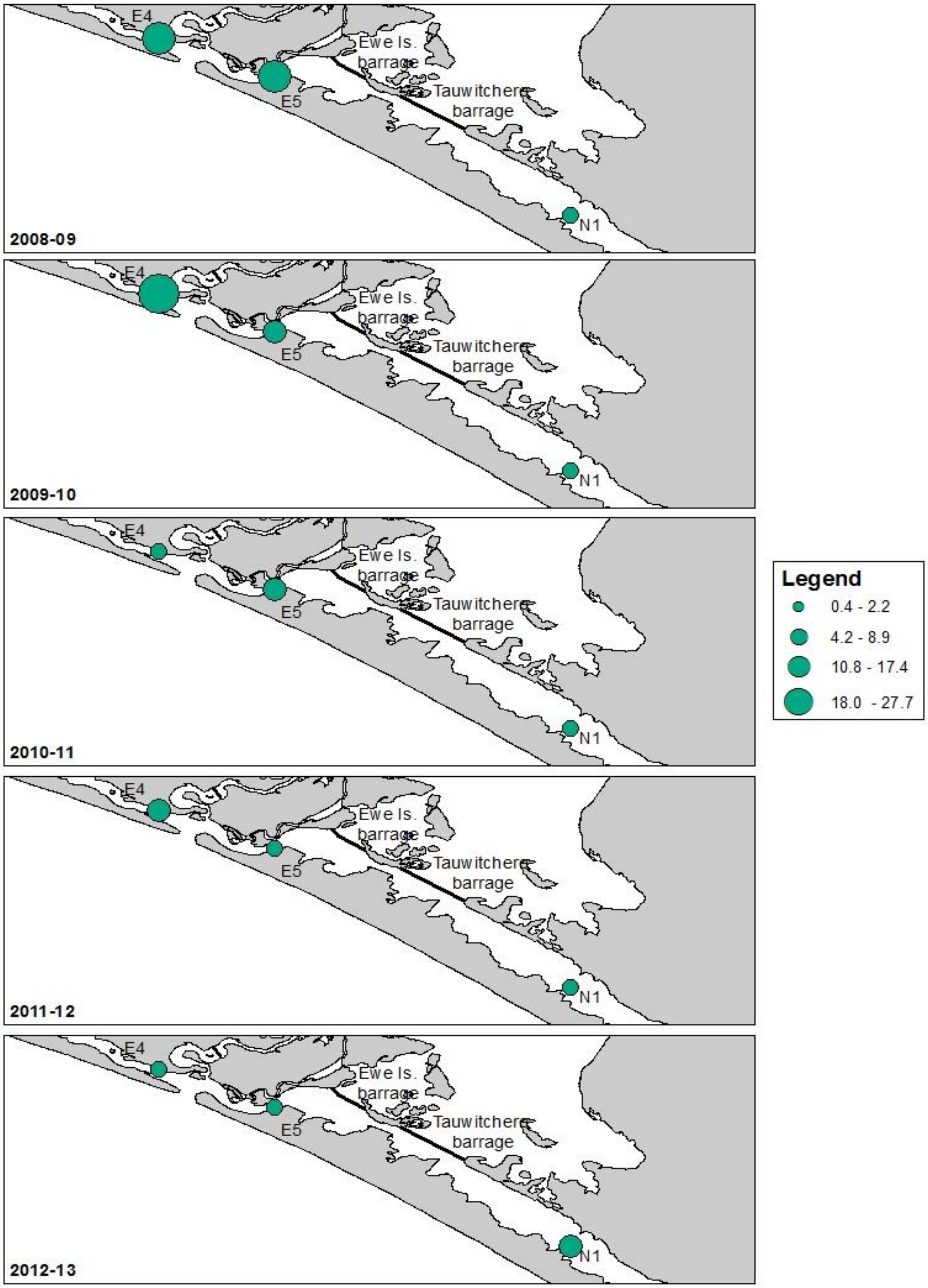


Figure 3.16. Coorong map showing relative abundance and distribution of juvenile greenback flounder from 2008/09 to 2012/13 (top to bottom).

Length frequency distributions of juvenile fish from the three sites combined are presented in Figure 3.17. The size of fish ranged from 20 to 170 mm TL. The presence of small juvenile flounder (<80 mm TL) in each year indicated that recruitment had occurred annually over the last five years in the Coorong. In the years post-flood (since 2010/11), the size distribution in January was dominated by larger fish compared to the previous drought years, although sample sizes were small in some years. It was also noted that the dominant size of new recruits sampled in November in 2011/12 and 2012/13 was ~20 mm TL larger than those sampled in 2010/11 (Figure 3.17).

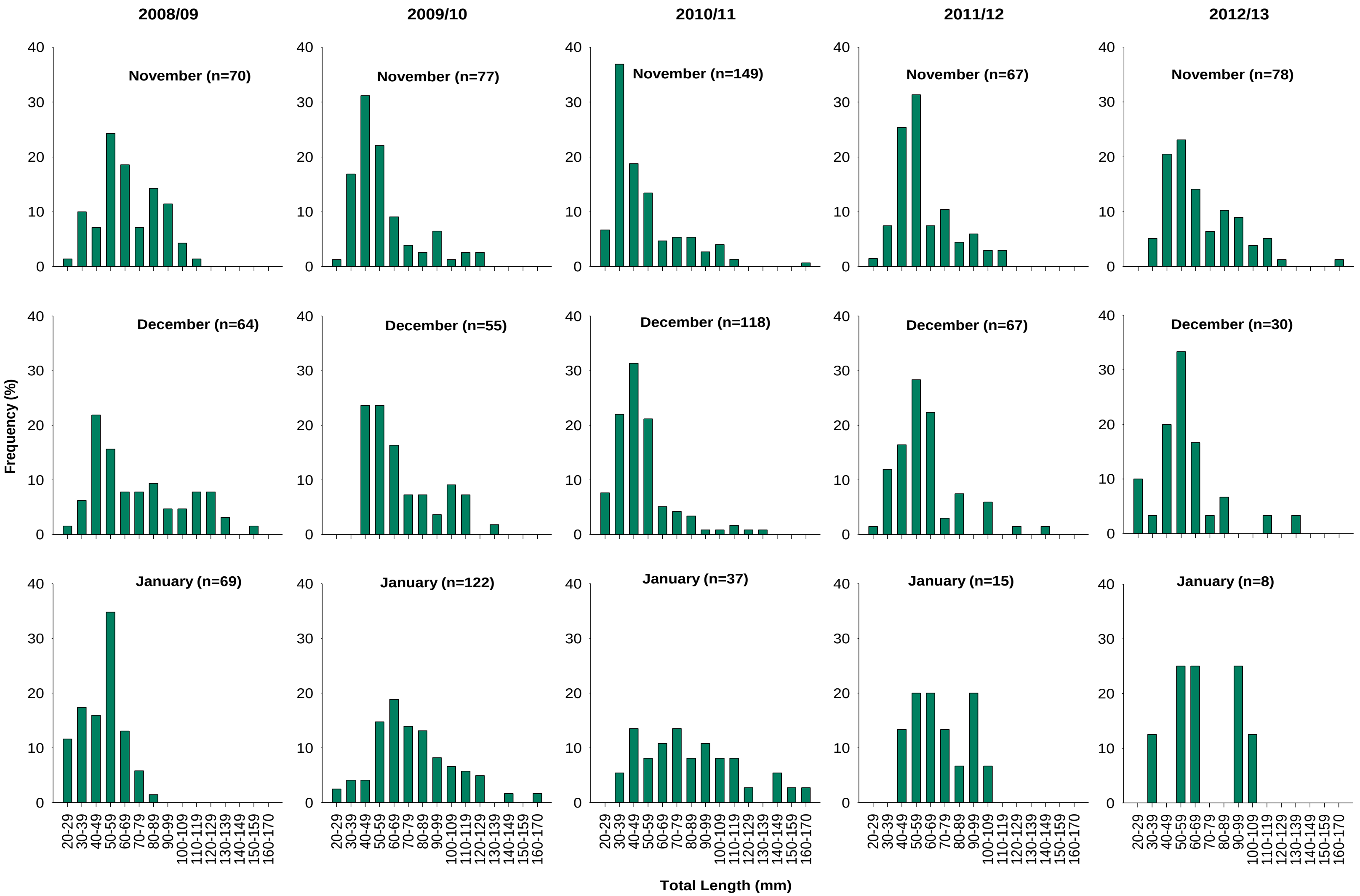


Figure 3.17. Length frequency distributions of juvenile greenback flounder from seine net samples in the Murray Estuary and Coorong from November to January between 2008/09 and 2012/13.

3.5 Smallmouthed Hardyhead

3.5.1 Abundance and distribution

The overall abundance of smallmouthed hardyhead in 2012/13 remained similar to 2011/12 (Table 3.9, Figure 3.18). A significant interaction (p=0.001) when comparing CPUE amongst years (2008/09-2012/13) across sites in the North Lagoon (Mark Point, Noonameena and Hells Gate) and the South Lagoon (Jack Point, Salt Creek and Salt Creek inside creek) indicated that the spatiotemporal pattern varied (Table 3.10).

Pairwise comparisons detected significant differences in abundance amongst years at all sites (Table 3.11). At Mark Point and Noonameena, the most significant increase of CPUE occurred from 2008/09 to 2009/10; the CPUE maintained at a relatively high level during 2010/11 and 2011/12, but declined in 2012/13 although the reduction was not statistically significant at Noonameena. At Hells Gate, Jack Point and Salt Creek, CPUE generally showed a significant increase from the drought (2008/09-2009/10) to the flood/high flow years (2010/11-2012/13), with further increases at these sites in 2011/12 or 2012/13. At Salt Creek inside creek, there was a significant decrease in CPUE from 2009/10 to 2010/11, followed by a recovery in 2011/12 and a substantial increase (> four times 2011/12) in 2012/13.

Pairwise comparisons also revealed a significant spatial difference in smallmouthed hardyhead abundance in each year (Table 3.12). During the drought years (2008/09 and 2009/10), CPUE at Noonameena was significantly greater than most of the other sites. In 2010/11, CPUE at both Noonameena and Hells Gate were significantly greater than Jack Point and Salt Creek inside creek. In the last two years, the main spatial difference was attributed to significantly lower CPUE at Mark Point, the most northern site, than at southern sites in the Coorong. In 2012/13, there appeared to be a general reduction in CPUE of this species in the North Lagoon, with an increase in the South Lagoon, when compared to 2011/12 (Figure 3.18).

Table 3.9. Catch per unit effort (CPUE) for smallmouthed hardyhead using standard seine net in the North and South lagoons of the Coorong from 2008/09 to 2012/13.

CPUE (fish per net.shot)	**2008/09**		**2009/10**		**2010/11**		**2011/12**		**2012/13**	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Mark Point	2.3	1.9	176.0	48.6	120.0	33.2	137.3	54.4	11.5	4.9
Noonameena	248.0	37.6	1057.0	259.2	1029.8	604.4	1043.8	358.6	442.1	162.2
Hells Gate	1.8	1.2	0.1	0.1	252.3	78.0	1013.8	266.6	776.7	141.8
Jack Point	0.0	0.0	0.4	0.3	38.3	15.4	931.7	169.1	1087.0	469.5
Salt Creek	0.4	0.4	79.7	30.1	168.1	60.3	742.5	131.5	405.0	100.9
Salt Creek inside creek	182.0	61.0	256.7	38.1	50.1	13.0	269.6	68.4	1251.3	666.6
Average across sites	**56.8**	**14.7**	**261.6**	**61.3**	**276.4**	**106.7**	**689.8**	**91.4**	**662.3**	**145.5**

Table 3.10. PERMANOVA results for CPUE of smallmouthed hardyhead (samples from standard seine net), comparison amongst years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

Source	df	MS	P(perm)
Year	4	88.668	**0.001**
Site	5	50.081	**0.001**
Year x Site	20	22.212	**0.001**

Table 3.11. PERMANOVA pairwise test factor level year, results for CPUE of smallmouthed hardyhead (samples from standard seine net), comparison amongst years for each site in the North and South lagoons of the Coorong. Bold *p* values are significant (FDR B-Y corrected *p*=0.00877 for 135 pairs).

Mark Point	Groups	t	P(perm)
	2008/09 x 2009/10	3.7565	**0.004**
	2008/09 x 2010/11	8.8304	**0.001**
	2008/09 x 2011/12	3.8083	**0.001**
	2008/09 x 2012/13	1.9016	0.092
	2009/10 x 2010/11	0.70986	0.475
	2009/10 x 2011/12	0.33185	0.716
	2009/10 x 2012/13	2.3671	0.025
	2010/11 x 2011/12	1.2682	0.197
	2010/11 x 2012/13	5.0482	**0.001**
	2011/12 x 2012/13	2.2153	0.037
Noonameena	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	3.8471	**0.001**
	2008/09 x 2010/11	1.2325	0.258
	2008/09 x 2011/12	1.6218	0.132
	2008/09 x 2012/13	0.49644	0.642
	2009/10 x 2010/11	1.1597	0.253
	2009/10 x 2011/12	0.8072	0.461
	2009/10 x 2012/13	2.7315	0.016
	2010/11 x 2011/12	0.29101	0.755
	2010/11 x 2012/13	1.282	0.195
	2011/12 x 2012/13	1.5742	0.137
Hells Gate	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	2.0403	0.108
	2008/09 x 2010/11	8.7805	**0.001**
	2008/09 x 2011/12	10.058	**0.001**
	2008/09 x 2012/13	14.855	**0.001**
	2009/10 x 2010/11	11.782	**0.001**
	2009/10 x 2011/12	12.029	**0.001**
	2009/10 x 2012/13	20.323	**0.001**
	2010/11 x 2011/12	3.0495	**0.008**
	2010/11 x 2012/13	4.0062	**0.001**
	2011/12 x 2012/13	0.11187	0.9
Jack Point	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	1.4577	0.454
	2008/09 x 2010/11	4.3264	**0.001**
	2008/09 x 2011/12	15.698	**0.001**
	2008/09 x 2012/13	7.605	**0.001**
	2009/10 x 2010/11	3.5751	**0.007**
	2009/10 x 2011/12	13.948	**0.001**
	2009/10 x 2012/13	7.0926	**0.001**
	2010/11 x 2011/12	7.0540	**0.001**
	2010/11 x 2012/13	4.1269	**0.002**
	2011/12 x 2012/13	0.89385	0.358

Salt Creek	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	3.7428	**0.007**
	2008/09 x 2010/11	5.4332	**0.001**
	2008/09 x 2011/12	18.394	**0.001**
	2008/09 x 2012/13	13.166	**0.001**
	2009/10 x 2010/11	1.153	0.247
	2009/10 x 2011/12	5.7614	**0.001**
	2009/10 x 2012/13	4.0028	**0.001**
	2010/11 x 2011/12	4.4118	**0.001**
	2010/11 x 2012/13	2.6697	0.015
	2011/12 x 2012/13	2.302	0.034
Salt Creek inside creek	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	0.58775	0.579
	2008/09 x 2010/11	2.5427	0.028
	2008/09 x 2011/12	0.46769	0.667
	2008/09 x 2012/13	1.6902	0.128
	2009/10 x 2010/11	4.8868	**0.001**
	2009/10 x 2011/12	9.48E-02	0.925
	2009/10 x 2012/13	2.6799	**0.006**
	2010/11 x 2011/12	4.5264	**0.001**
	2010/11 x 2012/13	5.5725	**0.001**
	2011/12 x 2012/13	2.6785	**0.006**

Table 3.12. PERMANOVA pairwise test factor level site, results for CPUE of smallmouthed hardyhead (samples from standard seine net), comparison amongst sites in the North and South lagoons of the Coorong for each year. Bold *p* values are significant (FDR B-Y corrected *p*=0.00877for 135 pairs).

2008/09	Groups	t	P(perm)
	Mark Point x Noonameena	13.292	**0.001**
	Mark Point x Hells Gate	0.75911	0.496
	Mark Point x Jack Point	1.4526	0.454
	Mark Point x Salt Creek	0.74363	0.753
	Mark Point x Salt Creek inside creek	7.2381	**0.003**
	Noonameena x Hells Gate	12.818	**0.001**
	Noonameena x Jack Point	23.59	**0.001**
	Noonameena x Salt Creek	18.163	**0.001**
	Noonameena x Salt Creek inside creek	0.72909	0.474
	Hells Gate x Jack Point	2.6198	0.036
	Hells Gate x Salt Creek	1.7044	0.132
	Hells Gate x Salt Creek inside creek	7.038	**0.003**
	Jack Point x Salt Creek	1	1
	Jack Point x Salt Creek inside creek	27.182	**0.005**
	Salt Creek x Salt Creek inside creek	12.038	**0.004**
2009/10	Groups	t	P(perm)
	Mark Point x Noonameena	4.0699	**0.001**
	Mark Point x Hells Gate	4.3462	**0.004**
	Mark Point x Jack Point	4.071	**0.001**
	Mark Point x Salt Creek	0.85013	0.384
	Mark Point x Salt Creek inside creek	2.0444	0.06
	Noonameena x Hells Gate	14.624	**0.001**
	Noonameena x Jack Point	13.672	**0.001**
	Noonameena x Salt Creek	5.6977	**0.001**
	Noonameena x Salt Creek inside creek	3.6867	**0.003**
	Hells Gate x Jack Point	0.73099	0.721
	Hells Gate x Salt Creek	3.8956	**0.003**
	Hells Gate x Salt Creek inside creek	17.161	**0.001**
	Jack Point x Salt Creek	3.5621	**0.002**
	Jack Point x Salt Creek inside creek	14.866	**0.001**
	Salt Creek x Salt Creek inside creek	3.6249	**0.001**
2010/11	Groups	t	P(perm)
	Mark Point x Noonameena	2.5346	0.011
	Mark Point x Hells Gate	1.5624	0.129
	Mark Point x Jack Point	3.1278	**0.006**
	Mark Point x Salt Creek	0.5899	0.554
	Mark Point x Salt Creek inside creek	2.1104	0.043
	Noonameena x Hells Gate	1.5226	0.139
	Noonameena x Jack Point	4.3084	**0.001**
	Noonameena x Salt Creek	2.5238	0.02
	Noonameena x Salt Creek inside creek	3.6541	**0.001**
	Hells Gate x Jack Point	4.1015	**0.001**
	Hells Gate x Salt Creek	1.6057	0.136

	Hells Gate x Salt Creek inside creek	3.4119	**0.004**
	Jack Point x Salt Creek	1.8033	0.091
	Jack Point x Salt Creek inside creek	1.6141	0.134
	Salt Creek x Salt Creek inside creek	0.71507	0.473
2011/12	Groups	t	P(perm)
	Mark Point x Noonameena	3.2748	**0.007**
	Mark Point x Hells Gate	4.3442	**0.002**
	Mark Point x Jack Point	4.8249	**0.001**
	Mark Point x Salt Creek	4.9005	**0.001**
	Mark Point x Salt Creek inside creek	2.6949	0.013
	Noonameena x Hells Gate	0.49442	0.6
	Noonameena x Jack Point	0.64648	0.51
	Noonameena x Salt Creek	0.3797	0.706
	Noonameena x Salt Creek inside creek	1.6219	0.125
	Hells Gate x Jack Point	0.14633	0.876
	Hells Gate x Salt Creek	0.23825	0.824
	Hells Gate x Salt Creek inside creek	2.8181	0.009
	Jack Point x Salt Creek	0.46767	0.615
	Jack Point x Salt Creek inside creek	3.4848	**0.006**
	Salt Creek x Salt Creek inside creek	3.7004	**0.003**
2012/13	Groups	t	P(perm)
	Mark Point x Noonameena	3.9916	**0.002**
	Mark Point x Hells Gate	10.155	**0.001**
	Mark Point x Jack Point	5.1869	**0.001**
	Mark Point x Salt Creek	7.3092	**0.001**
	Mark Point x Salt Creek inside creek	7.4399	**0.001**
	Noonameena x Hells Gate	2.5761	0.016
	Noonameena x Jack Point	1.2728	0.209
	Noonameena x Salt Creek	1.0048	0.339
	Noonameena x Salt Creek inside creek	2.2648	0.016
	Hells Gate x Jack Point	0.75113	0.461
	Hells Gate x Salt Creek	2.4832	0.028
	Hells Gate x Salt Creek inside creek	0.14853	0.899
	Jack Point x Salt Creek	0.62904	0.537
	Jack Point x Salt Creek inside creek	0.74543	0.472
	Salt Creek x Salt Creek inside creek	1.8505	0.078

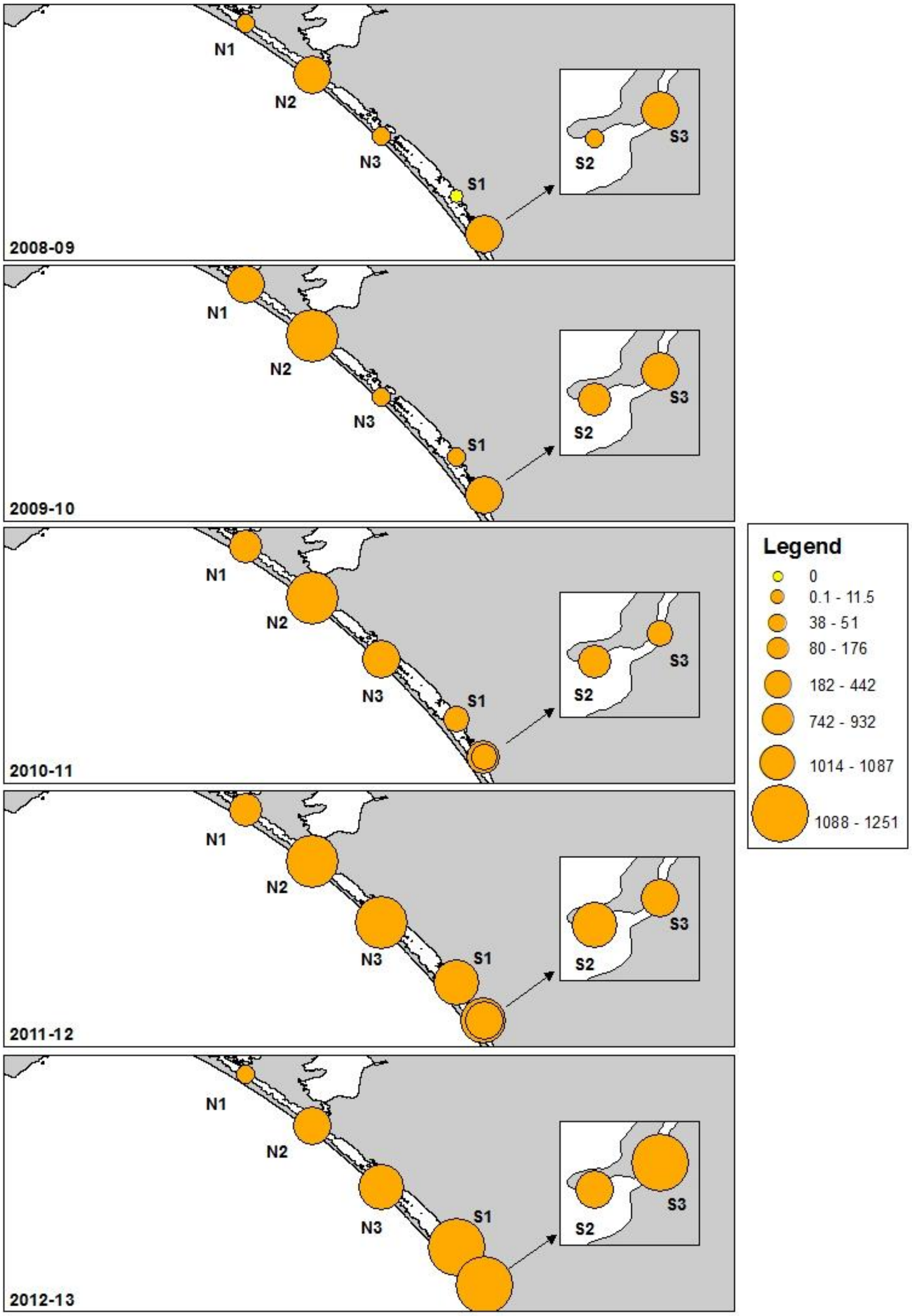


Figure 3.18. Coorong map showing relative abundance and distribution of smallmouthed hardyhead sampled using standard seine net from 2008/09 to 2012/13 (top to bottom). Inset map shows Salt Creek and Salt Creek inside creek sites.

3.5.2 Size structure

The length frequency distributions of smallmouthed hardyhead collected by both gear types from the North and South Lagoons throughout the sampling months are presented in Figure 3.19 and Figure 3.20, respectively. In the North Lagoon, fish size generally ranged from 10 to 100 mm TL. Modal progression was evident between months for small seine net samples in all years, except for 2008/09. There appeared to be a reduction in abundance of larger fish from December to February; however, it varied throughout the study years. In 2012/13, there was a distinct modal progression in small seine net samples from 10-19 mm in November to 20-29 mm in December; subsequently a size mode increase was evident in standard seine net samples from 20-29 mm in December to 30-39 mm in January. The presence of smaller fish (<39 mm) throughout the sampling months suggested recruitment success and a protracted spawning season.

In the South Lagoon, fish size ranged from 10 to 89 mm TL in most years, except in January 2013, some larger individuals were collected (90-100 mm). The 2008/09 data were patchy given the low abundance of smallmouthed hardyhead present within the lagoon; the size structure was mostly represented by samples from Salt Creek inside creek in February. It should be noted that sampling only commenced at this site in February 2009. Since 2009/10, modal progression between months has been detected either in standard seine net or small seine net samples in most years. There appeared to be a reduction in abundance of larger fish from December to February, however, the pattern varied between years.

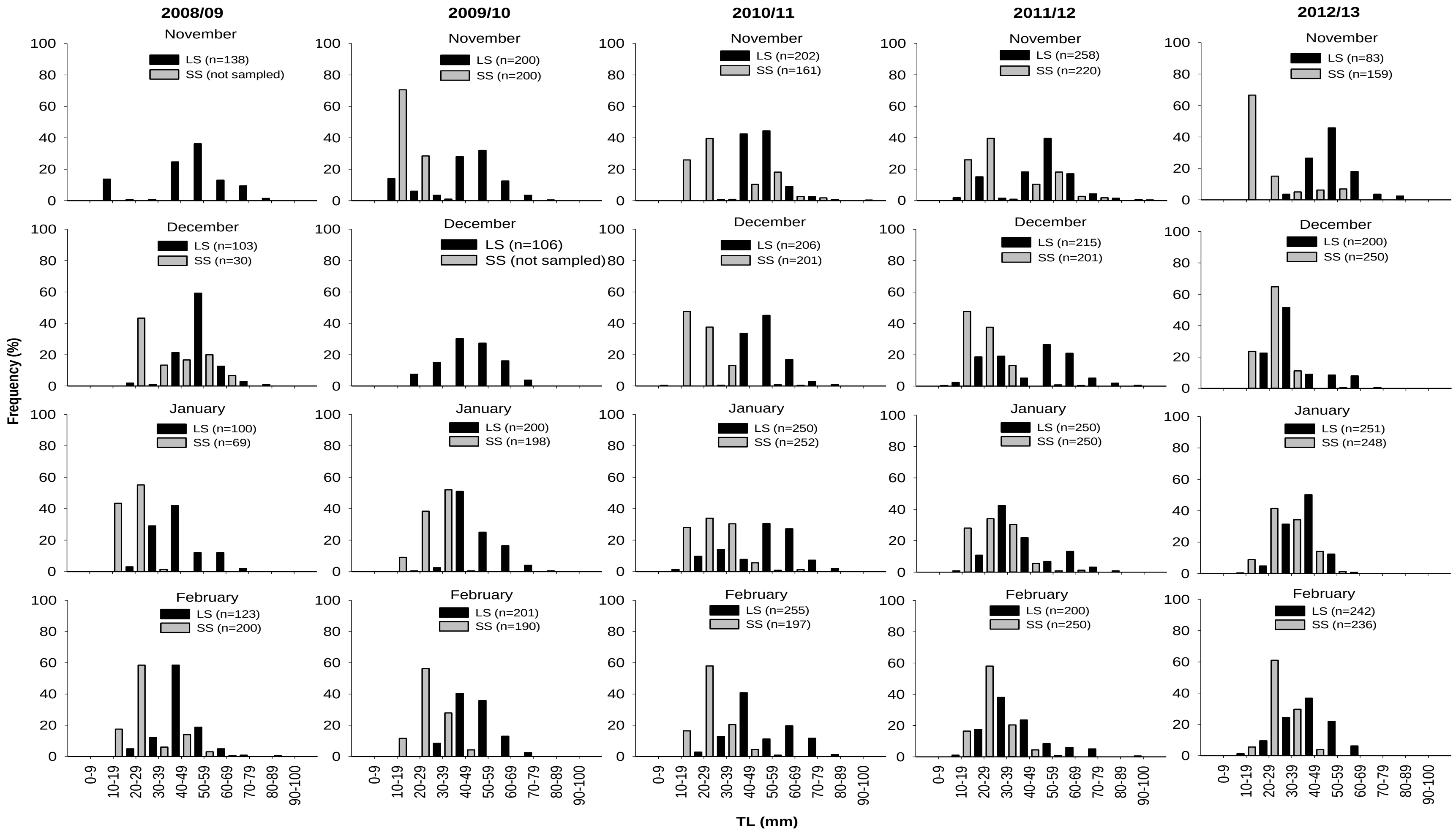


Figure 3.19. Length frequency distributions of smallmouthed hardyhead from standard (LS) and small (SS) seine nets in the North Lagoon sites from November to February between 2008/09 and 2012/13.

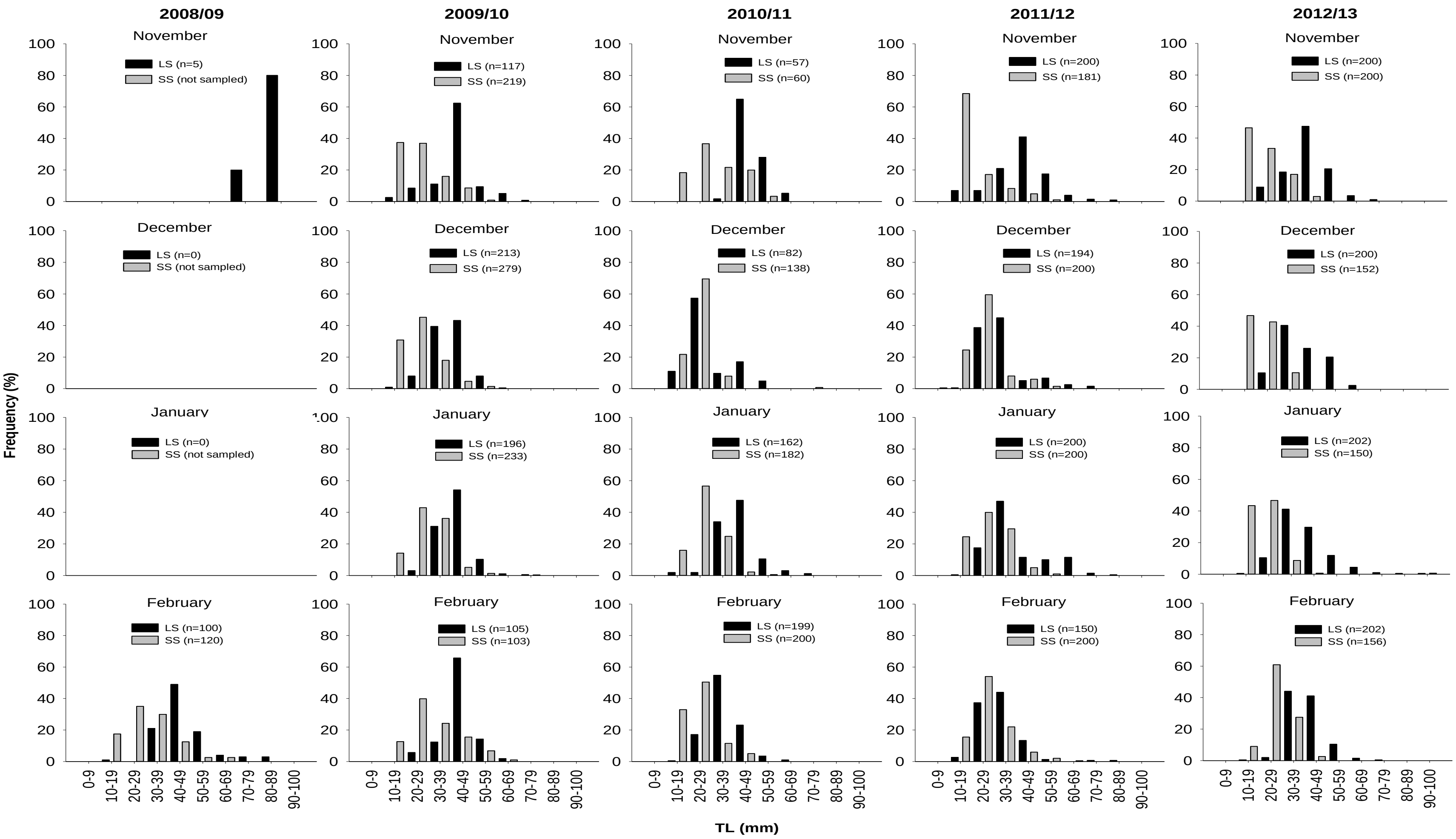


Figure 3.20. Length frequency distributions of smallmouthed hardyhead from standard (LS) and small (SS) seine nets in the South Lagoon sites from November to February between 2008/09 and 2012/13.

3.5.3 Recruitment

There were consistent and substantial increases in juvenile abundance of smallmouthed hardyhead over the first four study years in the North and South Lagoons of the Coorong, while a reduction occurred in 2012/13, particularly at the northern sites (i.e. Mark Point and Noonameena) (Table 3.13, Figure 3.21). A significant interaction (*p*=0.001) was detected when comparing CPUE of juvenile smallmouthed hardyhead amongst years across sites (Table 3.14), indicating that the spatiotemporal pattern was not consistent in all years and sites.

Pairwise comparisons detected significant temporal variation at each site (Table 3.15). In particular, CPUE increased significantly from 2008/09 to 2009/10 at Mark Point, and was then maintained at a similar level in the following two years before decreasing significantly in 2012/13. At Noonameena, Hells Gate and Jack Point, a significant increase in juvenile CPUE occurred between 2009/10 and 2010/11; and a further increase occurred at Jack Point in 2011/12, whilst CPUE remained similar to 2010/11 at the other two sites.

In 2012/13 there was a significant reduction in CPUE at Noonameena but not the other two sites. At Salt Creek, the most significant increase in CPUE was in 2011/12 compared to previous years, but CPUE declined significantly in 2012/13 although the level was still significantly higher than that of the drought year (2009/10).

At Salt Creek inside creek, CPUE of juveniles was exceptionally high in 2009/10, which was significantly different compared to the rest of study years; CPUE showed a significant decline in 2012/13 relative to 2010/11 and 2011/12. Pairwise comparisons also revealed a significant spatial difference in all years except 2008/09 although small seine netting was only conducted at three sites during this first sampling year (Table 3.16). In the last three years, there appeared to a southward shift in the peak of proportional abundance of new recruits in the Coorong (Table 3.13, Figure 3.21).

Table 3.13. Catch per unit effort (CPUE) for juvenile smallmouthed hardyhead using small seine net in the North and South Lagoons of the Coorong from 2008/09 to 2011/12.

CPUE (fish per net.shot)	2008/09		2009/10		2010/11		2011/12		2012/13	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Mark Point	114.3	43.6	396.9	46.0	407.9	166.4	316.7	105.5	95.3	24.7
Noonameena	175.3	41.1	195.9	28.3	2541.7	808.9	2598.3	992.6	145.3	43.4
Hells Gate			0.3	0.2	1122.1	288.3	1676.7	374.4	816.7	120.5
Jack Point			8.8	3.8	72.6	14.5	794.8	196.2	556.7	204.3
Salt Creek			238.0	129.3	290.5	60.8	2065.8	325.7	863.3	239.5
Salt Creek inside creek	59.0	18.2	520.0	75.8	60.0	12.9	82.7	23.9	15.3	12.3
Average across sites	116.2	24.7	220.3	36.3	749.1	175.2	1255.8	212.3	451.8	73.0

Table 3.14. PERMANOVA results for CPUE of juvenile smallmouthed hardyhead, comparison amongst years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

Source	df	MS	P(perm)
Year	4	5633.8	**0.001**
Site	5	2382.2	**0.001**
YearxSite	17	3686.6	**0.001**

Table 3.15. PERMANOVA pair-wise test factor level year, results for CPUE of juvenile smallmouthed hardyhead (samples from small seine net), comparison amongst years for each site in the North and South lagoons of the Coorong. Bold *p* values are significant (FDR B-Y corrected *p*=0.009083 for 111 pairs).

Mark Point	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	4.4463	**0.005**
	2008/09 x 2010/11	0.96716	0.379
	2008/09 x 2011/12	0.5076	0.653
	2008/09 x 2012/13	0.7182	0.543
	2009/10 x 2010/11	1.1194	0.274
	2009/10 x 2011/12	1.6628	0.092
	2009/10 x 2012/13	4.6227	**0.001**
	2010/11 x 2011/12	0.57062	0.569
	2010/11 x 2012/13	2.5199	0.019
	2011/12 x 2012/13	1.7473	0.079
Noonameena	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	0.23898	0.796
	2008/09 x 2010/11	2.5234	0.022
	2008/09 x 2011/12	1.6628	0.098
	2008/09 x 2012/13	0.879	0.425
	2009/10 x 2010/11	4.2742	**0.002**
	2009/10 x 2011/12	2.8224	0.011
	2009/10 x 2012/13	1.6589	0.116
	2010/11 x 2011/12	0.49386	0.664
	2010/11 x 2012/13	5.3194	**0.001**
	2011/12 x 2012/13	3.8835	**0.001**
Hells Gate	**Groups**	**t**	**P(perm)**
	2009/10 x 2010/11	8.833	**0.001**
	2009/10 x 2011/12	14.147	**0.001**
	2009/10 x 2012/13	18.997	**0.001**
	2010/11 x 2011/12	1.4371	0.165
	2010/11 x 2012/13	0.18518	0.853
	2011/12 x 2012/13	1.8854	0.075
Jack Point	**Groups**	**t**	**P(perm)**
	2009/10 x 2010/11	3.8614	**0.004**
	2009/10 x 2011/12	7.8432	**0.001**
	2009/10 x 2012/13	7.8828	**0.001**
	2010/11 x 2011/12	4.5925	**0.001**
	2010/11 x 2012/13	4.2418	**0.001**
	2011/12 x 2012/13	0.78954	0.447

Salt Creek	**Groups**	**t**	**P(perm)**
	2009/10 x 2010/11	1.4681	0.153
	2009/10 x 2011/12	6.0476	**0.001**
	2009/10 x 2012/13	3.3832	**0.004**
	2010/11 x 2011/12	6.0961	**0.001**
	2010/11 x 2012/13	2.4729	0.027
	2011/12 x 2012/13	3.3496	**0.004**
Salt Creek inside creek	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	4.3923	**0.003**
	2008/09 x 2010/11	0.24709	0.808
	2008/09 x 2011/12	3.56E-02	0.971
	2008/09 x 2012/13	2.2392	0.087
	2009/10 x 2010/11	7.6738	**0.001**
	2009/10 x 2011/12	6.0964	**0.002**
	2009/10 x 2012/13	7.9532	**0.001**
	2010/11 x 2011/12	0.22708	0.829
	2010/11 x 2012/13	3.7670	**0.003**
	2011/12 x 2012/13	3.2751	**0.004**

Table 3.16. PERMANOVA pair-wise test factor level site, results for CPUE of juvenile smallmouthed hardyhead (samples from small seine net), comparison amongst sites in the North and South lagoons of the Coorong for each year. Bold *p* values are significant (FDR B-Y corrected *p*=0.009083 for 111 pairs).

2008/09	Groups	t	P(perm)
	Mark Point x Noonameena	1.0851	0.324
	Mark Point x Salt Creek inside creek	1.2656	0.32
	Noonameena x Salt Creek inside creek	2.8276	0.108

2009/10	Groups	t	P(perm)
	Mark Point x Noonameena	3.7294	**0.001**
	Mark Point x Salt Creek inside creek	0.82644	0.407
	Mark Point x Hells Gate	21.176	**0.001**
	Mark Point x Jack Point	9.3807	**0.001**
	Mark Point x Salt Creek	2.5625	0.024
	Noonameena x Salt Creek inside creek	3.525	**0.006**
	Noonameena x Hells Gate	16.236	**0.001**
	Noonameena x Jack Point	7.2116	**0.001**
	Noonameena x Salt Creek	1.4471	0.171
	Salt Creek inside creek x Hells Gate	17.505	**0.001**
	Salt Creek inside creek x Jack Point	10.035	**0.001**
	Salt Creek inside creek x Salt Creek	3.1981	**0.004**
	Hells Gate x Jack Point	2.0312	0.057
	Hells Gate x Salt Creek	4.078	**0.001**
	Jack Point x Salt Creek	2.6663	0.013

2010/11	Groups	t	P(perm)
	Mark Point x Noonameena	3.8025	**0.002**
	Mark Point x Salt Creek inside creek	3.2146	**0.005**
	Mark Point x Hells Gate	1.8209	0.075
	Mark Point x Jack Point	2.8428	**0.007**
	Mark Point x Salt Creek	0.44629	0.657
	Noonameena x Salt Creek inside creek	6.7032	**0.001**
	Noonameena x Hells Gate	1.7302	0.105
	Noonameena x Jack Point	6.2117	**0.001**
	Noonameena x Salt Creek	4.1281	**0.001**
	Salt Creek inside creek x Hells Gate	4.4497	**0.001**
	Salt Creek inside creek x Jack Point	0.17199	0.881
	Salt Creek inside creek x Salt Creek	2.5701	0.02
	Hells Gate x Jack Point	4.1448	**0.002**
	Hells Gate x Salt Creek	2.1669	0.038
	Jack Point x Salt Creek	2.3087	0.034

2011/12	Groups	t	P(perm)
	Mark Point x Noonameena	2.937	**0.005**
	Mark Point x Salt Creek inside creek	1.923	0.067
	Mark Point x Hells Gate	4.3412	**0.003**
	Mark Point x Jack Point	2.1846	0.036
	Mark Point x Salt Creek	5.96	**0.001**
	Noonameena x Salt Creek inside creek	4.4534	**0.001**
	Noonameena x Hells Gate	8.31E-02	0.932

	Noonameena x Jack Point	1.408	0.18
	Noonameena x Salt Creek	0.78189	0.434
	Salt Creek inside creek x Hells Gate	7.3659	**0.001**
	Salt Creek inside creek x Jack Point	4.6448	**0.001**
	Salt Creek inside creek x Salt Creek	10.421	**0.001**
	Hells Gate x Jack Point	2.1604	0.038
	Hells Gate x Salt Creek	1.091	0.283
	Jack Point x Salt Creek	3.5253	**0.007**
2012/13	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	0.3738	0.715
	Mark Point x Salt Creek inside creek	2.9174	0.015
	Mark Point x Hells Gate	6.6626	**0.001**
	Mark Point x Jack Point	3.8882	**0.003**
	Mark Point x Salt Creek	4.7555	**0.001**
	Noonameena x Salt Creek inside creek	2.7789	0.018
	Noonameena x Hells Gate	5.2739	**0.001**
	Noonameena x Jack Point	3.0965	**0.004**
	Noonameena x Salt Creek	3.9545	**0.001**
	Salt Creek inside creek x Hells Gate	9.0025	**0.001**
	Salt Creek inside creek x Jack Point	5.8101	**0.001**
	Salt Creek inside creek x Salt Creek	6.1673	**0.001**
	Hells Gate x Jack Point	1.9373	0.068
	Hells Gate x Salt Creek	0.47977	0.621
	Jack Point x Salt Creek	1.1197	0.286

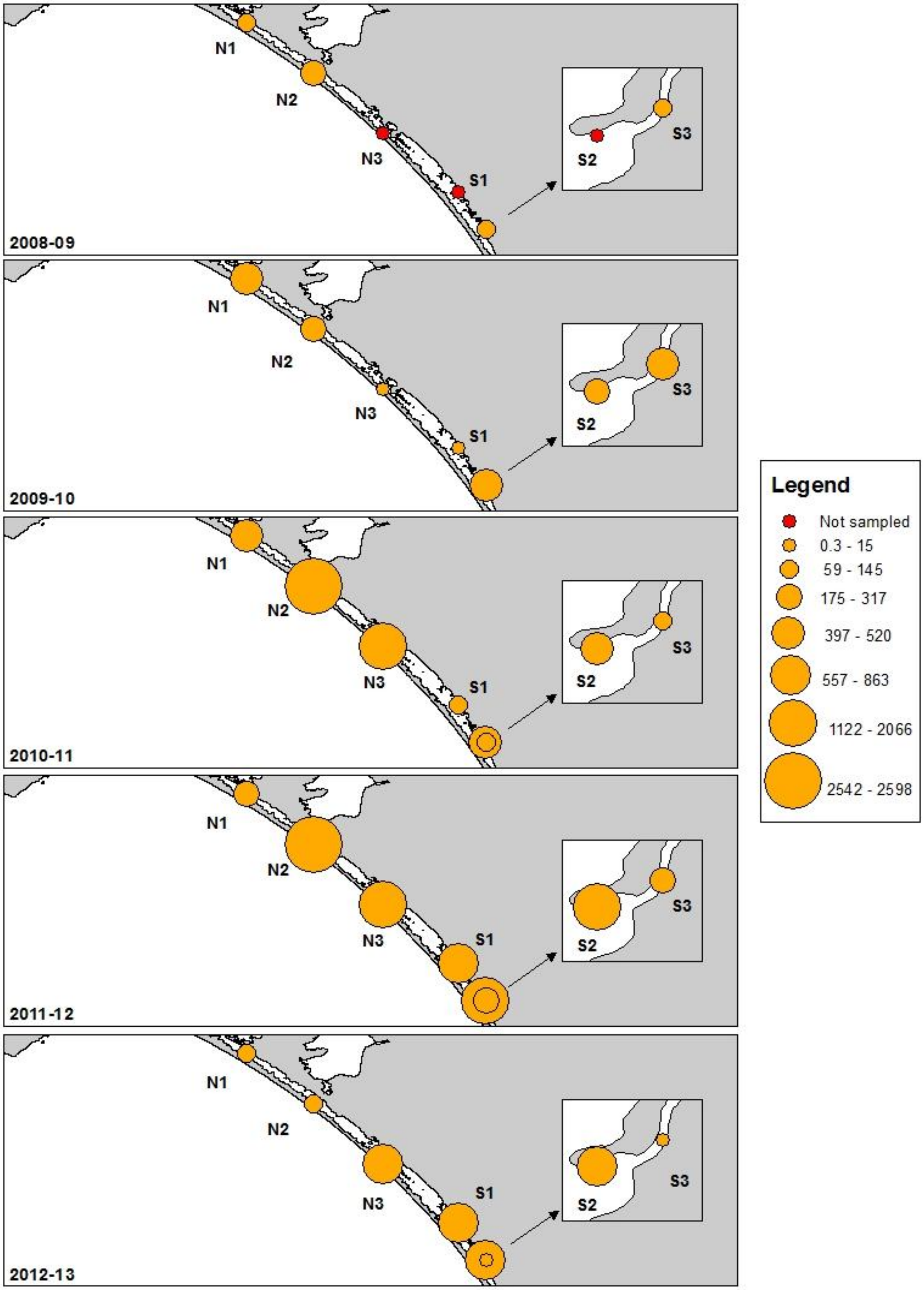


Figure 3.21. Coorong map showing relative abundance and distribution of juvenile smallmouthed hardyhead sampled using small seine net from 2008/09 to 2012/13 (top to bottom). Inset map shows Salt Creek and Salt Creek inside creek sites.

4 DISCUSSION

4.1 Freshwater inflow and salinity

Over a ten year period (2001-2010), extensive drought in the Murray–Darling Basin (MDB), combined with river regulation and water extraction, resulted in a significant reduction in annual freshwater flow to the Coorong, with annual discharge <1000 GL y^{-1} and a period of zero discharge between 2007/08 and 2009/10. Following increased rainfall in the MDB and significantly increased flow in the River Murray, the Lower Lakes refilled and freshwater releases to the Coorong in 2010/11 were amongst the highest (~13000 GL y^{-1}) for the last 28 years. In 2011/12 and 2012/13, there was a reduction in flow; however, it remained above the average level (~4000 GL y^{-1}) since 1984/85.

Salinities in the Coorong are highly variable, mainly driven by freshwater flows from the River Murray and tidal seawater exchange through the Murray Mouth (Geddes and Butler 1984). There is typically a strong north to south gradient with increasing salinities. During a previous fish assemblage study in the Coorong (2006-2008) (Noell *et al.* 2009), and the first two years (2008/09 and 2009/10) of the TLM Coorong fish condition monitoring, when there were no barrage releases, the Coorong essentially became a marine/hypersaline environment; salinities in the southern part of the North Lagoon exceeded 100 psu and those in the South Lagoon were about 3-4 times that of seawater (~140 psu). These salinities are higher than those recorded during the 1982 drought, when average salinities were 80 psu in the North Lagoon and 90-100 psu in the South Lagoon (Geddes and Butler 1984), and may represent the highest levels ever recorded for the Coorong. Increased salinities throughout the Murray Mouth and Coorong during the drought had a profound impact on fish assemblages in the region, with negative implications for several estuarine and diadromous species, including TLM target species: black bream, greenback flounder and congolli (Noell *et al.* 2009; Zampatti *et al.* 2010; Ye *et al.* 2012a).

With substantial freshwater inflows since September 2010, salinities have declined throughout the Coorong in the last three years, restoring fresh to brackish conditions to the Murray Estuary and an extended area of the North Lagoon, and salinities in the South Lagoon were reduced to <100 psu. Similarly, Geddes (1987) recorded a freshening of the Coorong in 1983/84, after drought, following a period of substantial flows from the River Murray; the North Lagoon became brackish (<30 psu) and the South Lagoon moderately hypersaline (55-70 psu). Following broadly decreased salinities and other freshwater induced environmental changes post 2010, there has been an increase in the diversity and abundance of estuarine and diadromous fish species, and many of them showed a southward range expansion in the Coorong (Ye *et al.* 2012a). In 2012/13, the flow to the Coorong was lower than that observed in the previous two flow years. The effects of the reduction in flow to salinity have already started to show, particularly in the Estuary subregion. This could potentially be caused by the intrusion of sea water when there was reduced freshwater flow through the Murray Mouth. In the North and South Lagoons, salinity was comparable to the previous two years, suggesting a potential lag in the response time in the southern part of the Coorong due to its distance from the mouth. If low flows into the Coorong continue, salinity in all the subregions is expected to increase, albeit at differential rates.

4.2 Black Bream

4.2.1 Abundance and distribution

The relative abundance of black bream, as indicated by commercial fishery catches, has declined substantially in the Murray Estuary and Coorong since 1984/85. The annual catch of this species dropped steeply from the mid to late 1980s, with a 92% reduction from the peak catch of 46.7 t in 1984/85 to 3.7 t in 1990/91. Since then, catches have remained less than 20% of the peak value, with the exception of 2002/03. Annual catches were historically low in 2008/09 (1.8 t) and 2009/10 (1.1 t), reflecting a substantial reduction in population abundance. Following barrage releases in 2010/11 and 2011/12, black bream catches showed a small increase, although remained low in an historical context (i.e. 2.3 t and 3 t), representing <7% of the historical peak in 1984/85 and <26% of a more recent peak in 2002/03. Corresponding to the catch increase from 2010/11 to 2011/12, there was an increase in CPUE, suggesting a potential increase in fish abundance. However, this needs to be interpreted with caution. For example, a combination of low catches and high CPUE during the recent decadal drought, suggests that CPUE ceased to be a meaningful estimate of relative abundance due to aggregation of black bream into smaller areas of favourable habitat. Therefore, interpretation of the fishery catch and CPUE data as a biological performance indicator of population abundance needs to consider a species' life history and likely response to environmental factors (King and McFarlance 2003), particularly in dynamic environments such as estuaries (Gillson *et al.* 2009).

Changes in the spatial distribution of commercial catches provided a useful indicator of changes in the distributional range of black bream along the Coorong. From the early 1990s to 2010/11, there was a contraction of the fishing ground from the North Lagoon to the Murray Estuary, and almost all black bream were harvested within the Estuary from 2005/06 to 2009/10. Notably, the contraction of fishing area occurred concurrent with consistent increases in mean annual CPUE from 1993/94 to 2007/08. This suggests an increase in catchability of black bream, as the population contracted into the reduced area of favourable habitat due to poor environmental conditions resulting from the recent extended drought. In 2010/11 and 2011/12, restoration of freshwater inflows freshened the Coorong and led to a substantial increase in proportional catch of black bream from the North Lagoon. An acoustic tagging study examining the movement and habitat use of black bream in the Murray Estuary and Coorong showed that the distributional range for this species increased during 2011/12 (high flow) relative to 2009/10 (drought) (Bice *et al.*, unpublished data). In 2009/10, a time of no freshwater inflow, tagged black bream resided primarily in the Estuary, while habitats south of Mark Point in the North Lagoon were rarely used. In contrast, in 2011/12 following several months of high freshwater discharge, numerous individuals expanded their range to southern parts of the North Lagoon, while some moved as far south as the South Lagoon. The fish intervention monitoring in the Coorong also demonstrated a similar extension of distributional range in this species (Ye *et al.* 2012a). This range extension likely reflected the increase in area of favourable salinities and associated conditions. This information further supports the conclusion that freshwater inflow plays a pivotal role in maintaining and extending favourable estuarine habitat for black bream in the Coorong.

4.2.2 Size and age structures

Black bream is a slow-growing, long-lived species with intermediate age of maturity and high fecundity, representing a periodic life history strategy within estuaries (Winemiller and Rose 1992; Norriss *et al.* 2002). Age structures for both females and males from 2007/08 were dominated by 4 and 10 year old fish, which persisted in the following years and were shown as 6 and 12 year olds in 2009/10, and 7 and 13 year olds in 2010/11, respectively. By 2011/12, a distinct 8 year old cohort of males was still present. These two strong cohorts originated from 2003/04, when there was an experimental barrage release of ~220 GL during spring (Geddes 2005), and 1997/98, when 682 GL of freshwater was discharged into the Coorong. The strong 1997/98 cohort was also identified in 2002 for the Coorong population, and was apparent in 2003 and 2004 (Ferguson and Ye 2008). Age structure in 2011/12 showed a new dominant year class from 2006/07, during which there was a low-volume (78 GL) barrage discharge between July and November 2006. In this study, despite the majority of adult samples coming from the commercial catches of gill nets, size and age structures are likely to accurately represent those of the population because the range of sizes was consistent across six study years, and two strong cohorts persisted in samples over multiple years (at least 9 years for 1997/98 cohort and 5 years for 2003/04 cohort).

Several studies have related recruitment success to freshwater inflows and associated factors, i.e. establishment of a favourable salinity gradient, maintenance of dissolved oxygen levels and increased larval food supply (Newton 1996; Norriss *et al.* 2002; Nicholson and Gunthorpe 2008). Notably, none of the barrage releases in 1997/98, 2003/04 or 2006/07 were major flow events, suggesting that the recruitment of black bream may benefit from small-scale inflows from the River Murray. While the influence of large-scale freshwater inflows (such as those entering the system during 2010/11) on recruitment of black bream remains to be seen and the mechanism is yet to be examined, there is evidence to suggest that the timing of flows, rather than volume, may be more important for successful recruitment of black bream. For instance, the small-scale barrage releases in 1997/98, 2003/04 and 2006/07 (all <700 GL), which coincided with the recruitment of the most dominant cohorts of the population during this study period, were all discharged into the system in late winter/spring. Given that black bream spawning in the Coorong typically occurs during spring/summer (Ye *et al.* 2013), such small volumes of freshwater entering the estuary in the months prior to the spawning and recruitment season may have enhanced biological productivity (i.e. food availability), reduced salinity levels in the Estuary and the upper North Lagoon, and improved habitat condition within the system, facilitating higher survival of eggs and larvae and ultimately recruitment success. A study in Western Australia also indicated that recruitment of juveniles was highest in moderate flow years (Hoeksema and Potter 2006). More recent studies in the southeastern estuaries found good recruitment events in black bream to occur during low flows compared to high flow/flood years (Greg Jenkins, unpublished data). Whilst it is likely that flow regime is important to facilitate recruitment success of black bream, additional research is required to determine the flow characteristics (i.e. timing, volume, duration) and other environmental factors and/or mechanisms that are critical for recruitment success of black bream in the Murray Estuary and Coorong.

Black bream has a life span of at least 29 years (Morison *et al.* 1998). The maximum age of black bream from the Coorong population reported in this study was 26 and 32 years for females and males, respectively. Nevertheless, few individuals (3%) more than 13 years old were present from 2007/08 to 2011/12. Such truncation of age structures has previously been reported for this population in 2002, 2003, 2004 and 2007 (Ferguson and Ye 2008). Given black bream typically complete their lifecycle within estuaries, the most likely explanation for the highly truncated age structures is that fishing, which removes older and larger individuals (Hilborn and Walters 1992; Planque *et al.* 2010; Walsh *et al.* 2010), has impacted this species (Sarre 2000; Ferguson and Ye 2008; Ye *et al.* 2012b; Ferguson *et al.* 2013). The commercial catch of black bream from the Coorong has also undergone a substantial reduction since the mid-1980s, reaching a historical low level in recent drought years without any distinct sign of recovery after the three high flow years. Truncated age structures indicate longevity overfishing, which suggests that capacity for egg production may be compromised (Beamish *et al.* 2006). Rebuilding and maintaining age structures is important for long-lived, environmentally-limited populations such as black bream. Such populations depend on infrequent strong year classes that originate from years when environmental conditions are favourable (Ferguson *et al.* 2013). This is important for the population in the Coorong where critical estuarine habitat has been severely impacted by the recent drought, recruitment success is uncertain even after the significant barrage releases in 2010/11-2012/13, potentially due to the constricted remnant population, and climate change predictions indicate further flow reduction (Hughes 2003).

4.2.3 Recruitment

The presence of YOY in the Murray Estuary (mostly below the Goolwa Barrage) and length frequency distributions of juveniles demonstrated successful recruitment of black bream in 2008/09 and 2009/10. However, the level of recruitment declined from 2008/09 to 2009/10, which was probably caused by environmental deterioration due to the continued lack of inflows to the Coorong. It has been suggested that black bream may depend on other environmental cues (e.g. temperature), as well as freshwater flows for successful spawning and recruitment (Hobday and Moran 1983; Norriss *et al.* 2002; Nicholson *et al.* 2008). Although there were no releases of freshwater to the Coorong from 2007/08 to 2009/10 (TLM Coorong fish condition monitoring commenced in 2008/09), some unintentional releases or leakage of freshwater had probably occurred at various times (most likely at Goolwa Barrage), which might have facilitated recruitment. Newton (1996) reported that aligning the timing of spawning with inflows and subsequent increased food supply for larval fish was likely an important part of the spawning strategy of black bream and may be a critical factor for recruitment success. In this regard, the lower level of recruitment in 2009/10 might have been partially attributed to the mismatch of incidental releases with the timing of spawning. In addition, the decline in population abundance may suggest a reduced spawning biomass, which has probably compromised recruitment capacity of this species.

Following significant flow releases, no new recruits (YOY) were found in 2010/11 and only four juveniles were collected in 2011/12 despite a substantial increase in sampling effort (145 fyke net.nights) across 28 sites along the Coorong (between Goolwa Barrage and Robs Point), suggesting no or low levels of recruitment. In 2012/13, a general increase in the abundance of juvenile black bream was a positive sign of recruitment success. Possible explanations for our failure to detect black bream juveniles in 2010/11 and 2011/12 are that the first two high flow events did not provide environmental conditions conducive to black bream recruitment in the Coorong or that reduced adult spawning biomass resulted in low recruitment output, in turn increasing the difficulty in detecting new recruits in 2010/11 and 2011/12. Interestingly, the strong cohort of 2006/07 would have increased reproductive capacity by 2012/13 (age at maturity females ≥ 4 years; males ≥ 3 years, Hall 1984), which in conjunction with appropriate flow-induced conditions, may have led to enhanced recruitment in black bream. Nevertheless, the results should be interpreted with caution because nil or low catches of juvenile black bream in 2010/11 and 2011/12 could also be an artifact of reduced sampling efficiency during the high flows (e.g. reduced fish density, dispersion or re-distribution, shifted location of favourable estuarine habitats). Fish sampling in 2012/13 was also more or less subject to such effects. Interestingly, adult black bream showed a southward range expansion into the North and South Lagoons following the flow events in 2010-12 compared to previous drought years (Ye *et al.* 2012a). If a reduction in sampling efficiency was the case, it is hypothesised that future fish monitoring would detect the 2010/11 and/or 2011/12 cohorts along with the 2012/13 cohort.

4.3 Greenback Flounder

4.3.1 Abundance and distribution

The relative abundance of greenback flounder, as indicated by fishery catches and CPUE, has declined substantially in the Murray Estuary and Coorong, particularly from 2000/01-2010/11. The annual catch peaked at 65.3 t in 1994/95 however, since 2002/03 the catches have dropped significantly. Annual catches were historically low between 2008/09 and 2010/11 ($\leq$1 t y^{-1}), suggesting very low abundance of harvestable sized fish (a legal minimum size of 25 cm TL for greenback flounder in SA). In 2011/12, the annual catch showed an increase to 29.6 t, well above the average (17 t y^{-1}) over the last 28 years; the CPUE also represented a historical peak since 1984/85. The increase in abundance was likely due to enhanced recruitment in this species following the high flows since 2010. Freshwater inflows have been suggested as one factor that may explain the variability in the abundance of greenback flounder in the Coorong (Hall 1984). Fishery catch generally provides a useful biological performance indicator for the abundance of greenback flounder however, CPUE is likely influenced by flow conditions and therefore needs to be interpreted with caution.

Spatially resolved fishery catches indicated extensive distribution and abundance of greenback flounder in the North Lagoon between 1984/85 and 2000/01. From 2001/02 to 2009/10, there was a significant reduction in freshwater inflow and a general increase in salinity in the Coorong, leading to a contraction of estuarine habitat. Consequently, the proportional catch of flounder from the Murray Estuary increased; by 2008/09 and 2009/10, almost all fishery catches (99%) were from the Estuary. The rise in CPUE in these two years, even when the biomass was low, can likely be attributed to an increase in catchability due to the range contraction as a result of increasing salinity throughout the North Lagoon. In 2010/11, although there were substantial inflows, fishery catches of flounder were still restricted to the Estuary, suggesting a low abundance of adult fish in the Coorong. Nevertheless, there was an increase in juvenile flounder abundance at multiple sites in the North Lagoon following the high flows in 2010/11 (Ye *et al.* 2012a), suggesting that flows may have had a positive influence on recruitment. Based on growth estimates (J. Earl, unpublished data) and age composition of the commercial catch of greenback flounder, this new cohort of juvenile fish would have most likely recruited to the fishery 12-18 months later. Subsequently, the considerable increases in catch and CPUE in 2011/12 were evident, with catches distributed throughout the North Lagoon (99% of total catch).

4.3.2 Size and age structures

Greenback flounder is a fast-growing species, and may attain >10 years of age; fish mature early at about one year old and fecundity is high (Kurth 1957; Crawford 1986; Sutton *et al.* 2010). The life history strategy of this species was suggested to be intermediate between an opportunist and periodic strategist (Ferguson *et al.* 2013). The maximum age reported in this study was 3 years for females and 4 years for males from the

Coorong population, although 98% of fish sampled were females. The dominance of females in samples has been reported previously for fishery catches from the Coorong (Ye *et al.* 2012b). Earlier studies suggested that greenback flounder partitioned the habitat by sex, and spawning aggregations of females formed in deeper habitats (Kurth 1957; Crawford 1984a). However, more recently, an acoustic monitoring study found that mature females were utilising both shallow flats and deeper channels/holes in the Murray Estuary and Coorong during the spawning season, indicating that habitat partitioning on such a fine-spatial scale is unlikely (J. Earl, unpublished data). Furthermore, the virtual absence of male greenback flounder from both deep and shallow habitats in the Estuary and Coorong suggests that sex-related partitioning may be occurring on a much broader spatial scale. This hypothesis is further corroborated by the observed movement of females between the Coorong and offshore habitats in the Southern Ocean during the spawning season (J. Earl, unpublished data). Whilst further research is required to assess the abundance and distribution of male and female greenback flounder in the near-shore habitats in the marine environment adjacent to the Murray Mouth, there is some evidence to suggest potential larger scale sex-related habitat partitioning than previously expected, i.e. male fish occupy offshore habitats, while females utilise habitats in the estuary.

Over the first four years of this study, the dominant age classes for female greenback flounder showed a general shift toward younger fish. Although, in 2010, the dominance of smaller and younger fish in the catch may be partially attributed to gear selectivity given that most of the samples were from fishery-independent sampling as reflected in size structure. Nevertheless, the age structure in 2011, which primarily came from fishery catches, confirmed the shift of the dominant cohort to one-year-olds; this cohort likely benefited from the 2010/11 flow event with an increase in productivity and food resources in the Coorong. Although no age determination was undertaken in 2012, the size frequency distribution showed a modal progression. It would not be surprising that the 2010/11 cohort continued to dominate the catch in 2011/12 (expected to be 1 year old in 2012). The general consistency of size structures of greenback flounder in this study with those from a previous study suggests age/size structures are representative of the population in the Coorong (Ferguson 2010). Given that greenback flounder can live to more than 10 years of age (Sutton *et al.* 2010), the highly truncated age structures suggest that fishing may have impacted on this species through the removal of larger, older individuals (Hall 1984; Ferguson *et al.* 2013). However, the influence of emigration of fish in their second or third years of life from the estuary, and their subsequent role in offshore habitats remain poorly understood in terms of the population dynamics of this species.

4.3.3 Recruitment

The presence of YOY and the length frequency distributions of juveniles indicated that recruitment of greenback flounder occurred in the Murray Estuary and Coorong annually over the last five years. From 2008/09 to 2009/10, there was a general reduction in the level of recruitment, possibly due to worsened environmental conditions caused by continuing drought and lack of barrage releases. Greenback flounder recruitment is likely influenced by freshwater flows to estuaries (Robins and Ye 2007). As this species spawns during autumn/winter (Crawford 1984b) before the typical high flow season, larval and juvenile growth may be enhanced by increased biological productivity (i.e. food availability) related to freshwater flows to estuaries, resulting in higher levels of recruitment success (Robins and Ye 2007). In addition, freshwater inflow is a key driver of the Coorong salinity regime (Geddes and Butler 1984; Geddes 1987; Brookes *et al.* 2009; Ye *et al.* 2012b). Salinity is known to play a key role in the reproductive biology of greenback flounder, with optimum fertilisation rates at 35-45 psu and an egg tolerance range of 14-45 psu after fertilisation (Hart and Purser 1995). During years of no barrage discharge, 2008/09 and 2009/10, average salinities in the North and South Lagoons increased to 49-134 psu (Figure 3.2), excluding a large area of the Coorong as a favourable spawning ground, potentially impacting recruitment success. However, it is worth mentioning that juvenile greenback flounder are more tolerant of hypersaline conditions than eggs, with laboratory estimates of lethal concentration for 50% test fish (LC_{50}) ranging from 79-88 psu (Ye *et al.* 2013). Tolerance data therefore concords with the collection of juvenile greenback flounder in the mid to northern part of the North Lagoon during recent drought years (Noell *et al.* 2009).

In the last three years, recruitment responses following freshwater inflows varied at different sampling sites. At the two sites within the Estuary, the abundance of new recruits decreased, probably due to a strong flow effect on this subregion given its close proximity to the Murray Mouth. However, there has been a steady increase in YOY abundance since 2010/11 at Mark Point (North Lagoon), reaching a significantly greater abundance in 2012/13 compared to the drought years. The intervention monitoring also suggested a broader distribution of YOY greenback flounder in the North Lagoon following the 2010-2013 flow events (Ye *et al.* 2012a; Livore *et al.* 2013). These reflect a positive ecological response to the freshwater inflows, having restored a large area of estuarine habitat and suitable nursery ground for greenback flounder throughout the North Lagoon.

4.4 Smallmouthed hardyhead

4.4.1 Abundance and distribution

Smallmouthed hardyhead is a euryhaline species with laboratory salinity tolerance of lower-upper LD_{50} ranging from 3.3-108 psu (Lui 1969), and an even greater tolerance range in natural conditions (e.g. smallmouthed hardyhead were present in small numbers up to 133.5 psu in the Coorong; Noell *et al.* 2009). Despite its strong salinity tolerance, the extreme hypersaline conditions (>100 psu) in recent years have restricted its southerly distribution in the Coorong. During 2008/09, no fish were collected at Jack Point and less than two fish per seine net shot were sampled at Hells Gate (southern end of the North Lagoon) and at

Salt Creek, where salinities ranged from 109-166 psu throughout the sampling season (November to February). The pattern of distribution and abundance of this species was similar to that in the previous drought year, 2007/08 (Noell *et al.* 2009). Both of these years represented an extremely hypersaline phase in the long term salinity fluctuations of the Coorong as a consequence of no freshwater inflows following a protracted drought in the MDB.

In 2009/10, a significant increase in abundance of smallmouthed hardyhead compared to 2008/09 was detected at some sites in the North Lagoon and at the southern end (i.e. Salt Creek) of the South Lagoon. The highest catch rate was maintained at Noonameena, even though there was a slight increase in salinity to 77-103 psu. Such hypersaline conditions, though within the tolerance range of smallmouthed hardyhead, probably provide them advantages by excluding potential predators and competitors that are unable to withstand such high salinities, thus allowing them broader access to food, space and habitat (Colburn 1988; Vega-Cendejas and Hernández de Santillana 2004). Increased salinities between 2005 and 2010 also facilitated the re-establishment of extensive beds of *Ruppia tuberosa* in the southern areas of the North Lagoon (Frahn *et al.* 2012; Paton and Bailey 2012). The presence of this native seagrass likely enhanced habitat quality and availability for smallmouthed hardyhead (Molsher *et al.* 1994), which may also partially explain the increase in the abundance of this species in the North Lagoon. Furthermore, a general reduction in abundance of piscivorous fish and birds throughout the Coorong (Brookes *et al.* 2009) during the drought would have also led to an increase in prey species' abundance. In contrast, the increase in fish numbers at Salt Creek in 2009/10 was most likely attributed to the increased inflow from the upper South East through Salt Creek, freshening the southern end of the Coorong, thus restoring favourable salinities and habitat for this species. Flow discharges also probably facilitated the dispersion of the abundant smallmouthed hardyhead from within Salt Creek (salinities 9-22 psu) to the South Lagoon. Whilst this positive biological response was only at a local scale (limited to the southern end of the South Lagoon), it highlights the importance and benefit of flows from Salt Creek to populations in the South Lagoon, especially during prolonged periods of no inflow from the River Murray. Periodic releases of freshwater from Salt Creek, particularly during dry years, will help to manage salinity levels in the South Lagoon and enhance the resilience of the smallmouthed hardyhead population in this subregion. Additional research is required to identify the flow requirements (i.e. volume, duration, intensity and timing) from the South East that would facilitate an increase in recruitment for smallmouthed hardyhead and maintain the productivity of the ecosystem in the South Lagoon in the context of the influence of the River Murray flow to this subregion.

In 2010/11 and 2011/12, the barrage releases caused a substantial reduction in salinity throughout the Coorong. Smallmouthed hardyhead abundance increased significantly in 2010/11 and even more remarkably in 2011/12, particularly in the South Lagoon. The increases occurred following salinity reductions to below 100 psu, and were likely a combined result of a range extension of this species from the North Lagoon, enhanced recruitment, and the dispersion of the remnant population and new recruits from within Salt Creek (Salt Creek inside creek site) into the South Lagoon. Higher abundances of smallmouthed hardyhead in the South Lagoon may also relate to the re-establishment of *Ruppia tuberosa* at various sites throughout the South Lagoon in 2011, thus increasing habitat quality and availability (Frahn *et al.* 2012; Paton and Bailey 2012). The increase of smallmouthed hardyhead abundance is of particular ecological significance, given the important role this keystone species plays in the trophic ecology of the region. In 2012/13, the abundance of smallmouthed hardyhead generally remained steady or showed a further increase in the South Lagoon, whereas there was a reduction in the North Lagoon. The recovery of piscivorous large-bodied fish in the North Lagoon of the Coorong (Livore *et al.* 2013) has probably led to increased predation on prey species, such as smallmouthed hardyhead, in this subregion; in contrast, the relative abundance of large-bodied fish was still low in the South Lagoon.

4.4.2 Size structure

The temporal pattern of length-frequency distributions provides a useful indication of recruitment dynamics of this species in the North and South Lagoons. Smallmouthed hardyhead spawn between September and December in the Coorong (Molsher *et al.* 1994). In this study, fish <39 mm TL were collected throughout the spring/summer sampling season, except for 2008/09; although the small seine net was not used in three out of four months during 2008/09, standard seine net data indicated no or very low numbers of adult fish within the South Lagoon. Furthermore, all fish caught in February 2009 (Figure 3.20) were from within Salt Creek (Ye *et al.* 2011b). These results suggest a recruitment failure in the South Lagoon. In contrast, from 2009/10-2012/13, size structures indicated successful recruitment in both the North Lagoon and South Lagoon.

On a few occasions, the length frequency distributions showed a decline in number of larger fish between December and February. This suggests post-breeding mortality, reflecting a one-year life cycle for this species as suggested in a previous study in the Coorong (Molsher *et al.* 1994). The maximum size of fish recorded during this study was slightly larger (i.e. 99 mm TL) than that found by Molsher *et al.* (1994) in this region (i.e. 85 mm TL).

4.4.3 Recruitment

There has been a general increase in recruitment of smallmouthed hardyhead in the Coorong since 2009/2010. In particular, there was a substantial increase in the number of new recruits throughout an extensive area of the North and South Lagoons (between Noonameena and Salt Creek) after significant flow events in 2010/11 and 2011/12. The small seine net was an effective sampling gear type for assessment of new recruit abundance, and CPUE provided a recruitment index for smallmouthed hardyhead. During the third flow year, 2012/13, the abundance of new recruits further increased in some South Lagoon sites; however, a general decline in the North Lagoon occurred, which may have been due to increased predation pressure given the increased abundance of piscivorous fish (Livore *et al.* 2013) and birds (Paton personal com.).

In 2008/09, recruitment was likely spatially restricted to the central areas of the North Lagoon and within Salt Creek. The constant high salinities (>109 psu) during the reproductive season likely represented a limiting factor for recruitment at the southern end of the North Lagoon (i.e. Hells Gate) and in the South Lagoon. Salinities in these areas were regularly higher than the laboratory determined tolerance (i.e. LC_{50} 108 psu) for this species (Liu 1969). High salinity is known to impact the reproductive performance of other atherinids (e.g. Carpelan 1955; Hedgpeth 1967). Although a previous study in the Coorong did not identify any clear influence of salinity on reproduction of smallmouthed hardyhead at a lower salinity range (32-74 psu), it was suggested that salinity might limit their food resources (Molsher *et al.* 1994). Successful recruitment in the central parts of the North Lagoon in 2008/09 may also relate to an increased biomass of *Ruppia tuberosa* in the region. The importance of macrophytes to atherinids has been well documented, as they provide a sessile medium to which eggs can adhere and be retained within the areas of favourable salinity, thus facilitating enhanced egg survival and subsequent recruitment (Molsher *et al.* 1994; Ivanstoff and Cowley 1996).

In 2009/10, small volumes of inflows from the South East significantly reduced the salinity in the southern end of the South Lagoon (i.e. Salt Creek). Restoration of favourable physico-chemical conditions (i.e. reduced salinities), probably led to enhanced recruitment of hardyhead at a local scale. The freshening effect may have extended northward to Jack Point, where a small salinity decline was observed and new recruits were collected in November and December 2009. However, local declines in salinity were short-lived, with reductions in the Upper South East inflow and an increased evaporation in summer, leading to salinity increases at the southern end of the South Lagoon from 29 psu in October 2009 to 135 psu in February 2010. Correspondingly, the distribution of smallmouthed hardyhead contracted southward toward Salt Creek, and it had disappeared from the South Lagoon by February 2010. Nevertheless, the 2009/10 data indicates that the fresh-brackish creek (i.e. Salt Creek inside creek) is an important area for smallmouthed hardyhead recruitment, which likely provides a source population for the South Lagoon when environmental conditions become favourable. On the other hand, recruitment success in the North Lagoon is no doubt important, and plays a key role in sustaining the core population in the Coorong.

Since 2010/11, significant freshwater inflows from the River Murray have resulted in broadly reduced salinities throughout the Coorong region, and salinities in the South Lagoon of <100 psu. Reductions in salinity, coupled with increased freshwater inflows, have restored extensive areas of suitable habitat and facilitated spawning and recruitment in smallmouthed hardyhead, leading to a remarkable increase in abundance, particularly in the southern North Lagoon and throughout the South Lagoon (from Noonameena to Salt Creek). Seasonal reduction of salinity by freshwater influence was suggested to be a partial cue to spawning in smallmouthed hardyhead (Molsher *et al.* 1994). In addition, freshwater inflows are important sources of nutrients and organic matter to the Coorong, along with a direct input of plankton as a food resource at least to the Estuary subregion (Shiel and Tan 2013); all these would benefit the food web (Brookes *et al.* 2009) and therefore fish recruitment. Smallmouthed hardyhead may have timed its breeding to take advantage of seasonal peaks in food availability. In the Coorong, they feed mainly on zooplankton, which are most abundant during winter and spring, when salinities are relatively low (Geddes 1987). A previous study indicated that freshwater releases from the Murray barrages led to an increased zooplankton abundance in the Murray Estuary and Coorong (Geddes 2005), which would enhance the survival and growth of larvae and juveniles, thereby benefiting the recruitment of many fish species, including smallmouthed hardyhead (Whitfield 1994; Gillanders and Kingsford 2002).

5 CONCLUSIONS

Monitoring of the smallmouthed hardyhead population indicated that management Target F3 was met following the barrage releases from 2010-2013, with significant increases in recruitment, abundance and distribution relative to 2008/09 and 2009/10. Although this species is highly tolerant of elevated salinity, in 2008/09, extreme hypersaline conditions (salinity up to 166 psu) restricted its southerly distribution. In 2009/10, there were some improvements in abundance and recruitment, with a localised recovery in the southern end of the Coorong following small volumes of freshwater inflows (~100 ML d^{-1}) from Salt Creek. This freshwater/brackish creek probably also served as a recruitment refuge for smallmouthed hardyhead over the period 2008-2010, facilitating later population recovery in the South Lagoon. From 2010/11 to 2012/13, broadly decreased salinities after barrage releases, coupled with other freshwater induced environment changes, led to a substantial increase in population abundance, distribution range and enhanced recruitment in this species, especially in the southern part of the Coorong where salinities decreased to <100 psu. This is of particular ecological significance, given the important role this keystone species plays in the trophic ecology of the region. The response of smallmouthed hardyhead to flows provides insight into population recovery when favourable conditions (i.e. salinity <100 psu) are restored, and shows the resilience of the population in the Coorong.

In contrast, for black bream and greenback flounder, condition monitoring in the Murray Estuary and North Lagoon prior to 2012/13 showed no indication that management Target F4 was met (Ye *et al.* 2012b). Nevertheless, the results of 2012/13 monitoring indicated some improvements in populations of these two species, suggesting that management Target F4 was partially met. This was reflected in the following changes.

For black bream:

- a gradual increase in abundance as indicated by the increasing commercial fishery catch from a historical low of 1.1 t in 2009/10 to 2.3 t and 3 t in 2010/11 and 2011/12, respectively, although these remained below the average of the previous ten years (5.5 t y^{-1});
- an increase in targeted CPUE from 2010/11 to 2011/12 (5.8 to 8 kg.fisher day^{-1})
- expansion of distributional range of fishery catch from the Estuary during the drought years into the North Lagoon post 2010 flows;
- a significant increase in abundance of new recruits in 2012/13 compared to the previous two years.

For greenback flounder:

- a substantial increase in population abundance as indicated by a significant increase in commercial fishery catch from 0.1 t in 2010/11 to 30 t in 2011/12, the 4th highest since 1984/85;
- a significant increase in targeted CPUE, reaching a historical high of 23.8 kg.fisher day^{-1} in 2011/12;
- a substantial range expansion, with the majority of the catch coming from the North Lagoon in 2011/12 whilst in the previous years (2008-2010), catches were mainly from the Estuary subregion;
- an increased abundance of new recruits in the North Lagoon despite a reduction in the Estuary subregion.

Although there were positive responses in the black bream and greenback flounder populations following 2-3 years of high flow events post-2010, it should be noted that the population level of black bream still remained low in the Coorong considering the substantial decline in abundance since the mid-1980s. A heavily truncated age structure of this long-lived species, as shown in previous years' age data, is of concern, suggesting reduced population resilience in the Coorong.

The recent barrage releases are ecologically significant given the critical role of freshwater flows in facilitating successful spawning and recruitment in black bream and greenback flounder and restoring/maintaining estuarine habitat (including a favourable salinity gradient). Ongoing monitoring will be required in subsequent years to: 1) continue investigations of population dynamics and recruitment of large-bodied estuarine species; 2) evaluate the benefit/impact of various flow scenarios (both natural and managed flows) for these populations; and 3) assess population recovery (abundance and demography). Importantly, environmental water management should take into account flow regimes of small to moderate freshwater releases which could be linked to the strong recruitment of black bream (as per the releases in 2003/04 and 2006/07). For instance, the protection of black bream from commercial and recreational exploitation during the spawning season (i.e. spring/early summer) when there are small/medium barrage releases may increase opportunities for successful spawning and ultimately enhance recruitment success. In addition, conservation management should seek to protect the remnant populations of these species and rebuild the age structures to improve population resilience. Further research/monitoring will be required to improve our understanding of primary environmental factors such as flow regime and habitat characteristics, which influence recruitment success of key estuarine species.

The first five years of fish condition monitoring has provided valuable information on the abundance, distribution, population age/size structures and recruitment ecology of the black bream, greenback flounder and smallmouthed hardyhead populations in the Coorong. Remarkably, the study occurred during an extreme drought period (2008/09 and 2009/10), followed by three significant flow years, all of which allowed quantitative assessment of biological responses to flows and an investigation of population recovery. The results of this study form an important basis for the delivery of environmental flows and adaptive management to ensure the ecological sustainability of iconic estuarine fish species in the LLCMM region.

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7 APPENDICES

Appendix A. Black bream fishery-independent samples

Numbers of adult black bream and gear type used for fishery-independent samples between 2008/09 and 2012/13.

Gear Type	2008/09	2009/10	2010/11	2011/12	2012/13	Total
Seine		47	37	5	4	93
Multi Panel Gill Net			8		1	9
Fyke Net	4	1				5
Fishway Trap			2			2
Line	1					1
Total	5	48	47	5	5	105

Appendix B. Greenback flounder fishery-independent samples

Numbers of adult greenback flounder and gear type used for fishery-independent samples between 2009 and 2012.

Gear Type	2009	2010	2011	2012	Total
Seine	17	196	7	5	225
Multi Panel Gill Net	2		1	6	9
Fyke Net	8			5	13
Total	27	196	8	16	231