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Coorong Fish Condition Monitoring 2008–2012:

The black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations

Qifeng Ye, Luciana Bucater, David Short and Jason Earl

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South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

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Author(s):	Qifeng Ye, Luciana Bucater, David Short and Jason Earl
Reviewer(s):	Chris Bice (SARDI), Adrienne Frears (Department for Water) and independent reviewer (MDBA)
Approved by:	Assoc. Prof. John Middleton Science Leader - Oceanography
Signed:	
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EXECUTIVE SUMMARY

The Coorong, Lower Lakes and Murray Mouth (CLLMM) 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 program (TLM). Over the recent decadal drought in the 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 CLLMM 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 four years (2008/09−2011/12) 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; Target F3: provide optimum conditions to improve recruitment success of smallmouthed hardyhead in the South Lagoon; and Target F4: 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 in 2010/11 and 2011/12, 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 ppt) 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. In 2010/11 and 2011/12, broadly decreased salinities after barrage releases, coupled with other freshwater induced environment changes, led to a dramatic increase in population abundance and enhanced recruitment in this species, especially in the southern part of the Coorong where salinities reduced to <100 ppt. 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 favorable conditions (i.e. salinity <100 ppt) 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 generally indicated that management Target F4 was not met during the last four years (2008/09−2011/12). This was reflected, for both species, by

- a continuation of significant declines in abundance (since the 1980s);
- historically low abundances from 2008-2011;
- a contraction of distributional range in recent years with black bream largely restricted to the Murray Estuary until 2009/10 and greenback flounder until 2010/11;
- heavily truncated age structures which may relate to over-exploitation of older fish by commercial and recreational fisheries, and/or emigration of adult fish (in the case of greenback flounder) during a period of poor environmental condition; and
- a decline in juvenile recruitment over the period 2008–2010 and uncertainty in recruitment success for black bream during the last two flow years.

Nevertheless, there have been positive responses to the 2010-2012 flow events, including an extended southward distribution for black bream following extensive salinity reductions, and enhanced recruitment for greenback flounder in the North Lagoon. Provisional fishing statistics for 2011/12 also suggest that the abundance and distributional range for greenback flounder in the North Lagoon increased relative to the four years prior.

The recent barrage releases are ecologically significant given the critical role of freshwater flows in facilitating successful spawning and recruitment in both black bream and greenback flounder and restoring/maintaining estuarine habitat with a favorable 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 small/medium barrage release periods 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 capacity for egg production and thus enhance 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 four 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 two significant flow years, which has established an excellent baseline by which future quantitative assessment can be made. 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 CLLMM region.

1. INTRODUCTION

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region is located at the terminus of Australia's largest river system, the Murray–Darling. It is recognised as a wetland of international importance under the Ramsar Convention (1985), 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 upon its unique ecological qualities, hydrological significance, economic and cultural values (Murray–Darling Basin Commission 2006).

The Coorong is a long (about 110 km) and narrow (<4 km wide) estuarine lagoon system with a strong north-south salinity gradient, generally ranging from brackish/marine in the Murray Mouth Estuary to hypersaline in the North and South Lagoons (Geddes and Butler 1984; Geddes 1987). Salinity within the Coorong is highly dependent on 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. Overall, consumptive water use has reduced average annual flow at the Murray Mouth by 61%, from 12233 GL y^{-1} to 4733 GL y^{-1}, over the 1895 to 2006 climate (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. In recent years, the impact of river regulation and water extraction was exacerbated by severe drought in the Basin, with very low or no flow releases through the barrages between 2002 and 2010 (DFW 2010). Subsequently, the Murray Mouth closed due to siltation and regular dredging has been required to maintain its opening from 2002 (DWLBC 2008) until December 2010. Over this period, the Coorong was transformed into a marine/hypersaline environment, with extreme salinities in the South Lagoon (i.e. >150 ppt) leading to severe and continuing degradation of critical habitats for nationally listed bird species (Rogers and Paton 2009). Such changes have severely impacted the regions ecology, compromising the Ramsar ecological character of the site (Brookes *et al.* 2009). Many native fish species that depend on the Coorong estuary as a refuge, breeding, nursery and feeding ground were also negatively affected (Noell *et al.* 2009; Ye *et al.* 2011b), and recruitment of diadromous fish failed due to lack of connectivity between freshwater and marine environments (Zampatti *et al.* 2010).

In 2010/11, significant rainfall and increased flow in the River Murray led to the refill of the Lower Lakes and an annual barrage release of 12849 GL. This resulted in broadly decreased salinities and other freshwater induced environmental changes in the Coorong, which elicited significant ecological responses in fish assemblages during 2010/11 (Ye *et al.* 2011a). These include an increase in the diversity and abundance of freshwater species, enhanced recruitment and abundance of small-bodied estuarine/opportunist species (smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (congolli), and a southward range expansion of some key species, such as black bream (Ye *et al.* 2011a). High flow conditions continued in 2011/12 and barrage discharge had totaled 6558 GL by mid March 2012.

Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma)* are target species in the CLLMM Icon Site Environmental Management Plan (EMP). A scientifically robust monitoring program has been implemented for these species in the Coorong (i.e. condition monitoring) (Maunsell Australia Pty Ltd. 2009) since 2008/09 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 Mouth Estuary and North Lagoon.

In relation to these targets, the current 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 first four years (2008–2012) of the Coorong fish condition monitoring using both commercial and fishery-independent data.

2. METHODS

2.1. Fishery catch, effort, CPUE and freshwater inflows

2.1.1. Data

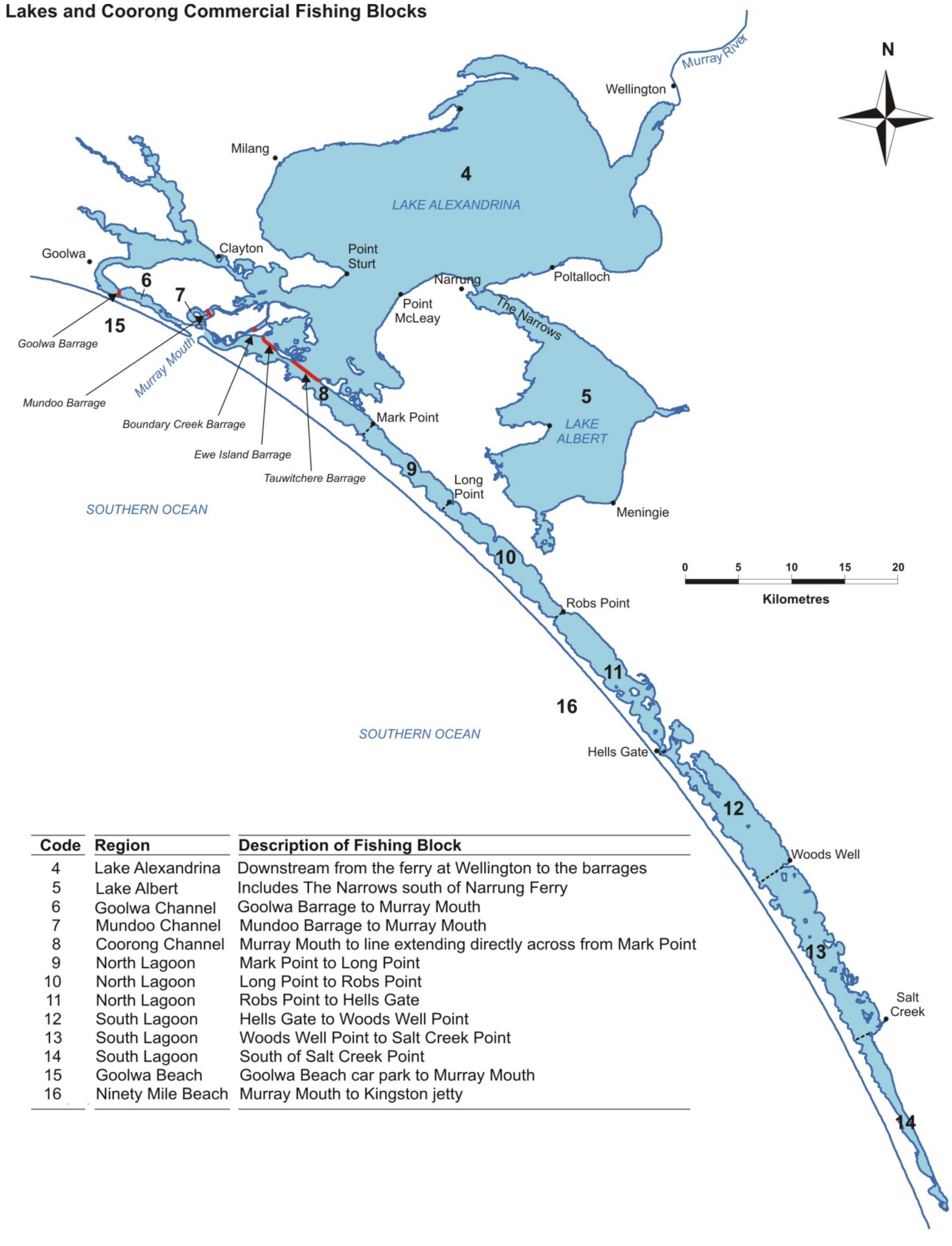
Commercial catch and effort data for black bream and greenback flounder from the Lakes and Coorong Fishery were available for the years 1984/85 to 2010/11. Data included catch (kg), effort (fisher days, net days), and spatial reporting block (Figure 2.1). Targeted catch is defined as the catch of a species when it is targeted by a fisher or fisher(s).

Annual and monthly freshwater discharge across the barrages were available for the period from July 1984 to March 2012 from the regression based Murray hydrological model (MDM, BIGMOD, MDBA). In addition, estimates of daily freshwater discharge from Salt Creek to the South Lagoon of the Coorong, as well as estimates of daily salinity at the mouth of Salt Creek (Station A2390568) were obtained from the Surface Water Archive produced by the Department for Water (2012).

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 for each species. A comparison of the available effort measures was done using linear regression in SPSS 14.

Linear regression was also used to investigate the relationship between targeted catch and effort, as well as the influence of freshwater inflow to the Coorong on catches of black bream and greenback flounder from the area south of Mark Point for current or following years. An investigation of the spatial distribution of catches was also conducted in relation to freshwater inflows to the Coorong.



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 2011/12 to establish the population age/size structures for these species. Adult black bream were collected during spring/early summer each year, mainly from the Goolwa channel and Long Point (Figure 2.2) and adult greenback flounder were collected during winter each year from the Goolwa channel and near Mark Point and Long Point in the North Lagoon (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.

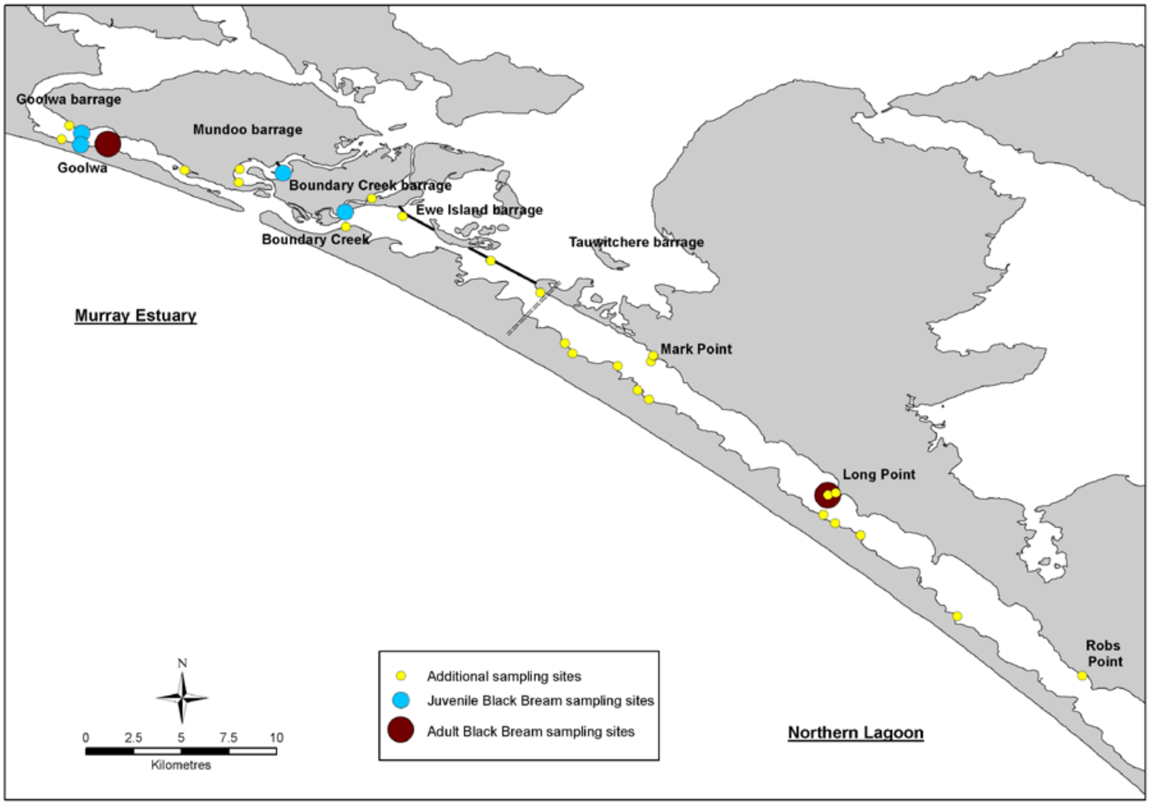


Figure 2.2. Icon site condition monitoring sampling sites for adult and juvenile black bream in the Coorong. Adult black bream sampling sites represent fishery sampling sites.

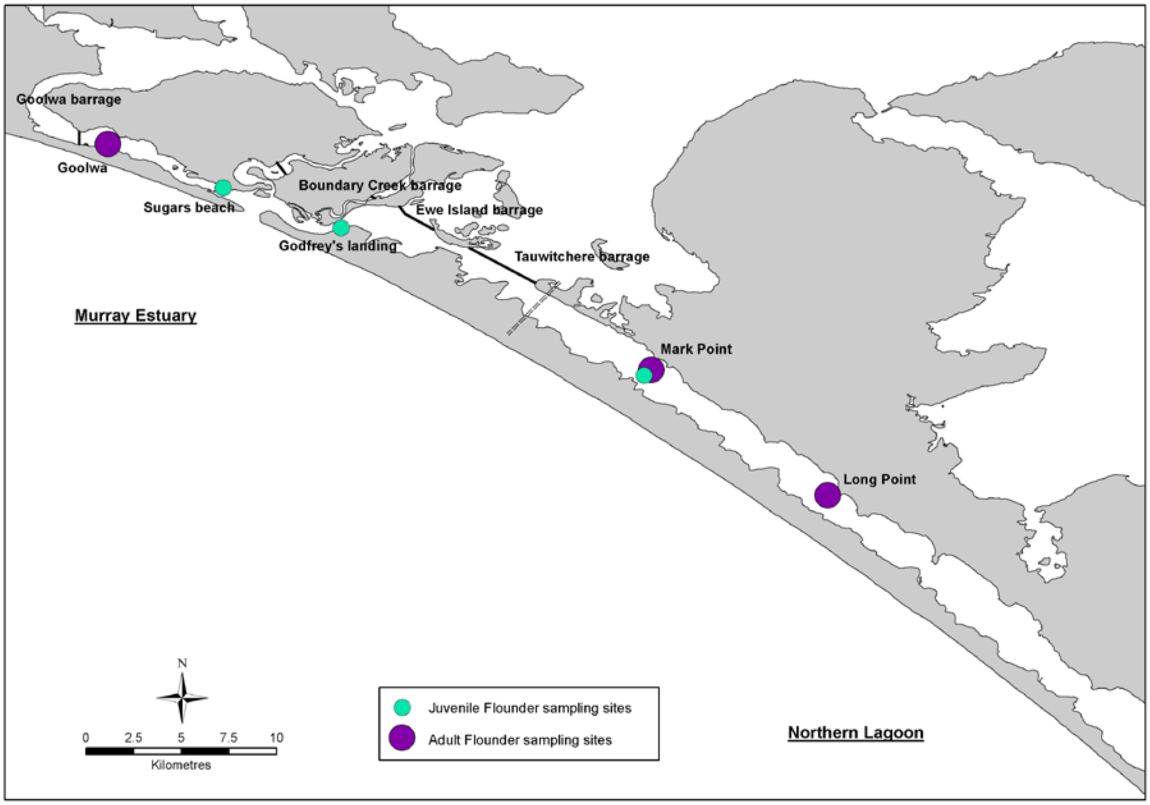


Figure 2.3. Icon site condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong. Adult flounder sampling sites represent fishery sampling sites.

Table 2.1. Numbers of adult black bream collected from commercial fishery and fishery independent sampling and fish aged between 2008/09 and 2011/12.

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

Table 2.2. Numbers of adult greenback flounder collected from commercial fishery and fishery independent sampling and fish aged between 2009 and 2011.

	2009			2010			2011		
Month	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total	Commercial	Fishery Independent	Total
January					1	1		3	3
February		18	18						
March								1	1
May	14		14	37	58	95			
June	24	9	33		52	52			
July	38		38		47	47			
August	29		29	14	33	47			
October							1		1
November					5	5	31		31
December							35	4	39
Overall	**105**	**27**	**132**	**51**	**196**	**247**	**67**	**8**	**72**
Aged			**108**			**245**			**67**

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 were presented in Tables 2.1 and 2.2.

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, to establish annual recruitment indices. For black bream, juvenile sampling was conducted at three regular sites (i.e. two below the Goolwa Barrage and one in Boundary Creek) (Figure 2.2). In 2010/11 and 2011/12, regular sampling was also conducted below Mundoo Barrage during late summer/early autumn each year using single-wing fyke nets (*n*=3 trips/year); other suitable sites for sampling juveniles were assessed during the season (e.g. upstream of Goolwa Barrage, Mundoo and Tauwitchere Barrages, Pelican Point, Mark Point, Long Point and Noonameena). 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 occasion, 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/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 comprised of 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 between 2008/09 and 2011/12.

Number of fyke net.nights per year Location	2008/09	2009/10	2010/11	2011/12
Regular sampling sites				
Goolwa Barrage sw side HI	21	24	28	15
Goolwa Barrage sw side SRP	31	24	20	22
Boundary Creek	31	24		16
Mundoo Barrage	4		24	24
Additional sampling sites				
Boundary Creek Barrage	4			
Cattle Point			4	12
Ewe Island Causeway	4	16		
Godfrey's Landing				4
Goolwa Barrage fw side HI	4			
Goolwa Barrage frw side SRP	2	4		
Goolwa channel HI side				4
Long Point			8	4
Long Point beach				4
Long Point reef				4
Long Point sand dune			4	
Long Point YHP side				4
Mark Point	8		8	12
Mark Point beach				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 Rumbelow Shack				4
Robs Point			4	
South Cattle point				4
Tauwitchere Barrage	3	4		
Overall	**132**	**96**	**104**	**145**

Table 2.4. Sampling effort used to collect juvenile greenback flounder using standard seine net at in the Coorong between 2008/09 and 2011/12.

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

Standardised seine netting 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 four years (2008–2012) (n=4 trips per year), targeting the main spawning and recruitment season. A small seine net was also adopted in 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 net measured for total length (mm). To confirm if fish collected were YOY, estimates of age (in days) were made by counting daily rings in a sub-sample of 50 otoliths per species during the first two years of condition monitoring (Ye *et al.* 2011b).

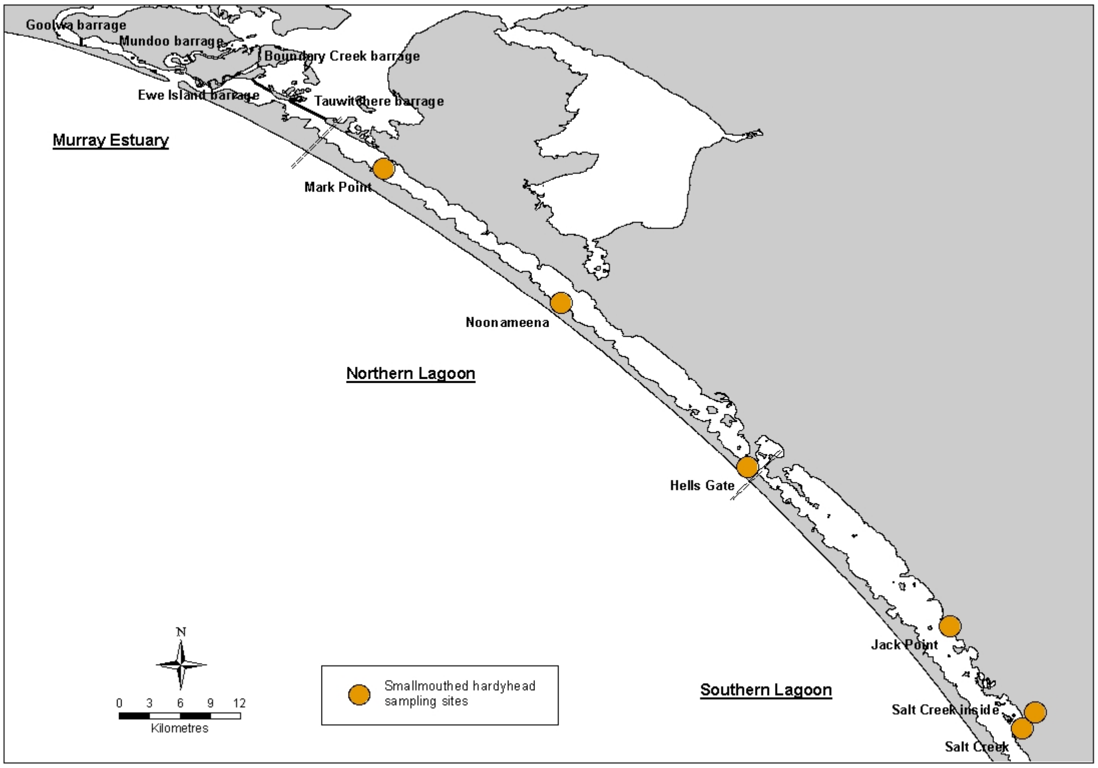


Figure 2.4. Icon site condition monitoring sampling sites for smallmouthed hardyhead in the Coorong.

Table 2.5. Sampling effort for juvenile and adult smallmouthed hardyhead using large and small seine nets in the Coorong between 2008/09 and 2011/12.

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

Table 2.6. List of sites sampled, species targeted and fishing gear used.

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

Water quality parameters (i.e. salinity, temperature, pH) were recorded using a TPS water quality meter and water transparency were 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 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. 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.

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 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 Bray-Curtis similarity measures (Bray and Curtis 1957), with a dummy variable added (value=1). 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).

For both black bream and greenback flounder, recruitment success could also be corroborated using year class strength in the population age structure. 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).

3. RESULTS

3.1. Freshwater inflow

From 1984–2012, the Murray Estuary and Coorong has experienced substantial fluctuations in freshwater inflows. Between 1989/90 and 1993/94, freshwater inflows to the Estuary were consistently high with annual discharge ranging between 10 500 and 12 500 GL y^{-1} and peak monthly inflows during spring >2000 GL m^{-1} (Figure 3.1). After 1993/94, inflows to the Coorong generally declined with annual discharge of ~9000 GL, ~3000 GL and ~5000 GL in 1996/97, 1998/99 and 2000/01, respectively. Every year between 2001/02 and 2009/10, annual discharge totaled <800 GL, and between 2007/08 and 2009/10, no freshwater was discharged to the Coorong. Following significant increases in inflows in the MDB, there have been significant barrage releases in 2010/11 and 2011/12 of ~13000 GL and ~6500 GL, respectively. Peak monthly inflow of ~2400 GL occurred in March 2011 and ~1400 GL in September 2011 (Figure 3.1).

From 2001–2012, freshwater inflows from Salt Creek into the South Lagoon were highly variable between years (Figure 3.2). Inflows were consistent, but highly seasonal in most years. Overall, peak flow rates were lowest in 2007 and 2009, failing to exceed 60 ML d^{-1} in each of these years. In contrast, discharge rates were highest in 2010 and 2011, reaching peaks in excess of 450 and 500 ML d^{-1}, respectively, in each year.

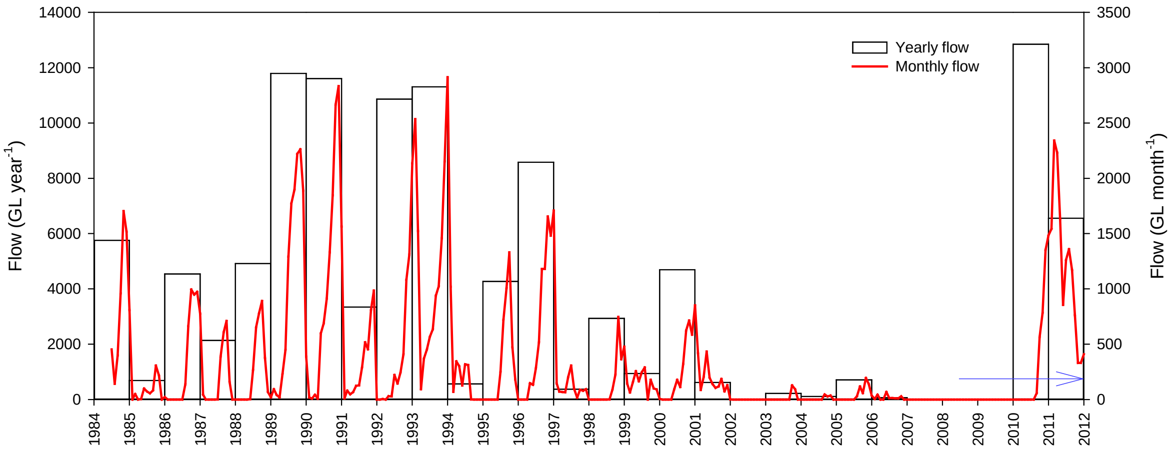


Figure 3.1. Average annual and monthly freshwater inflows across the barrages from July 1984 to March 2012 (source: MDBA, 2012) Blue arrow indicates time period of fish condition monitoring.

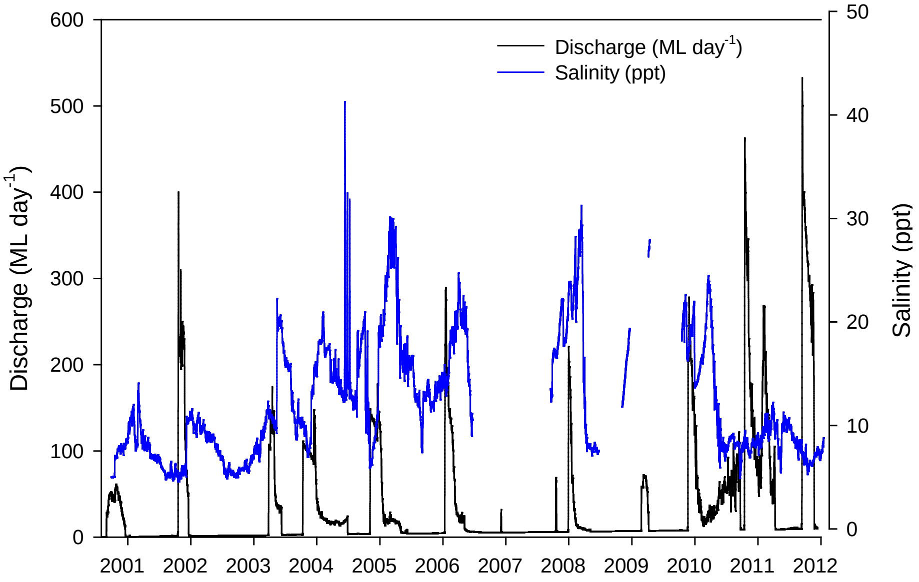


Figure 3.2. Daily flow discharge through the Salt Creek with salinity levels (DFW 2012, Surface Water Archive, Station A2390568).

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 in 2010/11 and 2011/12. In 2008/09 and 2009/10, mean salinities ranged from 38-44 ppt in the Murray Estuary, 49-133 ppt in the North Lagoon, and 82-134 ppt in the South Lagoon. In contrast, in 2010/11 and 2011/12, salinities reduced to 0-14 ppt in the Murray Estuary, 9-76 ppt in the North Lagoon, and 54-98 ppt in the South Lagoon. Reduced salinities observed in the South Lagoon in 2010 and 2011, also coincided with an increase in freshwater discharge from Salt Creek (Figure 3.2). Accompanying River Murray inflows, a decline in transparency was observed in the Estuary in 2010/11 and 2011/12 compared to previous years in this subregion. There was no substantial change in other environmental parameters.

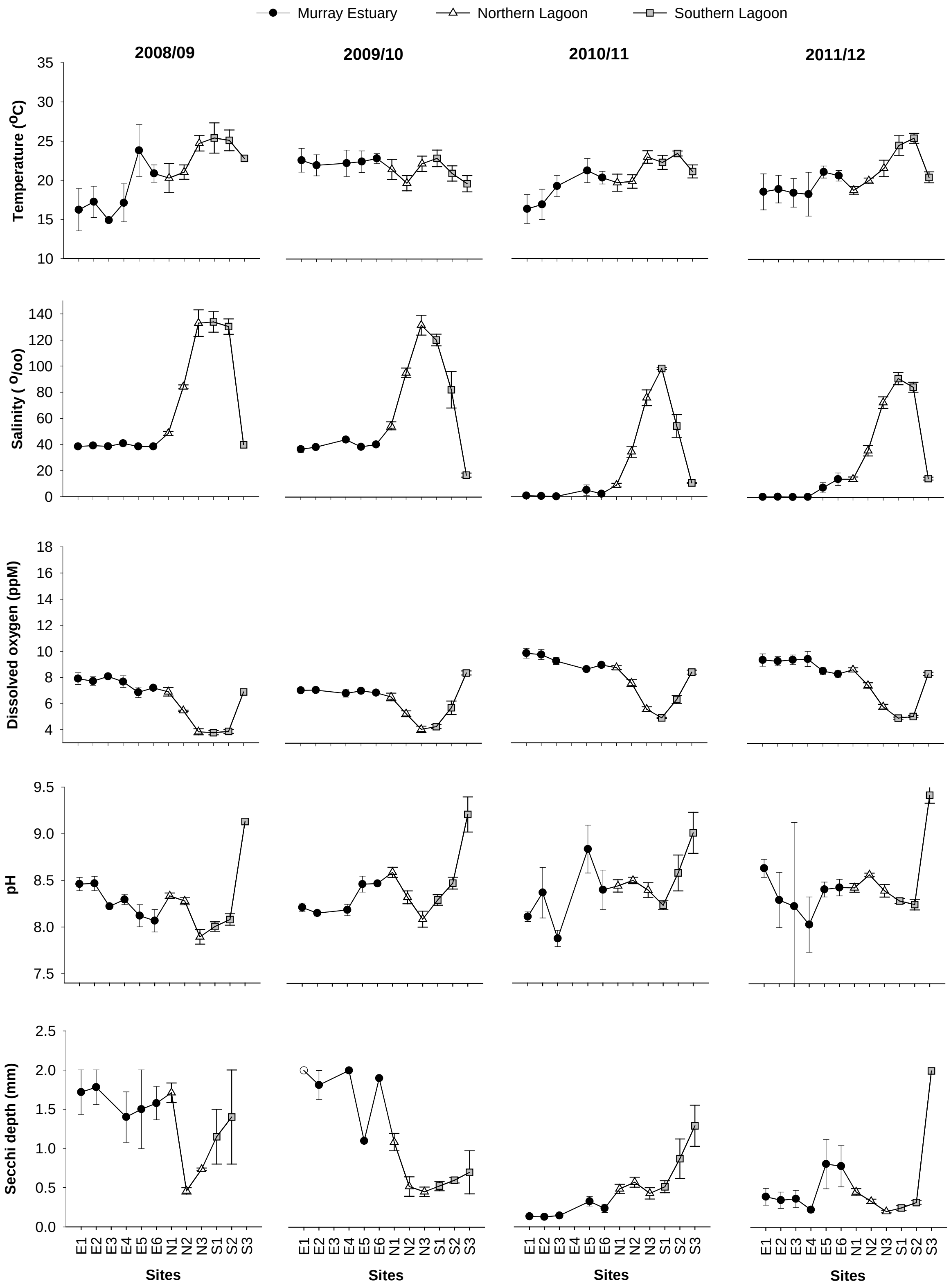


Figure 3.3. Mean values ± S.E. of water temperature, salinity, dissolved oxygen, pH and Secchi depth for the sampled period at each sampling site (sampling occasions pooled) within the Murray Mouth and Coorong region between 2008/09 and 2011/12.

3.3. Black Bream

3.3.1. Fishery catch, effort and CPUE

Since 1984/85, approximately 93% of the Lakes and Coorong Fishery's total commercial catch of black bream came from the Coorong. 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 in 2010/11, there was a small increase in annual catch to 2.3 t, but this figure remains below the past ten years' average (5.5 t y^{-1}). The dominant gear in all years was the large mesh gill net, accounting for more than 77% of annual catches of black bream (Figure 3.4).

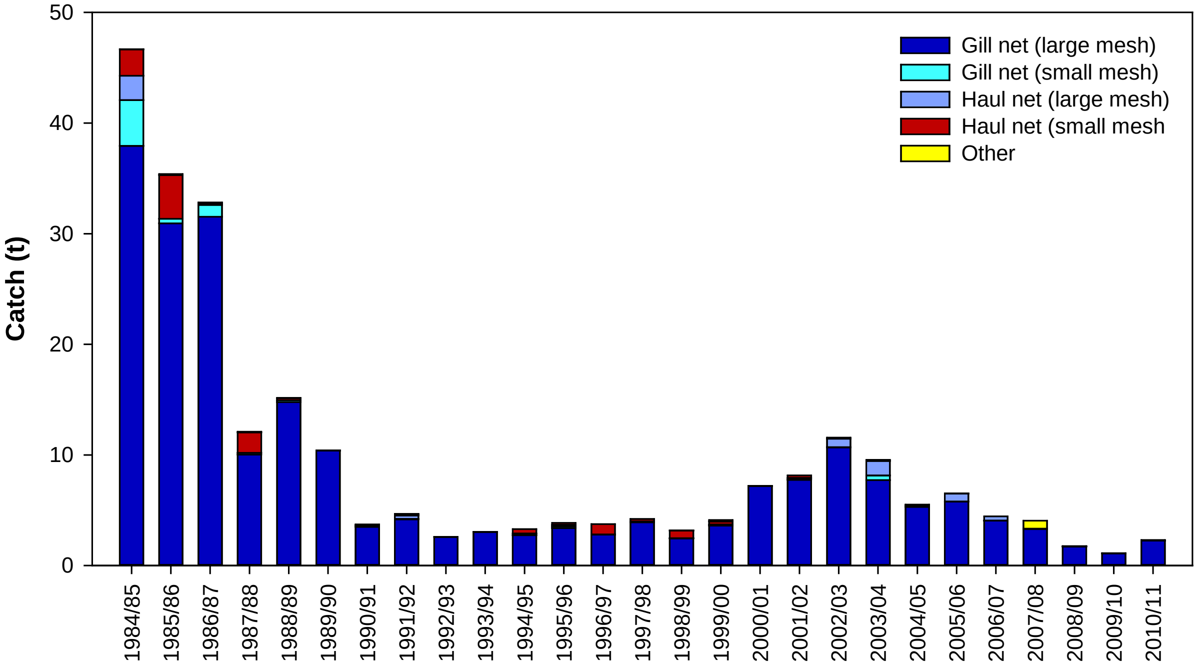


Figure 3.4. Annual catches of black bream taken by gear type in the Coorong.

Catches of black bream were highly seasonal, with most of the annual catch taken between August and October (i.e. 51% in the years 2006/07 to 2010/11; and 48% in the years 1984/85 to 2010/11). In most years the peak monthly catch was in September (Figure 3.5).

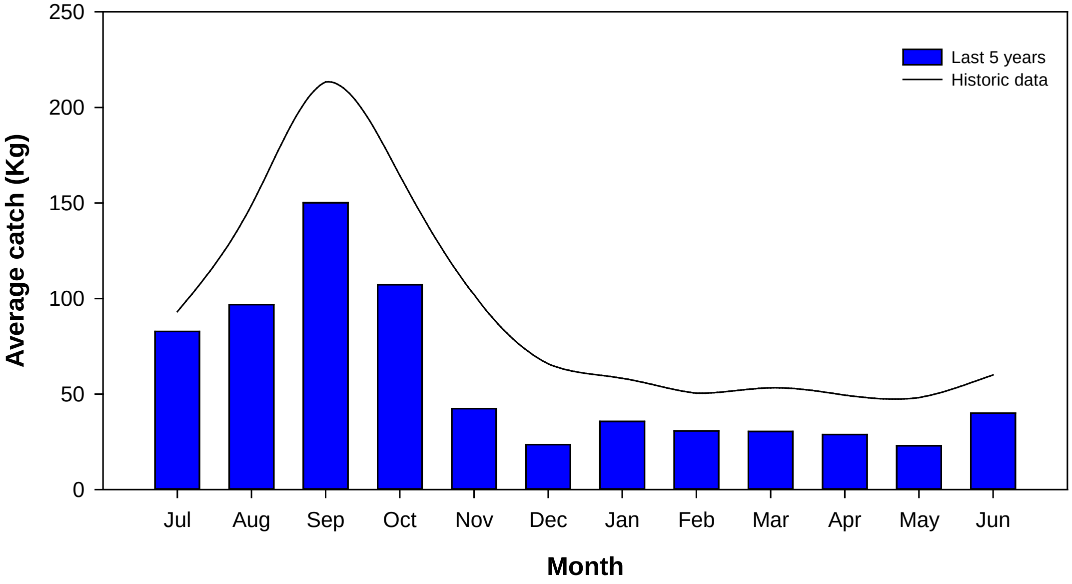


Figure 3.5. Long-term average monthly catches of black bream from the Coorong Fishery (1984/85 to 2010/11) and average monthly catches from the last five years (2006/07 to 2010/11).

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 (Figure 3.6 A). The catch then declined dramatically to 0.2 t in 1991/92. Targeted catch did not exceed 1 t y^{-1} between 1990/91 and 2001/02, but increased to 5.9 t in 2002/03 before a gradual decline to <1 t in 2008/09 (exact catch amount cannot be presented due to confidentiality arrangements, as catches were reported from less than five fishers) and a nil report in 2009/10. The targeted catch was 0.5 t in 2010/11, which comprised 24% of the total catch. The contribution of targeted catch to total catch varied greatly between years (Figure 3.6 A).

Trends in targeted effort (fisher days) were similar to those for targeted catch. Effort peaked at 2430 and 3365 fisher days in 1984/85 and 1985/86, respectively (Figure 3.6 B). Effort then declined steeply to a historic low of 50 fisher days in 1991/92. After that, the highest targeted effort was 471 fisher days in 2002/03, and it remained <200 fisher days in the last five years. Targteted effort was 93 fisher days and 1329 net days in 2010/11.

Trends in targeted effort measured as both fisher days and net days were similar and linearly related (LR: $R^2=0.97$, $F_{1,25}=778.92$, $p<0.001$) (Figure 3.6 B). Variability in targeted effort (fisher days) explained 87% of the variability in targeted catch (LR: $R^2=0.87$, $F_{1,25}=162.13$, $p<0.001$), while effort (net days) exaplained 86% of the variability in targeted catch (LR: $R^2=0.86$, $F_{1,25}=154.96$, $p<0.001$).

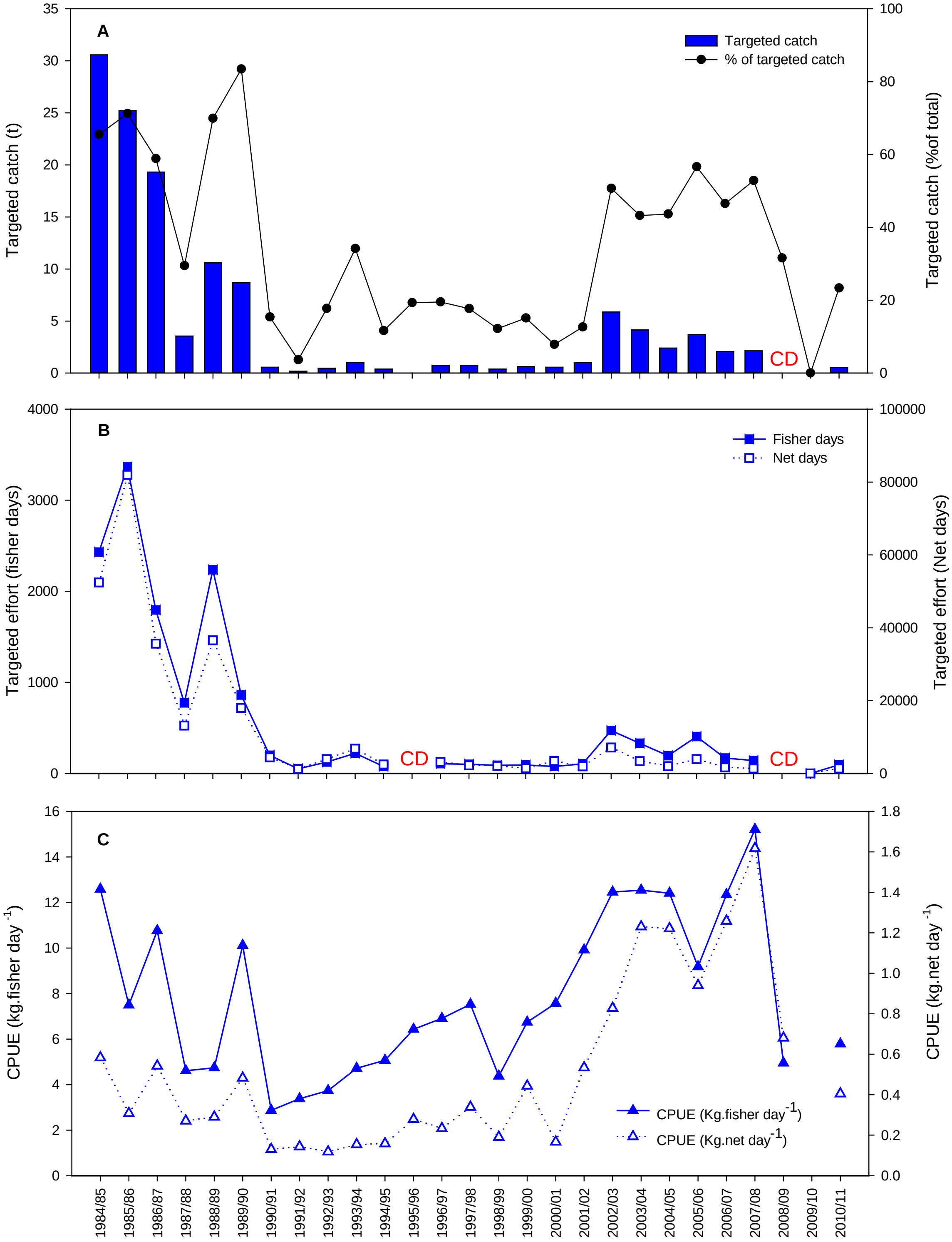


Figure 3.6. Annual targeted catch and effort for black bream caught in the large mesh gill nets. (A) Targeted catch shown in tones, and as percentage of total catch, (B) Comparison of two measures of effort, and (C) Comparison of two estimates of CPUE. CD: confidential data, as these involved fewer than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

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 steady increase to 1997/98 and a steeper increase in the following ten years to a historical peak (15.2 kg.fisher day^{-1}) in 2007/08. The CPUE dropped substantially to 4.9 kg.fisher day^{-1} in 2008/09 and there was no targeted catch for black bream in 2009/10. In 2010/11, CPUE was 5.8 kg.fisher day^{-1}. Trends in CPUE (kg.net day^{-1}) generally followed those of CPUE (kg.fisher day^{-1}).

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). Block numbers increase from north to south i.e. Goolwa (Block 6) to Salt Creek (Block 14). 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 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 totaled <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.

The general positive relationship was shown between freshwater inflow to the Coorong and proportional catch of black bream from the area south of Mark Point (circa North and South lagoons) (Figure 3.8). This suggests that the extent of the fishing area is reduced when freshwater inflow to the Coorong decline. Reduction in the number of spatial reporting blocks fished during the decadal drought period (2001-2009) also 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 in 2010/11, the catches of black bream have extended throughout the North Lagoon (Blocks 9, 10, 11) (Figure 3.7 A).

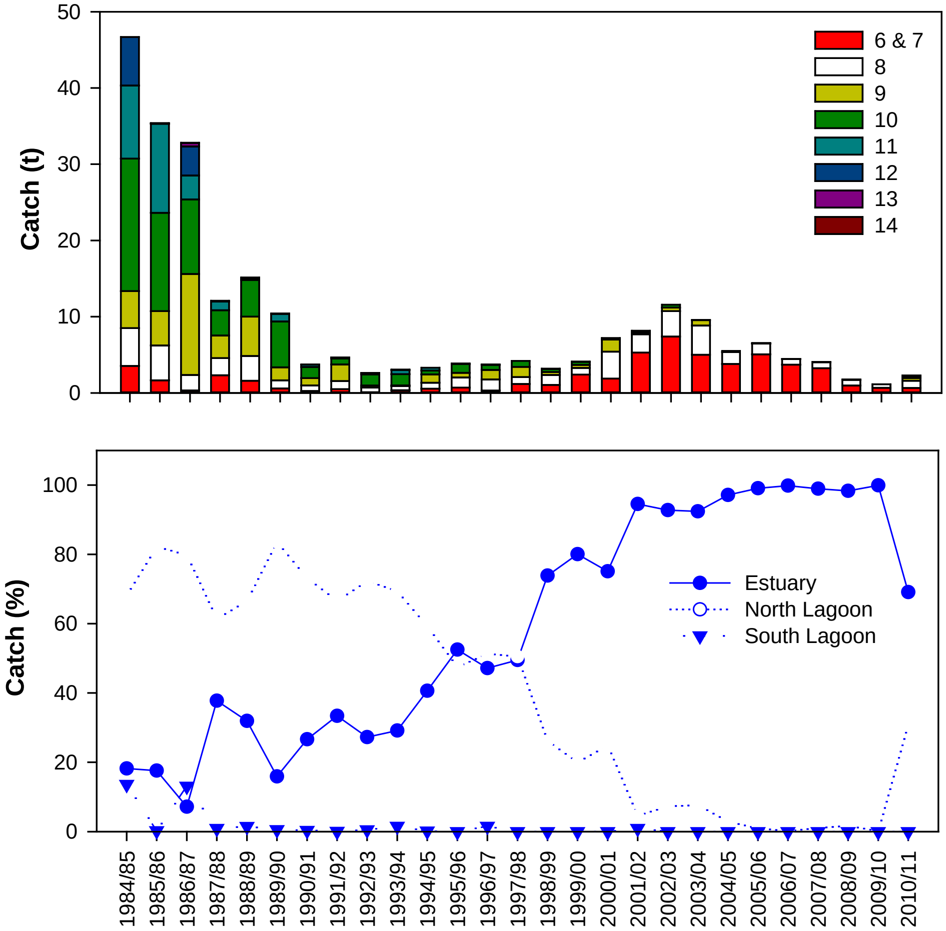


Figure 3.7. Black bream catches from (A) reporting blocks within the Coorong lagoons, and (B) contribution to total catch by areas in the Estuary, North and South lagoons.

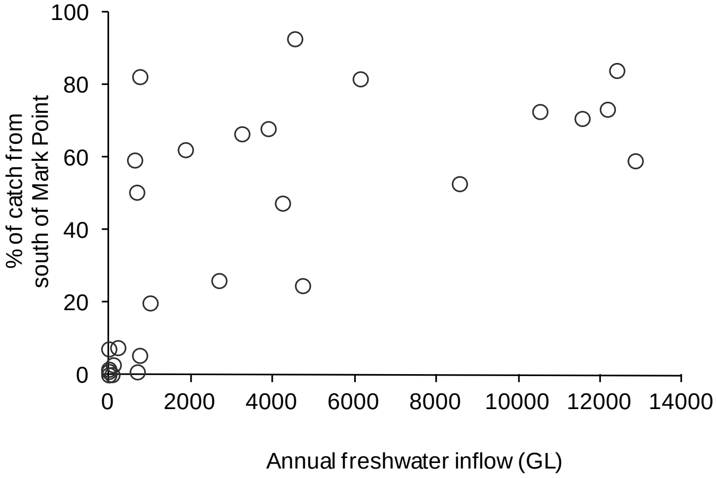


Figure 3.8. The annual contribution (%) of black bream catch from the area south of Mark Point to the total catch plotted against freshwater inflows to the Coorong between 1984/85 and 2010/11.

3.3.3. Size and age structures

Size and age structures for female and male black bream in the last five years are shown in Figure 3.9. In 2007/08, ages ranged from 3 to 25 years and 3 to 13 years for females and males, respectively. The age structures of both sexes showed a bimodal distribution, with a dominant mode at 3 years (34% for females and 33% for males) and a secondary mode at 9 years (24% for females and 31% for males). In 2008/09, ages ranged from 2 years (both sexes) to 12 years for females and 14 years for males. There was a unimodal distribution for both females and males, with a mode at 4 years (45% for females and 38% for males).

In 2009/10, ages ranged from 1 to 15 years and 2 to 13 years for females and males, respectively. There was a bimodal distribution for both sexes, with a dominant mode at 5 years (44% for females and 40% for males) and a secondary mode at 11 years (14% for both sexes). In 2010/11, ages ranged from 2 to 14 years for both sexes. The age structures showed a bimodal distribution, with a dominant mode at 6 years (27% females and 32% males) and a secondary mode at 12 years (20% females and 25% males). In 2011/12, ages ranged from 3 to 13 years for females and 1 to 31 years for males. There was a unimodal distribution for both sexes, with the dominant mode at 4 years (83% for females and 58% for males).

Overall, the strongest cohort was the 2003/04 year class. This cohort was present as 3 year olds in 2007/08, and persisted as 4, 5 and 6 year olds in samples from 2008/09, 2009/10 and 2010/11, respectively, and appeared in 2011/12 as 7 year olds only for males. The second strongest cohort originated in 1997/98, and persisted as 9, 11 and 12 year olds in 2007/08, 2009/10 and 2010/11, respectively. In 2011/12, a new strong cohort (i.e. 4 years old) appeared, representing the 2006/07 year class.

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 five years.

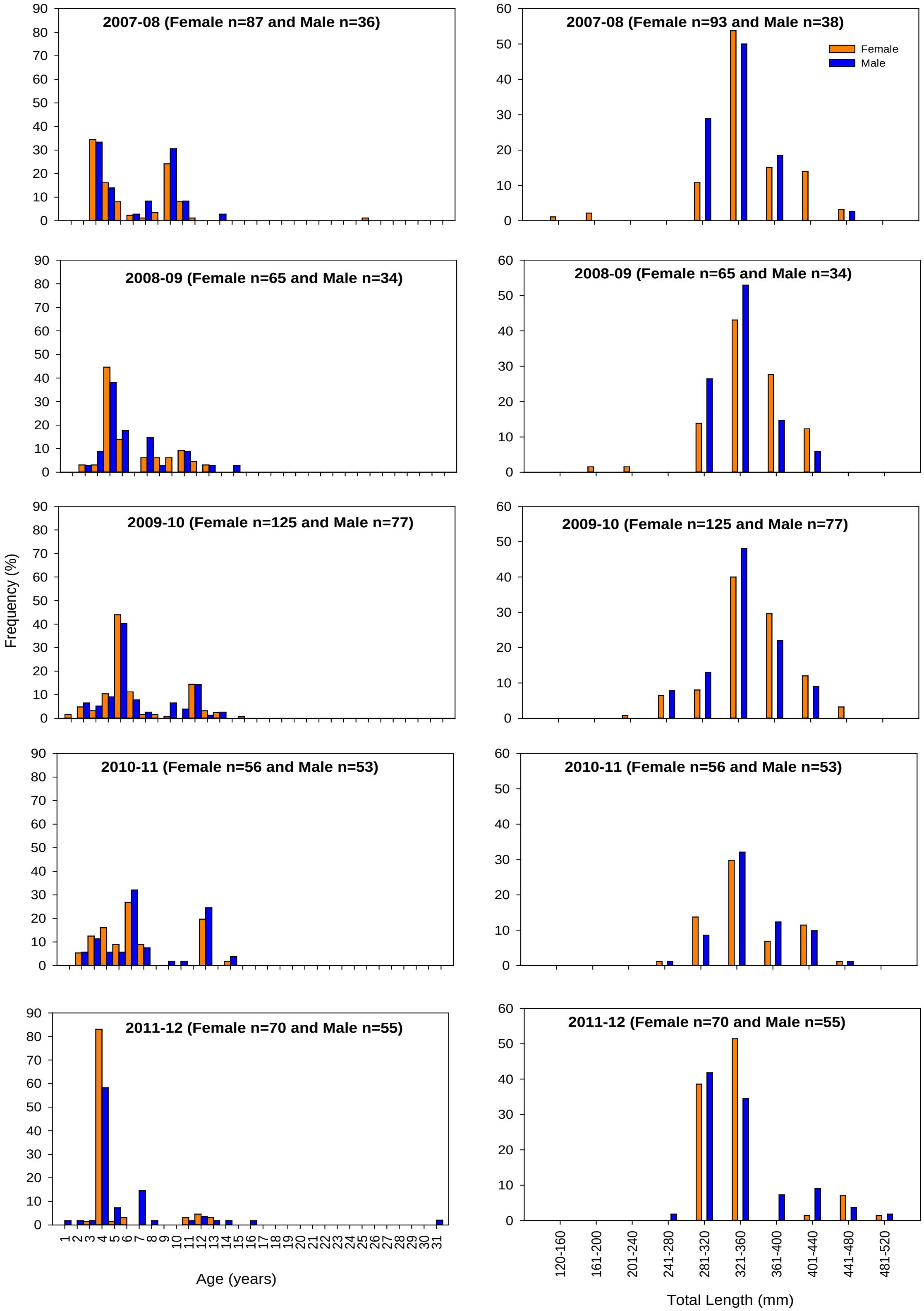


Figure 3.9. Age (left) and size (right) structures of black bream from the Murray Estuary and Coorong between 2007/08 and 2011/12 (most of the samples were from commercial catches).

3.3.4. Recruitment

Abundance of juvenile black bream exhibited a general decline from 2008/09 to 2011/12 (Table 3.1, Figure 3.10). PERMANOVA detected a significant interaction (p=0.001) when comparing CPUE of juvenile black bream between four years (2008/09-2011/12) 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 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 (p<0.005), but not at Mundoo Barrage and Boundary Creek. There has been a significant decrease (p<0.01) 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) and one additional sampling site (Godfrey's landing) although the increase was not statistically significant.

The analysis also revealed significant spatial differences in 2008/09 and 2009/10, but not in 2010/11 and 2011/12. In 2008/09, CPUE at Boundary Creek was significantly lower than at both Goolwa Barrage sites (both p=0.001), whilst in 2009/10, CPUE differed among three sites (Boundary Creek and two Goolwa Barrage sites) (p<0.05).

Length frequency distributions of juvenile black bream from all sites combined are presented for each year (Figure 3.11). In both 2008/09 and 2009/10, a modal progression from March to April was identified with a distinct size class appearing at 20-39 mm in March then progressing to 40-59 mm in April. No juvenile black bream were collected in 2010/11 and only four were present in the March samples, despite extra sampling effort.

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 2011/12. (Regular sampling sites are in bold. HI-Hindmarsh Island; SRP-Sir Richard Peninsula; YHP-Young Husband Peninsula; SE= standard error).

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

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

Source	df	MS	P(perm)
Year	3	9908	**0.001**
Site	3	7261	**0.001**
YearxSite	7	2266	**0.001**

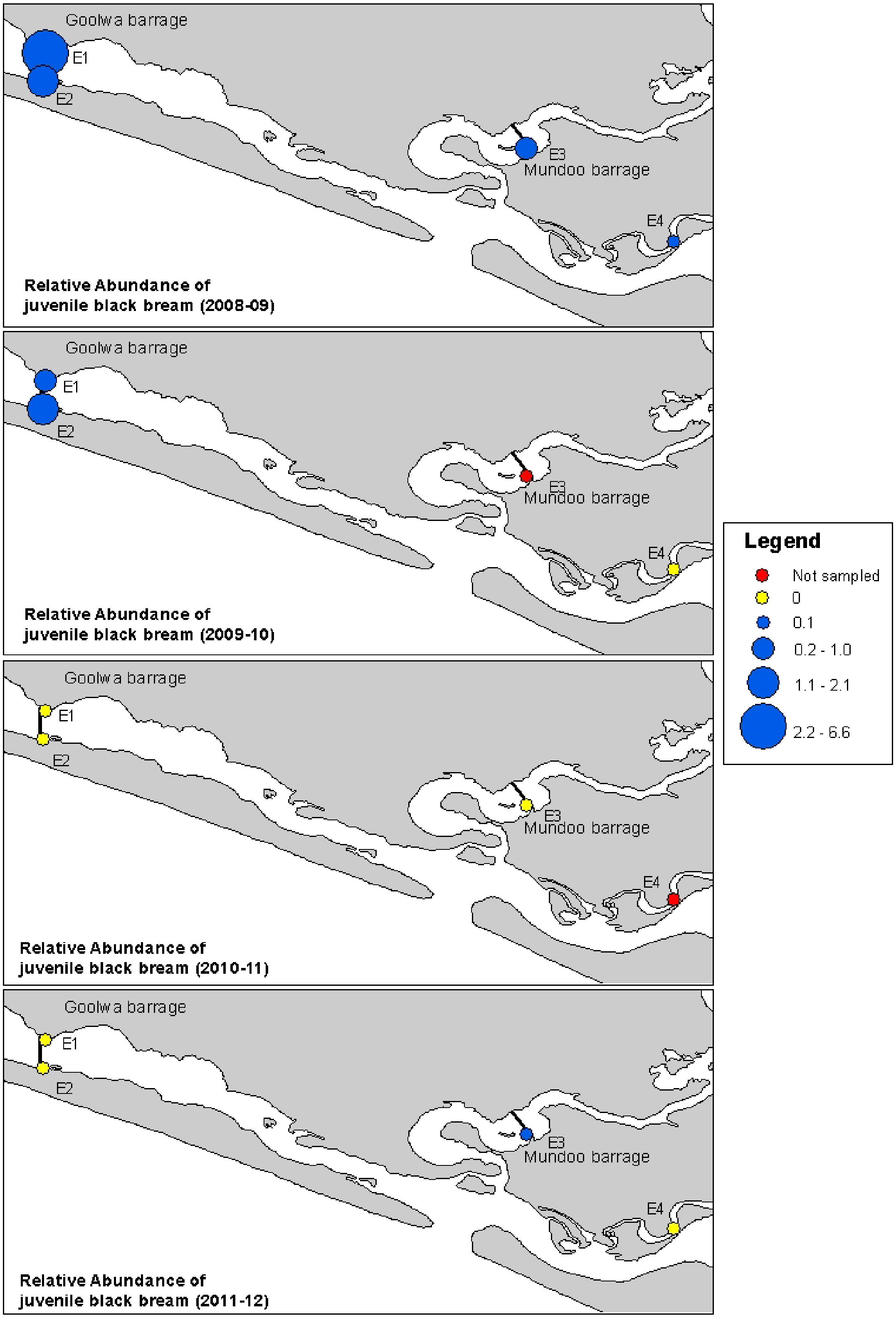


Figure 3.10. Murray Estuary map showing juvenile black bream relative abundance and distribution from 2008/09 to 2011/12 (top to bottom).

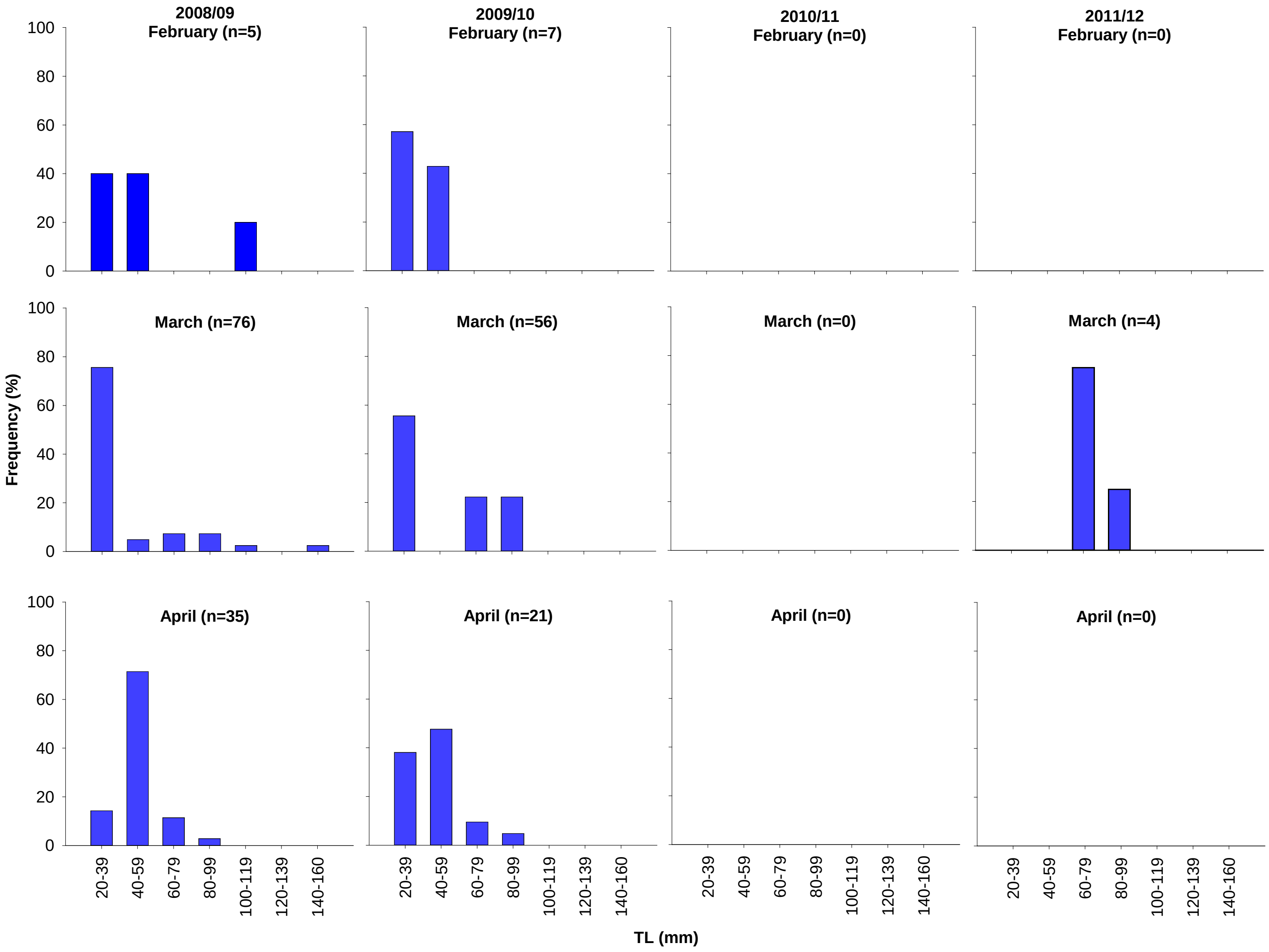


Figure 3.11. Length frequency distributions of juvenile black bream from fyke net samples in the Murray Estuary and Coorong from February to April between 2008/09 and 2011/12.

3.4. Greenback flounder

3.4.1. Fishery catch, effort and CPUE

In the past 27 years, about 99.6% of the Lakes and Coorong Fishery catch of the greenback flounder has come from the Coorong. 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 (Figure 3.12). Annual catches remained stable from 1995/96 to 2001/02 then declined to less than 5 t in 2002/03. Catches represented a historical low in 2008/09 and 2009/10 with 0.5 t and 1.0 t, respectively. In 2010/11, catches remained low with a total of 0.1 t. The dominant gear was the large mesh gill net, accounting for more 95% of the catch from the Coorong over 27 years (Figure 3.12).

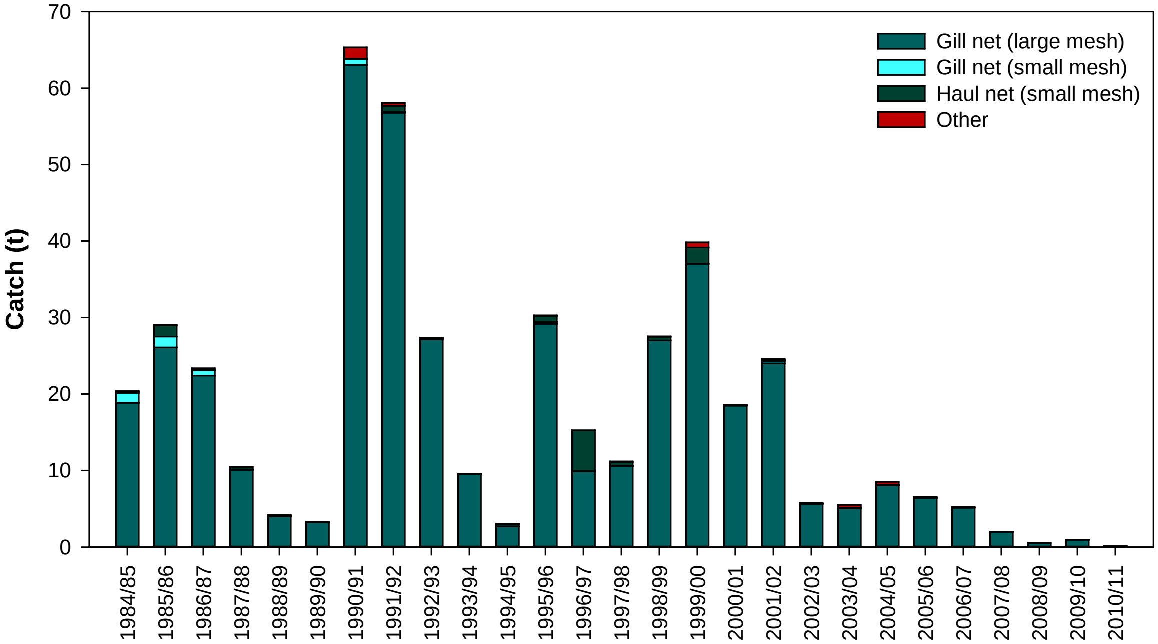


Figure 3.12. Annual catches of greenback flounder taken by gear type in the Coorong.

Historically, catches of greenback flounder were highly seasonal, with 78% of the annual catch taken between October and April, since 1984/85 (Figure 3.13). However such seasonality of catches was less defined from 2006/07 to 2010/11.

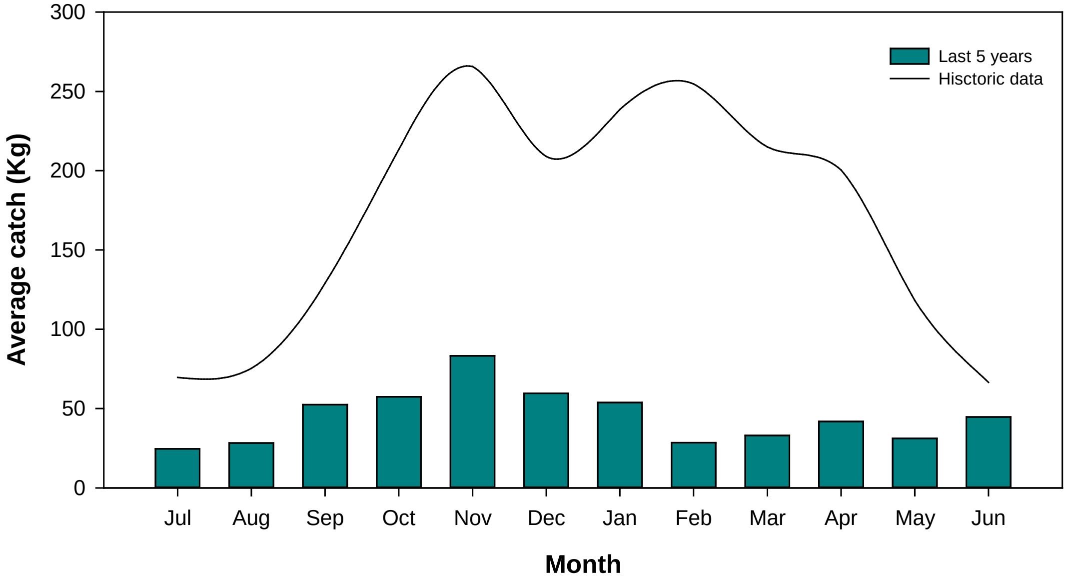


Figure 3.13. Long-term average monthly catches of greenback flounder from the Coorong Fishery (1984/85 to 2010/11) and average monthly catches from the last five years (2006/07 to 2010/11).

Annual targeted catch, effort, and CPUE for greenback flounder in large mesh gill nets are shown in Figure 3.14. The highest targeted catch was 45.8 t in 1990/91 (Figure 3.14 A). Targeted catch then declined to 0.5 t in 1994/95 before increasing to 29.2 t in 1999/2000. Since then targeted annual catches have declined to historically low levels. Targeted annual catch was 0.1 t in 2009/10 and similarly low in 2008/09 (catch amount cannot be presented due to confidentiality). In 2010/11, there was no targeted catch for greenback flounder. The contribution of targeted catch to total catch varied greatly between years, from 0% to 82% (Figure 3.14 A). In the last six years, the proportion of targeted catch declined continuously from 58% (2005/06) to 0% (2010/11).

Trends in annual targeted effort (fisher days) were similar to those of targeted catch. Highest effort occurred in 1990/91, 1991/92 and 1992/93 when there were more than 2000 fisher days per year (Figure 3.14 B). Targeted effort declined steeply to 79 fisher days in 1994/95, before rising to 1248 fisher days in 1999/2000. 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 for greenback flounder in 2010/11.

Trends in effort defined as fisher days and net days were similar with both measures linearly related (LR: $R^2=0.95$, $F_{1,25}=496.75$, $p<0.001$). Variability in targeted effort (fisher day) explained 79% of the variability in targeted catch (LR: $R^2=0.79$, $F_{1,25}=91.84$, $p<0.001$), while effort (net days) explained 81% of the catch (LR: $R^2=0.81$, $F_{1,25}=105.79$, $p<0.001$).

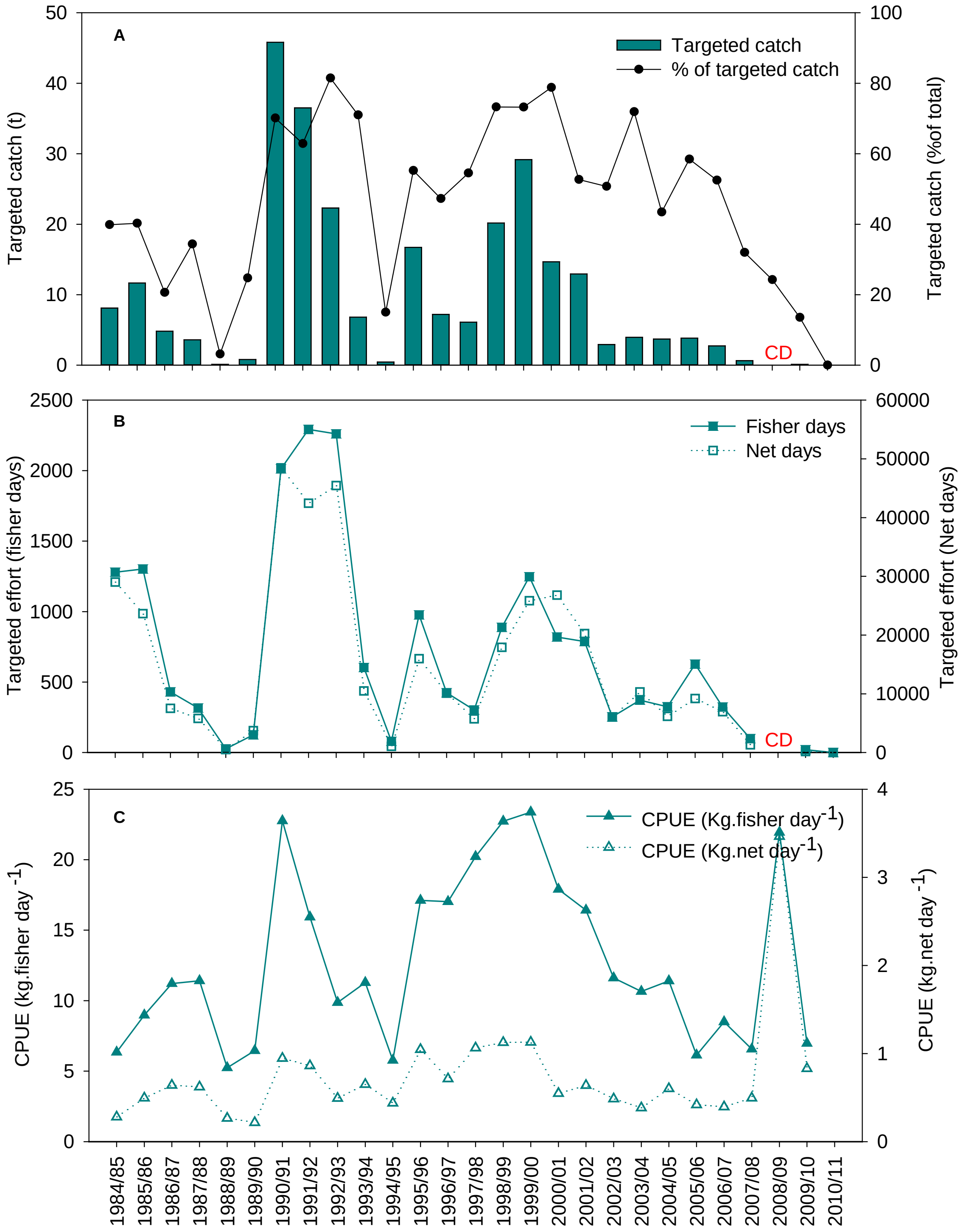


Figure 3.14. Annual targeted catch and effort for greenback flounder caught in the large mesh gill nets. (A) Targeted catch shown in tonnes, and as percentage of total catch, (B) Comparison of two measures of effort, and (C) Comparison of two estimates of CPUE. CD: confidential data, as these involved fewer than five fishers.

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 3.14 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. 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. Trends in net day–based CPUE (kg.net day^{-1}) were generally similar to those for fisher day-based CPUE (kg.fisher day^{-1}).

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 catches of greenback flounder (averaging 75%) came from the North Lagoon of the Coorong (Blocks 9, 10, 11) prior to 2005/06 (Figure 3.15). Since 2006/07, the proportional catch from the North Lagoon has reduced significantly such that by 2009/10 and 2010/11, 100% of catches were from the Estuary (Blocks 6, 7, 8) (Figure 3.15 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% of the catch came from this subregion (Figure 3.15 B). Since 2002/03, there have been no catch records of greenback flounder from the South Lagoon.

Proportional catch of greenback flounder from the area south of Mark Point (circa North and South lagoons) did not have a distinct positive relationship with the existing year's freshwater inflow to the Coorong. However, it appeared to be positively related to the previous year's flow (Figure 3.16).

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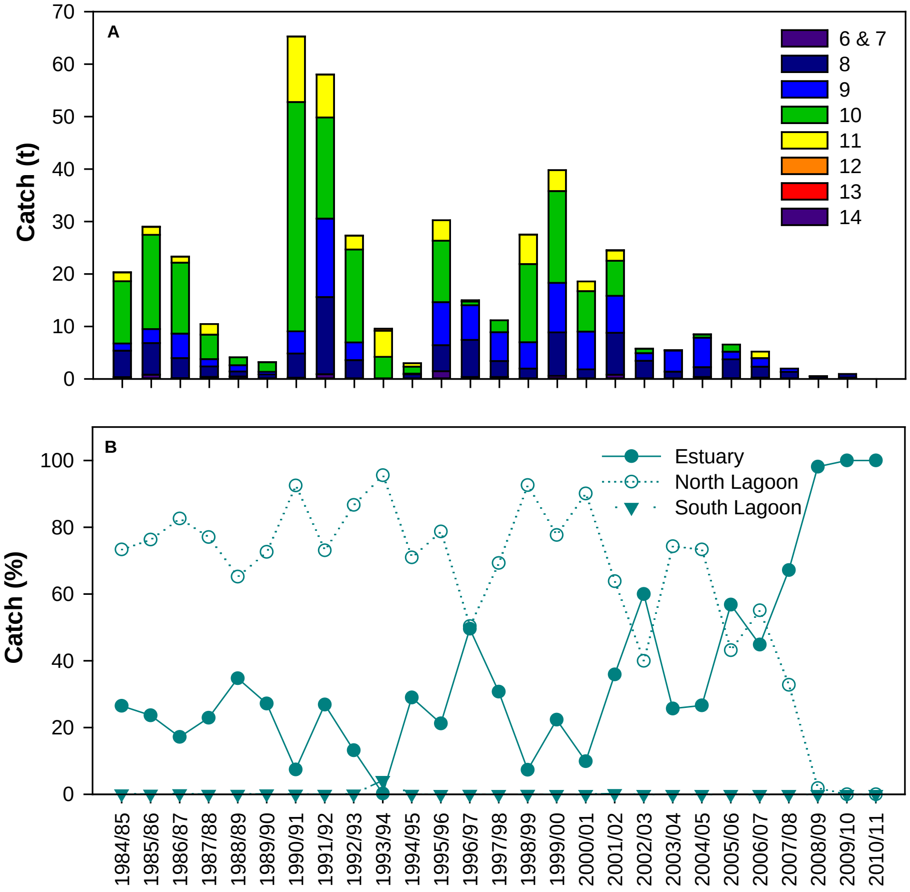

Figure 3.15. Greenback flounder catches from (A) reporting blocks within the Coorong lagoons, and (B) contribution to total catch by areas in the Estuary, North and South lagoons.

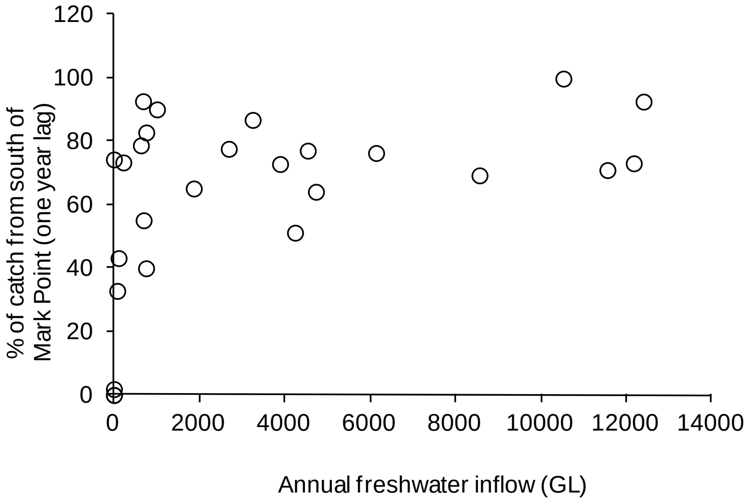

Figure 3.16. The relationship between freshwater inflows to the Coorong and contribution of greenback flounder catch from the area south of Mark Point to the total catch in the following year.

3.4.3. Size and age structures

Age structures of female and male greenback flounder are shown in Figure 3.17. 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 were 1 year olds; age ranged from 1 to 3 years for both sexes in 2010 and for female in 2011; only two males were collected in 2011 both of which were 1 year old. In 2010, most of the samples were derived from fishery-independent sampling and therefore the age structure difference may be attributed to gear selectivity.

In 2007 and 2010, the size distributions of female flounder were bimodal with distinct modes at 260-279 and 340-359 mm TL, and at 220-239 mm and 280-299 mm, respectively (Figure 3.17). Whilst in 2009 and 2011, the size distributions of females were unimodal with the majority (70% and 99%) being between 240 and 339 mm TL. Only eleven males were collected in 2007, 2010 and 2011 with sizes ranging from 220 to 359 mm; whilst no males were collected in 2009.

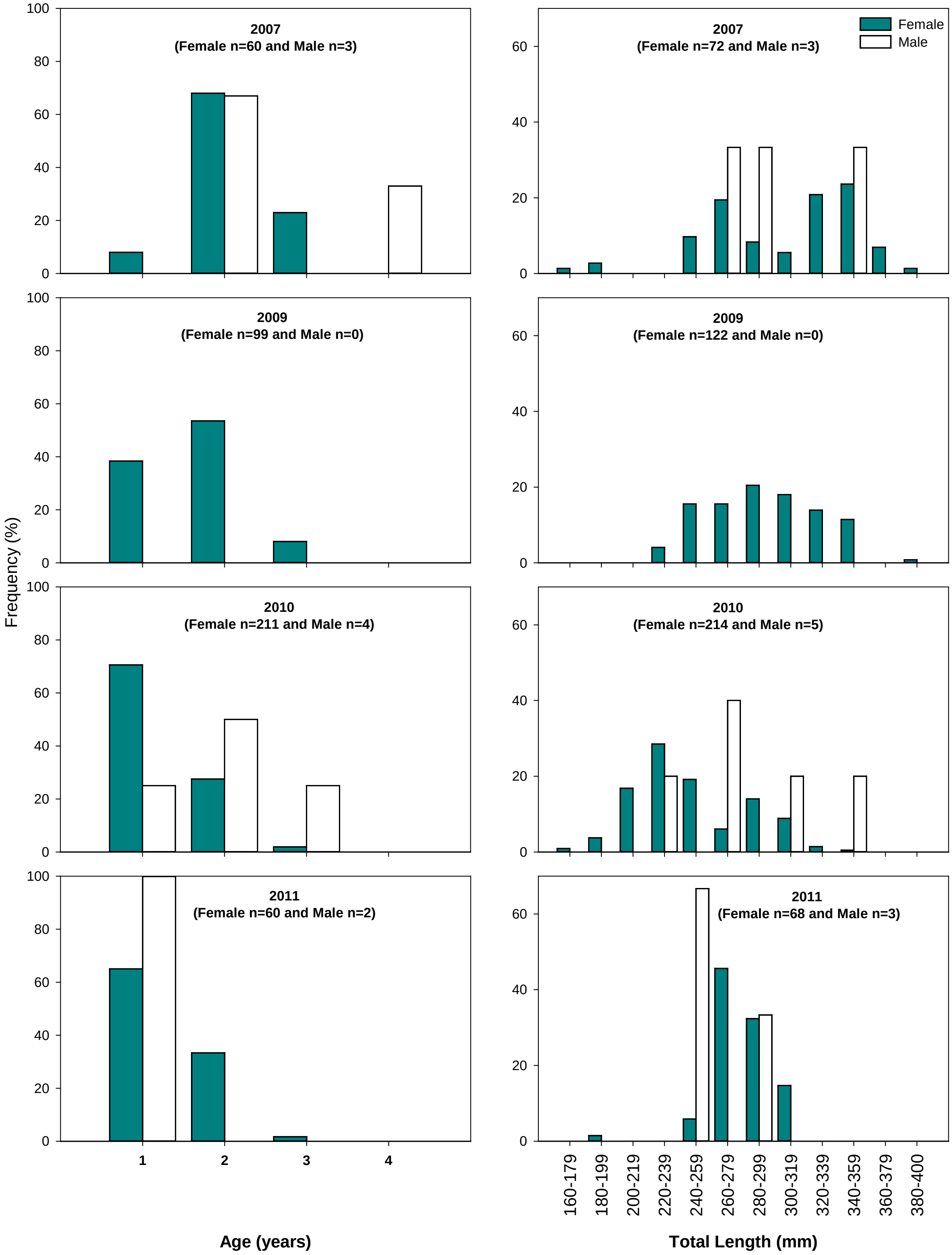

Figure 3.17. Age (left) and size (right) structures of greenback flounder from the Murray Estuary and Coorong in 2007, 2009, 2010 and 2011 (most of the samples were from commercial catches in 2007 and 2009 whilst 2010 samples were mainly from fishery-independent sampling).

3.4.4. Recruitment

The relative abundance of juvenile greenback flounder varied greatly across sites between years (2008/09-2011/12) in the Murray Estuary and Coorong (Table 3.3, Figure 3.18). PERMANOVA detected a significant interaction (*p*=0.001) between four years across three sites (Sugars Beach, Godfrey's Landing and Mark Point) (Table 3.4), indicating that the spatiotemporal pattern was not consistent across all years and sites. Pairwise comparisons revealed significant temporal variation at each site (Table 3.5). At Sugars Beach, the abundance of juvenile flounder was similar in 2008/09 and 2009/10; decreased significantly in 2010/11 following substantial barrage releases; and increased significantly in the second high flow year in 2011/12 (Tables 3.3 and 3.5). At Godfrey's Landing, CPUE showed a significant reduction from 2008/09 to 2009/10 and from 2010/11 to 2011/12. In contrast, at Mark Point, there was a significant increase in abundance of juveniles in the flood year (i.e. 2010/11), and CPUE remained at a similar level in 2011/12. Pairwise comparisons also identified spatial variation in each year, except 2011/12 (Table 3.6).

Length frequency distributions of juvenile fish from the three sites combined are presented in Figure 3.19. The size of fish ranged from 20 to 170 mm TL. Presence of small juvenile flounder (<80 mm TL) in each year indicated that recruitment had occurred annually over the last four years in the Coorong. In both 2010/11 and 2011/12, the size distribution in January was comprised of more larger fish compared to the previous drought years (Figure 3.19).

Table 3.3. Catch per unit effort (CPUE) for juvenile greenback flounder using seine net in the Murray Estuary and Coorong from 2008/09 to 2011/12.

CPUE (fish per net.shot)	**2008/09**		**2009/10**		**2010/11**		**2011/12**	
Regular sites	**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
Godfrey's Landing	17.4	3.2	4.3	1.1	8.9	2.7	1.3	0.8
Mark Point	0.4	0.2	0.4	0.2	1.8	0.5	2.2	1.7
Average across sites	9.6	2.0	10.8	3.7	3.8	1.1	2.6	0.9

Table 3.4. PERMANOVA results for CPUE of juvenile greenback flounder, comparison between years and sites in the Murray Estuary and Coorong. Bold *p* values are significant.

Source	df	MS	P(perm)
Year	3	4635.8	**0.002**
Site	2	15302.0	**0.001**
YearxSite	6	6937.9	**0.001**

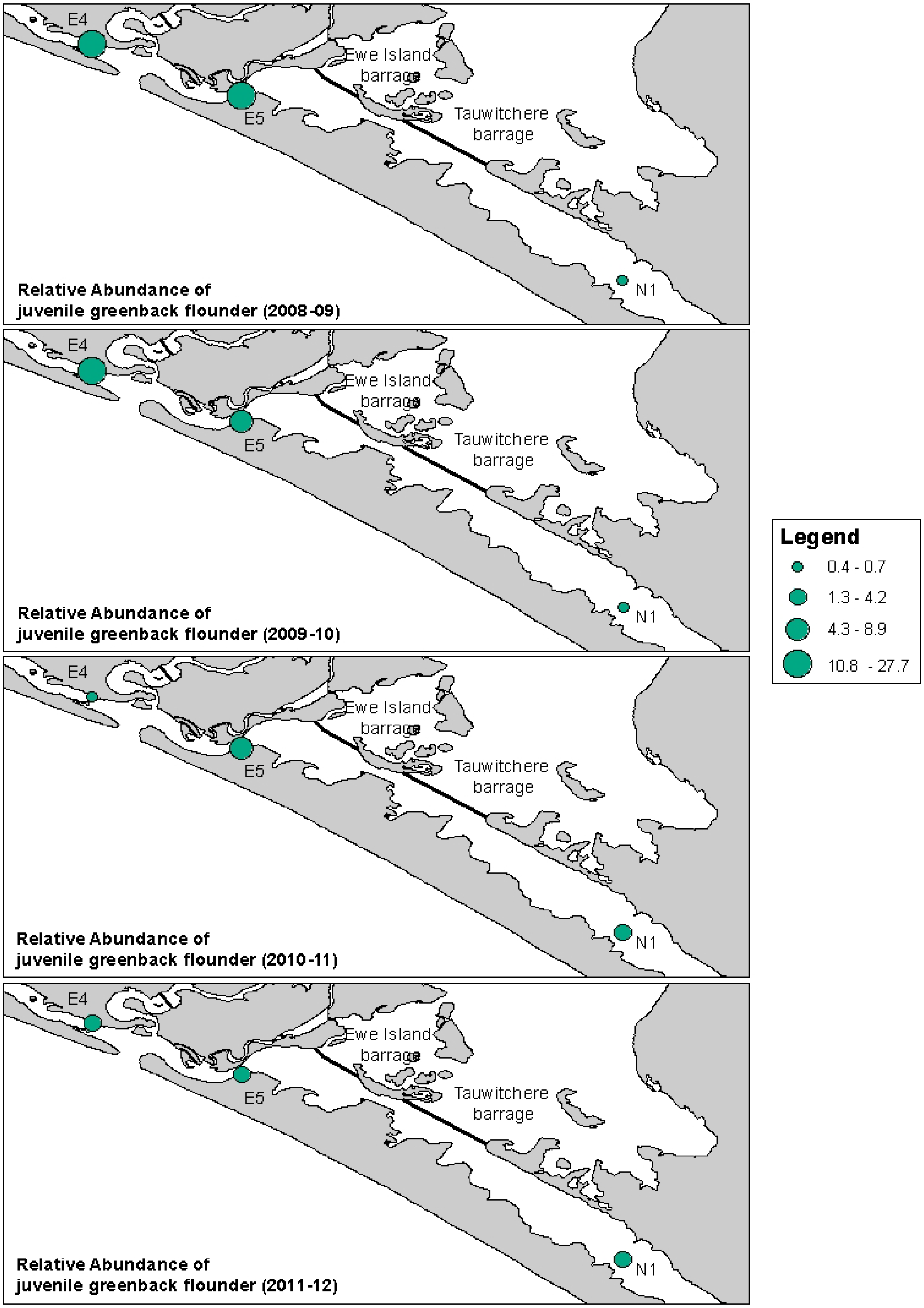

Figure 3.18. Coorong map showing juvenile greenback flounder relative abundance and distribution from 2008/09 to 2011/12 (top to bottom).

Table 3.5. PERMANOVA pair-wise test factor level year, results for CPUE of juvenile greenback flounder, comparison between years and sites in the Murray Estuary and Coorong. Bold *p* values are significant.

Sugars beach	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	1.4707	0.138
	2008/09 x 2010/11	3.7118	**0.001**
	2008/09 x 2011/12	1.5099	0.137
	2009/10 x 2010/11	4.9856	**0.001**
	2009/10 x 2011/12	2.7671	**0.003**
	2010/11 x 2011/12	1.9535	0.044
Godfrey's landing	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	2.6670	**0.005**
	2008/09 x 2010/11	1.6945	0.085
	2008/09 x 2011/12	4.7894	**0.001**
	2009/10 x 2010/11	0.8870	0.444
	2009/10 x 2011/12	2.1837	0.05
	2010/11 x 2011/12	2.7789	**0.008**
Mark Point	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	0.2852	1
	2008/09 x 2010/11	1.9629	0.091
	2008/0 9x 2011/12	0.7566	0.646
	2009/10 x 2010/11	1.9658	0.054
	2009/10 x 2011/12	0.8041	0.807
	2010/11 x 2011/12	1.1447	0.293

Table 3.6. PERMANOVA pair-wise test factor level site, results for CPUE of juvenile greenback flounder, comparison between years and sites in the Murray Estuary and Coorong. Bold *p* values are significant.

2008/09	**Groups**	**t**	**P(perm)**
	Sugars Beach x Godfrey's Landing	1.3699	0.181
	Sugars Beach x Mark Point	4.1687	**0.002**
	Godfrey's Landing x Mark Point	6.1287	**0.001**
2009/10	**Groups**	**t**	**P(perm)**
	Sugars Beach x Godfrey's landing	2.6136	**0.002**
	Sugars Beach x Mark Point	5.6931	**0.001**
	Godfrey's Landing x Mark Point	3.1719	**0.013**
2010/11	**Groups**	**t**	**P(perm)**
	Sugars Beach x Godfrey's Landing	3.2795	**0.004**
	Sugars Beach x Mark Point	1.5506	0.134
	Godfrey's Landing x Mark Point	2.1459	**0.023**
2011/12	**Groups**	**t**	**P(perm)**
	Sugars Beach x Godfrey's Landing	1.5066	0.111
	Sugars Beach x Mark Point	1.4239	0.158
	Godfrey's Landing x Mark Point	0.3314	0.911

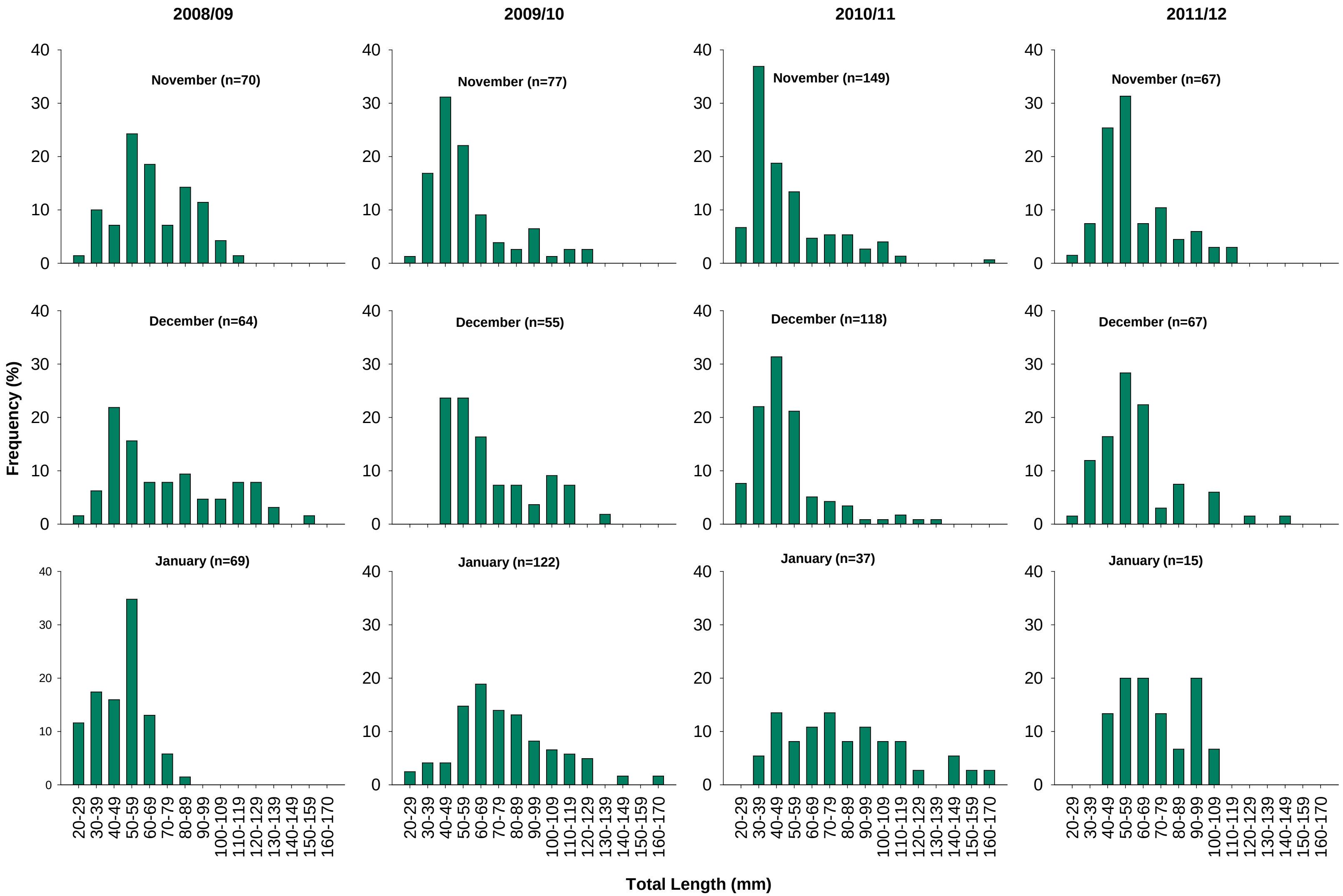

Figure 3.19. Length frequency distributions of juvenile greenback flounder from seine net samples in the Murray Estuary and Coorong from November to January between 2008/09 and 2011/12.

3.5. Smallmouthed Hardyhead

3.5.1. Abundance and distribution

There has been a substantial increase in the abundance of smallmouthed hardyhead in 2011/12 relative to previous years (Table 3.7, Figure 3.20). A significant interaction (*p*=0.001) when comparing CPUE between years (2008/09-2011/12) 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 3.8). Pairwise comparisons detected significant differences in abundance between years at all sites (Table 3.9). At Mark Point, Noonameena and Salt Creek, relative abundance increased significantly from 2008/09 to 2009/10, with similar abundances in 2010/11 and 2011/12, except for a further significant increase in abundance at Salt Creek in 2011/12. At Hells Gate and Jack Point, abundance was not significantly different between 2008/09 and 2009/10, but increased significantly in 2010/11, and again in 2011/12. CPUE at Salt Creek inside creek showed a significant decrease from 2009/10 to 2010/11, followed by a significant increase in 2011/12 to a similar level to that of the first two years. Pairwise comparisons also revealed a significant spatial difference in smallmouthed hardyhead abundance in each year (Table 3.10); nevertheless, in 2011/12 the difference only occurred at the most northern site (Mark Point) and Salt Creek inside creek whilst fish were consistently abundant between Noonameena and Salt Creek. The distributional range of this species has also expanded in the South Lagoon since 2008/09 (Figure 3.20).

Table 3.7. 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 2011/12.

CPUE (fish per net.shot)	**2008/09**		**2009/10**		**2010/11**		**2011/12**	
Regular sites	**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
Noonameena	248.0	37.6	1057.0	259.2	1029.8	604.4	1043.8	358.6
Hells Gate	1.8	1.2	0.1	0.1	252.3	78.0	1013.8	266.6
Jack Point	0.0	0.0	0.4	0.3	38.3	15.4	931.7	169.1
Salt Creek	0.4	0.4	79.7	30.1	168.1	60.3	742.5	131.5
Salt Creek inside creek	182.0	61.0	256.7	38.1	50.1	13.0	269.6	68.4
Average across sites	**56.8**	**14.7**	**261.6**	**61.3**	**276.4**	**106.7**	**689.8**	**91.4**

Table 3.8. PERMANOVA results for CPUE of smallmouthed hardyhead (samples from standard seine net), comparison between years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

Source	**df**	**MS**	**P(perm)**
Year	3	26312.0	**0.001**
Site	5	9990.2	**0.001**
Year x Site	15	4079.5	**0.001**

Table 3.9. PERMANOVA pairwise test factor level year, results for CPUE of smallmouthed hardyhead (samples from standard seine net), comparison between years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

Mark Point	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	3.3450	**0.004**
	2008/09 x 2010/11	8.5036	**0.001**
	2008/09 x 2011/12	3.9163	**0.002**
	2009/10 x 2010/11	1.6780	0.089
	2009/10 x 2011/12	0.5344	0.683
	2010/11 x 2011/12	1.7702	0.064
Noonameena	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	3.8096	**0.002**
	2008/09 x 2010/11	1.0532	0.325
	2008/09 x 2011/12	1.3525	0.181
	2009/10 x 2010/11	1.4137	0.162
	2009/10 x 2011/12	1.0899	0.261
	2010/11 x 2011/12	0.2658	0.889
Hells Gate	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	2.0192	0.12
	2008/09 x 2010/11	7.4926	**0.001**
	2008/09 x 2011/12	8.5763	**0.001**
	2009/10 x 2010/11	14.806	**0.001**
	2009/10 x 2011/12	15.4960	**0.001**
	2010/11 x 2011/12	2.9671	**0.007**
Jack Point	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	1.4694	0.489
	2008/09 x 2010/11	4.8417	**0.001**
	2008/09 x 2011/12	24.136	**0.001**
	2009/10 x 2010/11	3.5344	**0.006**
	2009/10 x 2011/12	12.8320	**0.001**
	2010/11 x 2011/12	4.8728	**0.001**
Salt Creek	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	3.7123	**0.002**
	2008/09 x 2010/11	6.1077	**0.001**
	2008/09 x 2011/12	16.6810	**0.001**
	2009/10 x 2010/11	1.1146	0.26
	2009/10 x 2011/12	3.9501	**0.001**
	2010/11 x 2011/12	3.4800	**0.002**
Salt Creek inside creek	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	0.5055	0.676
	2008/09 x 2010/11	2.1880	**0.025**
	2008/09 x 2011/12	0.4178	0.69
	2009/10 x 2010/11	4.3467	**0.001**
	2009/10 x 2011/12	0.1360	0.938
	2010/11 x 2011/12	4.2427	**0.001**

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

2008/09	Groups	t	P(perm)
	Mark Point x Noonameena	10.2770	**0.001**
	Mark Point x Hells Gate	1.0167	0.362
	Mark Point x Jack Point	1.4687	0.463
	Mark Point x Salt Creek	0.6753	0.726
	Mark Point x Salt Creek inside creek	5.0658	**0.004**
	Noonameena x Hells Gate	8.5384	**0.001**
	Noonameena x Jack Point	37.9880	**0.001**
	Noonameena x Salt Creek	15.7030	**0.001**
	Noonameena x Salt Creek inside creek	0.6998	0.49
	Hells Gate x Jack Point	2.7117	**0.045**
	Hells Gate x Salt Creek	1.7915	0.119
	Hells Gate x Salt Creek inside creek	4.1567	**0.003**
	Jack Point x Salt Creek	1.0000	1
	Jack Point x Salt Creek inside creek	45.0600	**0.002**
	Salt Creek x Salt Creek inside creek	8.1234	**0.002**
2009/10	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	2.9573	**0.003**
	Mark Point x Hells Gate	4.2016	**0.003**
	Mark Point x Jack Point	3.7058	**0.002**
	Mark Point x Salt Creek	0.5911	0.617
	Mark Point x Salt Creek inside creek	2.1901	**0.053**
	Noonameena x Hells Gate	17.6590	**0.001**
	Noonameena x Jack Point	13.1650	**0.001**
	Noonameena x Salt Creek	3.9746	**0.001**
	Noonameena x Salt Creek inside creek	3.4975	**0.004**
	Hells Gate x Jack Point	0.6820	0.735
	Hells Gate x Salt Creek	3.9202	**0.003**
	Hells Gate x Salt Creek inside creek	17.4090	**0.001**
	Jack Point x Salt Creek	3.3685	**0.005**
	Jack Point x Salt Creek inside creek	12.3920	**0.001**
	Salt Creek x Salt Creek inside creek	3.0485	**0.002**
2010/11	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	2.4170	**0.014**
	Mark Point x Hells Gate	1.5156	0.145
	Mark Point x Jack Point	2.8952	**0.007**
	Mark Point x Salt Creek	1.1648	0.232
	Mark Point x Salt Creek inside creek	2.0451	0.057
	Noonameena x Hells Gate	1.3511	0.168
	Noonameena x Jack Point	3.6562	**0.001**
	Noonameena x Salt Creek	2.1918	**0.028**
	Noonameena x Salt Creek inside creek	3.6334	**0.003**
	Hells Gate x Jack Point	3.4597	**0.001**
	Hells Gate x Salt Creek	1.7484	0.083
	Hells Gate x Salt Creek inside creek	3.2857	**0.002**
	Jack Point x Salt Creek	1.4765	0.163
	Salt Creek x Salt Creek inside creek	0.7713	0.507

2011/12	Groups	t	P(perm)
	Mark Point x Noonameena	2.7349	**0.007**
	Mark Point x Hells Gate	3.5026	**0.001**
	Mark Point x Jack Point	3.7044	**0.001**
	Mark Point x Salt Creek	3.7787	**0.001**
	Mark Point x Salt Creek inside creek	2.6457	**0.013**
	Noonameena x Hells Gate	0.7236	0.508
	Noonameena x Jack Point	0.9457	0.354
	Noonameena x Salt Creek	0.9371	0.379
	Noonameena x Salt Creek inside creek	1.3636	0.172
	Hells Gate x Jack Point	0.2581	0.827
	Hells Gate x Salt Creek	0.3098	0.799
	Hells Gate x Salt Creek inside creek	2.7045	**0.011**
	Jack Point x Salt Creek	0.3941	0.692
	Jack Point x Salt Creek inside creek	3.2707	**0.004**
	Salt Creek x Salt Creek inside creek	3.6837	**0.004**

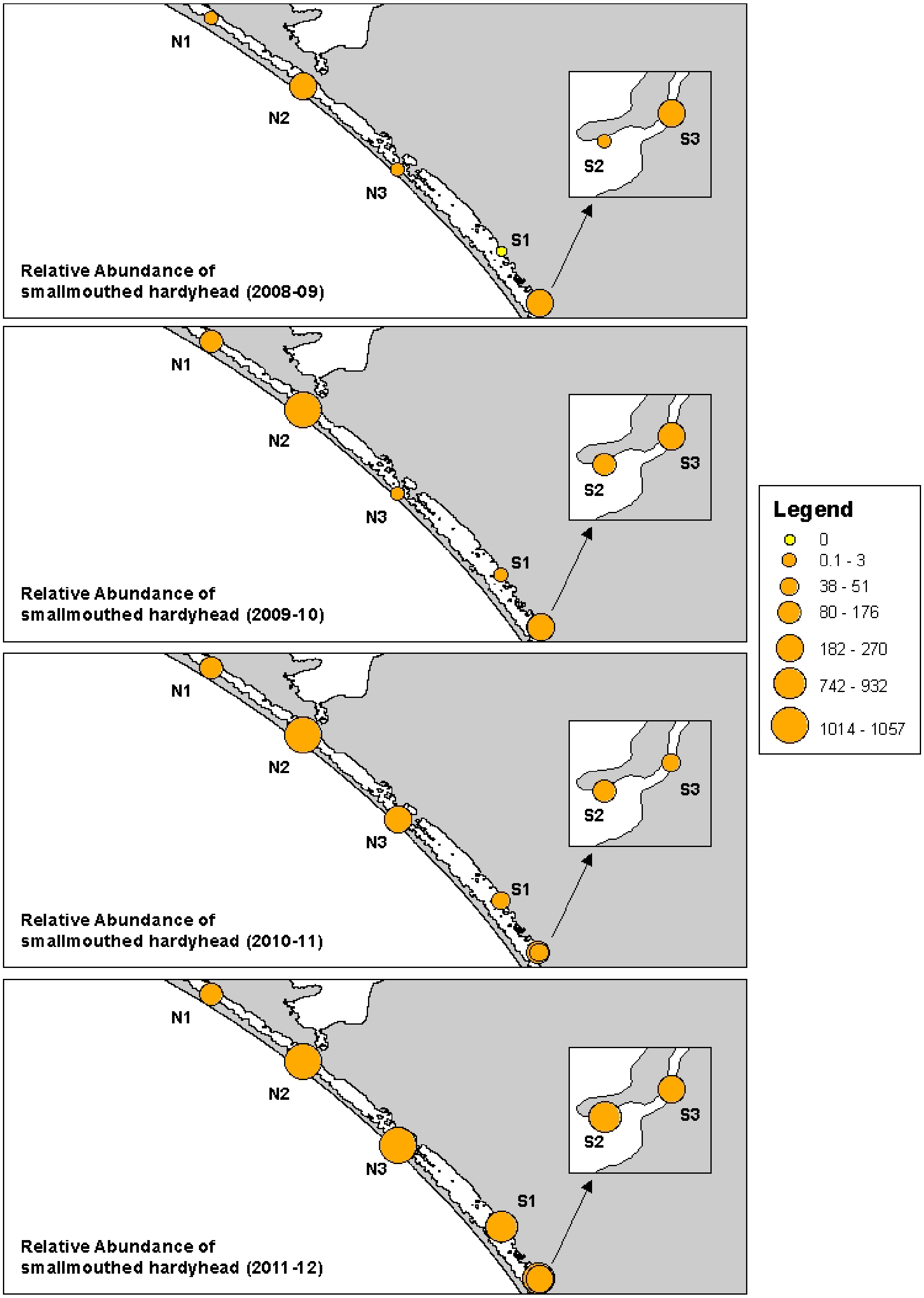

Figure 3.20. Coorong map showing relative abundance and distribution of smallmouthed hardyhead sampled using standard seine net from 2008/09 to 2011/12 (top to bottom). Inset map shows Salt Creek and Salt Creek inside creek sites.

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 3.21 and Figure 3.22. In the North Lagoon, fish size ranged from 10 to 89 mm TL in all years, except for 2011/12, when larger fish were collected (100 mm TL). No modal progression was identified between months in 2008/09, and there appeared to be a reduction in larger fish between December and January. In 2009/10, samples from the small seine net showed a modal progression from 10-19 mm in November to 30-39 mm TL in January, but the relative abundance of larger fish also somewhat reduced in January. Contrastingly, in 2010/11, a distinct modal progression was present throughout the sampling season, and the decline in number of larger fish did not occur until February. Contrastingly, in 2011/12, the modal progression only occurred from December to January (from 10-19 mm to 20-29 mm). The presence of smaller fish (<39 mm) throughout the sampling months suggested a protracted spawning season.

In the South Lagoon, fish size ranged from 10 to 89 mm TL, except in 2009/10 and 2010/11, when all fish collected were ≤79 mm TL. The 2008/09 data were patchy given low abundance of smallmouthed hardyhead present within the lagoon; the size structure was mostly represented by samples from the Salt Creek inside creek in February. It should be noted that sampling only commenced at this site in February 2009. No distinct modal progression was detected in 2009/10. In 2010/11, a considerable reduction of larger fish occurred in December, followed by a modal progression in the large seine net samples from December to January (20-29 mm to 40-49 mm TL, respectively). Between January and February 2011, there appeared to be another reduction in abundance of larger fish. In 2011/2012, there was a clear modal progression for samples from the small seine net from November to December (10-19 mm to 20-19 mm TL) and similar to 2010/11, a reduction of larger fish occurred in December.

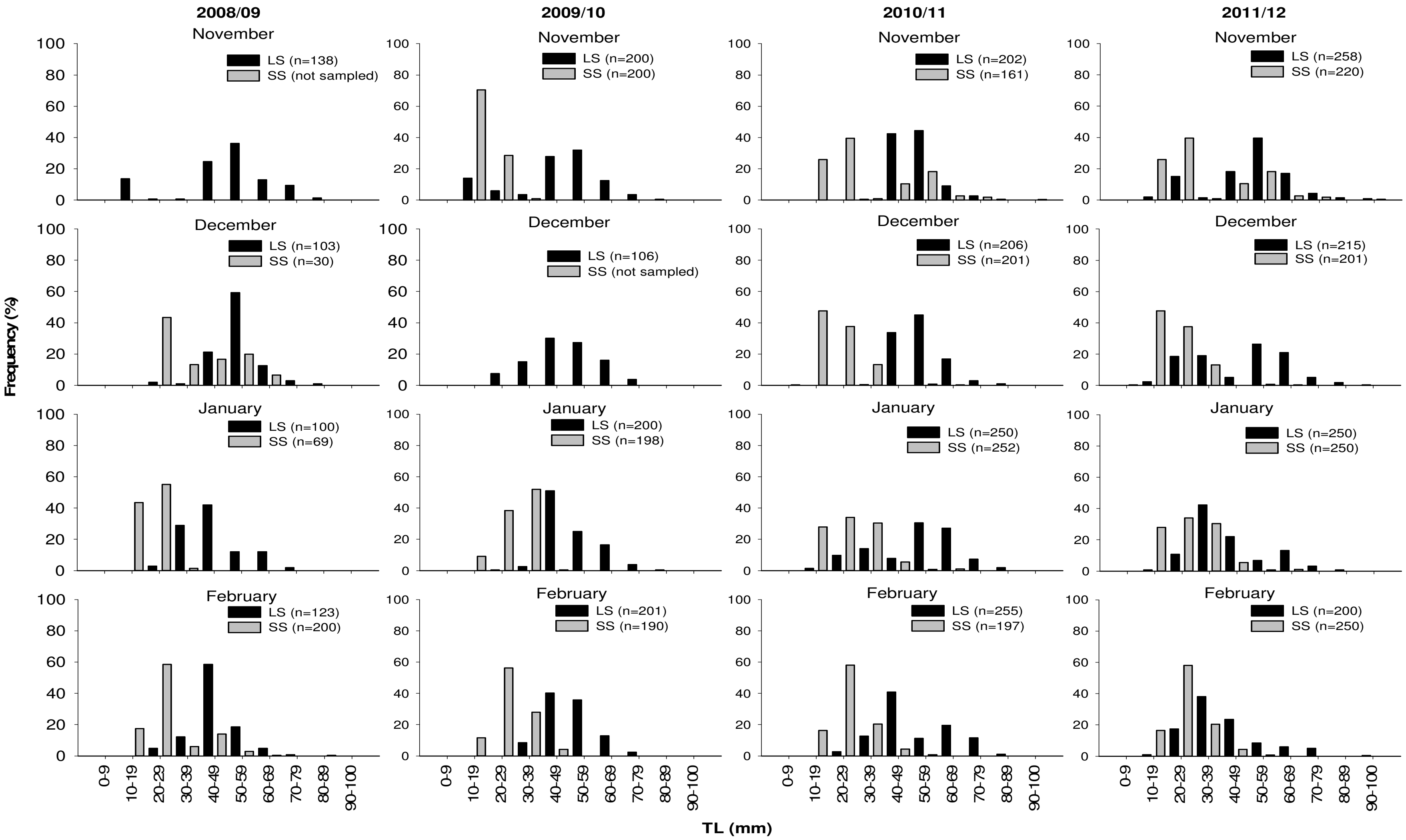

Figure 3.21. Length frequency distributions of smallmouthed hardyhead from standard (LS) and small (SS) seine nets in the North Lagoon sites from November to February between 2008/09 and 2011/12.

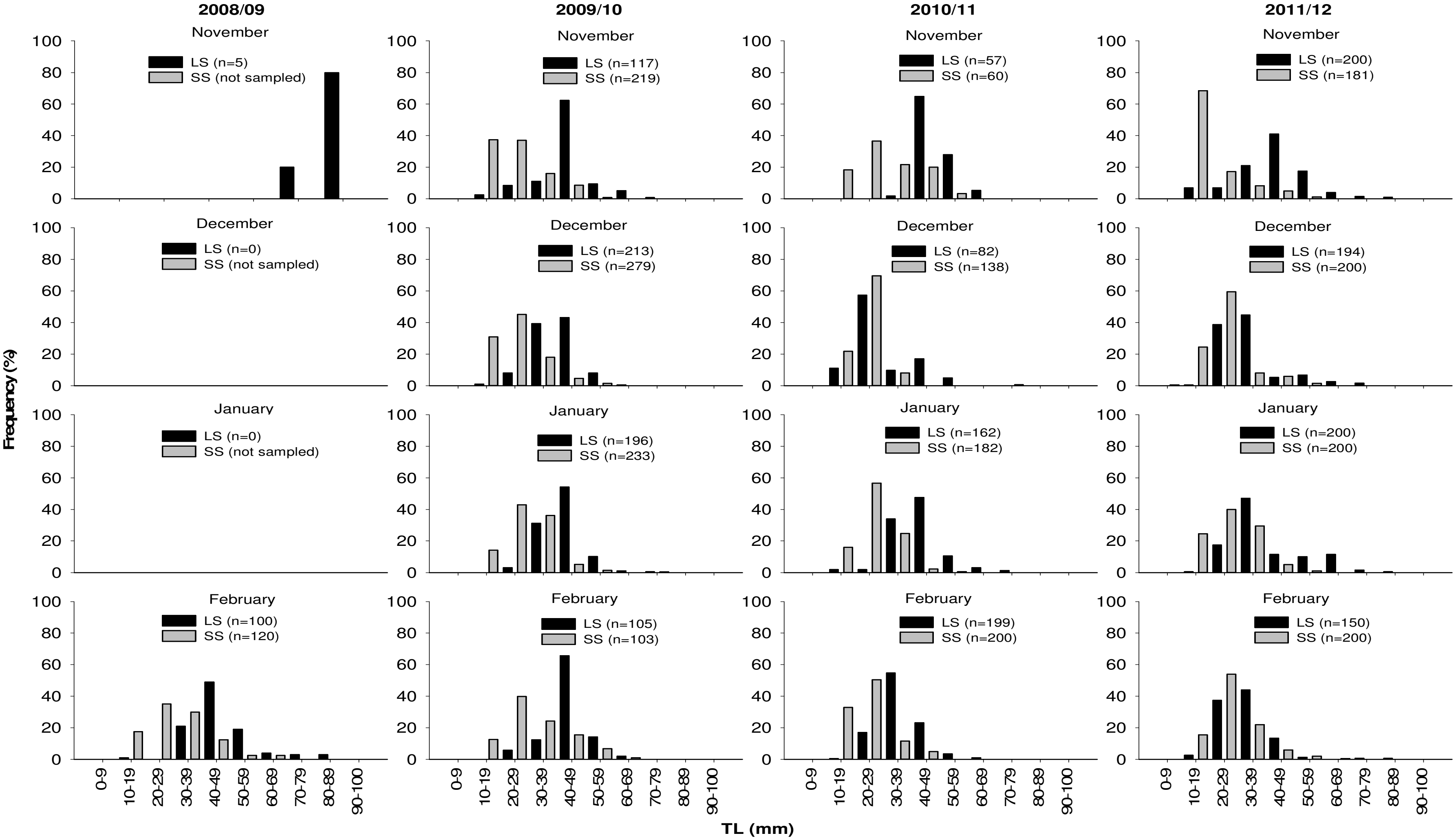

Figure 3.22. Length frequency distributions of smallmouthed hardyhead from standard (LS) and small (SS) seine nets in the South Lagoon sites from November to February between 2008/09 and 2011/12.

3.5.3. Recruitment

There have been consistent and substantial increases in the abundance of juvenile smallmouthed hardyhead over the last four years in the North and South Lagoons of the Coorong (Table 3.11, Figure 3.23). A significant interaction (*p*=0.001) was detected when comparing CPUE of juvenile smallmouthed hardyhead between years across sites (Table 3.12), indicating that the spatiotemporal pattern was not consistent in all years and sites. Pairwise comparisons detected significant temporal variation at each site (Table 3.13). In particular, CPUE increased significantly from 2008/09 to 2009/10 at Mark Point, then maintained at a similar level in the following two years. 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 in the following year at Jack Point. Pairwise comparisons also revealed a significant spatial difference in all years (Table 3.14).

Table 3.11. 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**	
Regular sites	**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
Noonameena	175.3	41.1	195.9	28.3	2541.7	808.9	2598.3	992.6
Hells Gate			0.3	0.2	1122.1	288.3	1676.7	374.4
Jack Point			8.8	3.8	72.6	14.5	794.8	196.2
Salt Creek			238.0	129.3	290.5	60.8	2065.8	325.7
Salt Creek inside creek	59.0	18.2	520.0	75.8	60.0	12.9	82.7	23.9
Average across sites	116.2	24.7	220.3	36.3	749.1	175.2	1255.8	212.3

Table 3.12. PERMANOVA results for CPUE of juvenile smallmouthed hardyhead, comparison between years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

Source	df	MS	P(perm)
Year	3	7413.9	**0.001**
Site	5	3413.8	**0.001**
Year x Site	12	3595.3	**0.001**

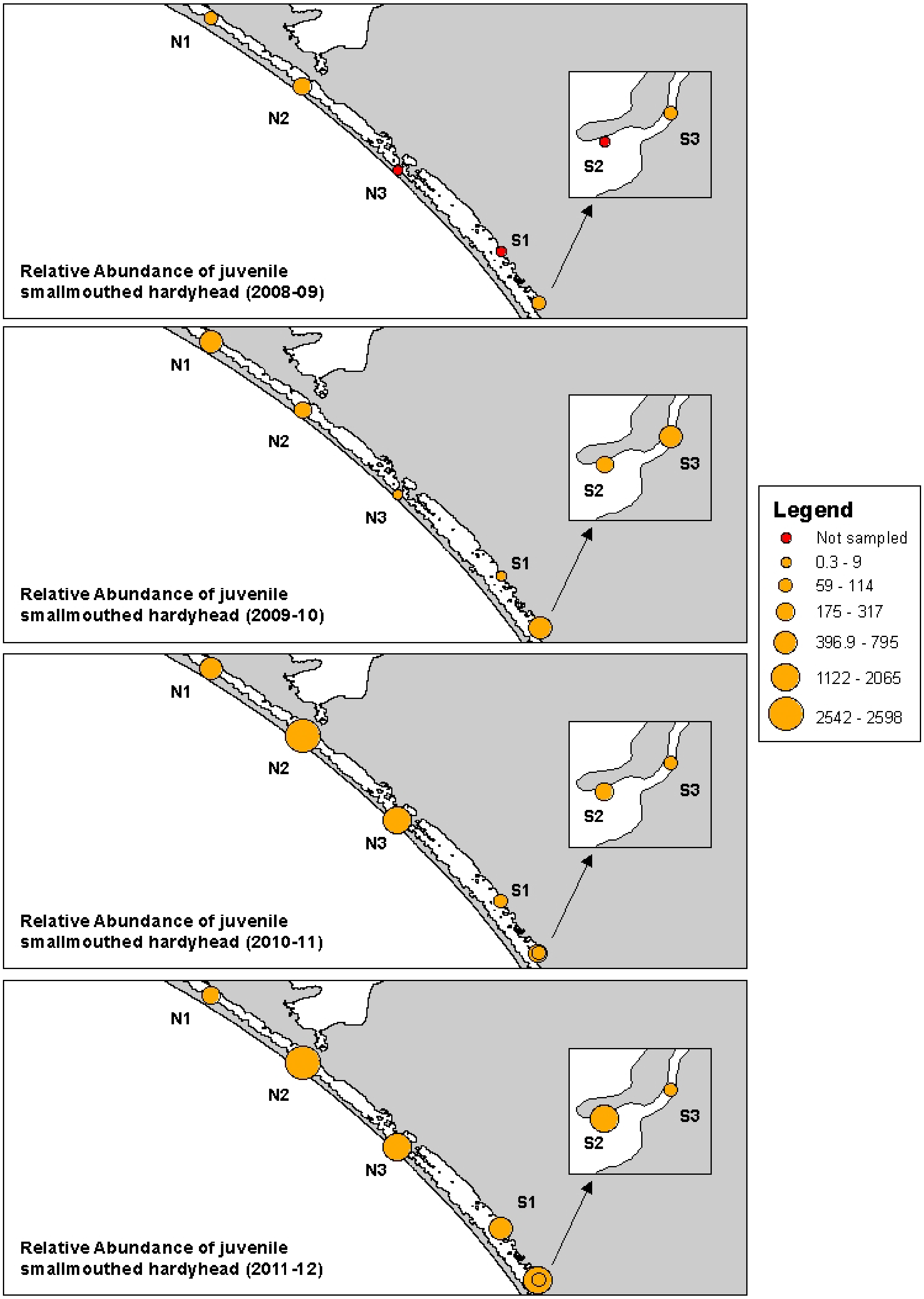

Figure 3.23. Coorong map showing relative abundance and distribution of juvenile smallmouthed hardyhead sampled using small seine net from 2008/09 to 2011/12 (top to bottom). Inset map shows Salt Creek and Salt Creek inside creek sites.

Table 3.13. PERMANOVA pair-wise test factor level year, results for CPUE of juvenile smallmouthed hardyhead (samples from small seine net), comparison between years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

Mark Point	Groups	t	P(perm)
	2008/09 x 2009/10	4.6308	**0.004**
	2008/09 x 2010/11	0.9551	0.394
	2008/09 x 2011/12	0.4359	0.715
	2009/10 x 2010/11	1.5241	0.147
	2009/10 x 2011/12	1.7990	0.068
	2010/11 x 2011/12	0.6725	0.531
Noonameena	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	0.2091	0.8
	2008/09 x 2010/11	2.9054	**0.017**
	2008/09 x 2011/12	1.7941	0.092
	2009/10 x 2010/11	4.7501	**0.001**
	2009/10 x 2011/12	2.9670	**0.008**
	2010/11 x 2011/12	0.7269	0.483
Hells Gate	**Groups**	**t**	**P(perm)**
	2009/10 x 2010/11	9.4107	**0.001**
	2009/10 x 2011/12	12.644	**0.001**
	2010/11 x 2011/12	1.4729	0.167
Jack Point	**Groups**	**t**	**P(perm)**
	2009/10 x 2010/11	3.2098	**0.005**
	2009/10 x 2011/12	5.9292	**0.001**
	2010/11 x 2011/12	3.4673	**0.003**
Salt Creek	**Groups**	**t**	**P(perm)**
	2009/10 x 2010/11	1.565	0.136
	2009/10 x 2011/12	3.8812	**0.001**
	2010/11 x 2011/12	4.5939	**0.001**
Salt Creek inside creek	**Groups**	**t**	**P(perm)**
	2008/09 x 2009/10	4.8403	**0.003**
	2008/09 x 2010/11	0.3328	0.755
	2008/09 x 2011/12	0.2784	0.809
	2009/10 x 2010/11	7.2328	**0.001**
	2009/10 x 2011/12	5.5189	**0.001**
	2010/11 x 2011/12	0.2315	0.89

Table 3.14. PERMANOVA pair-wise test factor level site, results for CPUE of juvenile smallmouthed hardyhead (samples from small seine net), comparison between years and sites in the North and South lagoons of the Coorong. Bold *p* values are significant.

2008/09	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	1.1010	0.301
	Mark Point x Salt Creek inside creek	1.2808	0.321
	Noonameena x Salt Creek inside creek	2.8194	0.091

2009/10	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	3.6161	**0.002**
	Mark Point x Salt Creek inside creek	0.7148	0.49
	Mark Point x Hells Gate	11.5060	**0.001**
	Mark Point x Jack Point	5.4919	**0.001**
	Mark Point x Salt Creek	2.2963	**0.022**
	Noonameena x Salt Creek inside creek	3.4200	**0.003**
	Noonameena x Hells Gate	10.428	**0.001**
	Noonameena x Jack Point	4.8476	**0.001**
	Noonameena x Salt Creek	1.7946	0.084
	Salt Creek inside creek x Hells Gate	12.6820	**0.001**
	Salt Creek inside creek x Jack Point	6.3355	**0.001**
	Salt Creek inside creek x Salt Creek	2.7246	**0.004**
	Hells Gate x Jack Point	1.7719	0.091
	Hells Gate x Salt Creek	3.9108	**0.002**
	Jack Point x Salt Creek	2.0993	0.035

2010/11	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	3.8834	**0.002**
	Mark Point x Salt Creek inside creek	3.3387	**0.003**
	Mark Point x Hells Gate	1.6337	0.128
	Mark Point x Jack Point	2.2643	**0.007**
	Mark Point x Salt Creek	0.5158	0.683
	Noonameena x Salt Creek inside creek	7.6372	**0.001**
	Noonameena x Hells Gate	1.6227	0.108
	Noonameena x Jack Point	4.9332	**0.001**
	Noonameena x Salt Creek	3.5607	**0.001**
	Salt Creek inside creek x Hells Gate	4.3057	**0.001**
	Salt Creek inside creek x Jack Point	0.6771	0.651

2010/11	**Groups**	**t**	**P(perm)**
	Salt Creek inside creek x Salt Creek	2.1384	**0.052**
	Hells Gate x Jack Point	3.1596	**0.002**
	Hells Gate x Salt Creek	1.7161	0.095
	Jack Point x Salt Creek	1.6300	0.084

2011/12	**Groups**	**t**	**P(perm)**
	Mark Point x Noonameena	2.7104	**0.006**
	Mark Point x Salt Creek inside creek	1.6726	0.099
	Mark Point x Hells Gate	3.7839	**0.001**
	Mark Point x Jack Point	2.0342	**0.048**
	Mark Point x Salt Creek	4.8521	**0.001**
	Noonameena x Salt Creek inside creek	4.7900	**0.001**
	Noonameena x Hells Gate	0.5820	0.58
	Noonameena x Jack Point	1.1971	0.253

2011/12	**Groups**	**t**	**P(perm)**
	Noonameena x Salt Creek	1.3274	0.213
	Salt Creek inside creek x Hells Gate	6.9842	**0.001**
	Salt Creek inside creek x Jack Point	4.5205	**0.001**
	Salt Creek inside creek x Salt Creek	8.9983	**0.001**
	Hells Gate x Jack Point	2.0873	0.055
	Hells Gate x Salt Creek	1.1425	0.281
	Jack Point x Salt Creek	3.3707	**0.002**

4. DISCUSSION

4.1. Freshwater inflow and salinity

Over the past ten years (2001-2010), extensive drought in the Murray–Darling Basin, 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 among the highest (~13000 GL y^{-1}) for the last 28 years.

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 no barrage releases were made, the Coorong essentially became a marine/hypersaline environment; salinities in the southern part of the North Lagoon exceeded 100 ppt and those in the South Lagoon were about 3-4 times that of seawater (~140 ppt). These salinities are higher than those recorded during the 1982 drought, when average salinities were 80 ppt in the North Lagoon and 90-100 ppt 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.* 2011b).

With substantial freshwater inflows since September 2010, salinities declined throughout the Coorong in 2010/11 and 2011/12, 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 ppt. Similarly, Geddes (1987) recorded a refreshing of the Coorong in 1983/84 after drought following a period of substantial flows from the River Murray; the North Lagoon became brackish (<30 ppt) and the South Lagoon moderately hypersaline (55-70 ppt). Following broadly decreased salinities and other freshwater induced environmental changes in the Coorong during 2010-2012, fish assemblage structure changed significantly compared to that of the drought years. Firstly, there has been an increase in the diversity and abundance of freshwater species and increased abundances of small-bodied estuarine/opportunist species and catadromous species (congolli); and secondly, several estuarine species had a southward extension of their distribution (Ye *et al.* 2011a).

4.2. Black Bream

4.2.1. Abundance and distribution

The relative abundance of black bream, as indicated by fishery catches, has declined substantially in the Murray Estuary and Coorong in recent decades. 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 decline in population abundance. Following barrage releases in 2010/11, black bream catches showed a small increase but remained low in an historical context (2.3 t), representing 5% of the historical peak in 1984/85 and 20% of a more recent peak in 2002/03. A combination of low catches and high CPUE suggest that CPUE ceased to be a meaningful estimate of relative abundance during the drought due to aggregation of black bream into smaller areas of favorable habitat. Therefore, interpretation of the fishery catch and CPUE data as a biological performance indicator of population abundance needs to be in context of each 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. In the past 20 years prior to 2010/11, there has been a contraction of the fishing ground from the North Lagoon to the Murray Estuary; i.e. almost all black bream were harvested within the Estuary subregion from 2005/06 to 2009/10. Notably, the contraction of fishing area occurred concurrently 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 favorable habitat due to poor environmental conditions resulting from the decadal drought. In 2010/11, restoration of freshwater inflows refreshed the Coorong and led to a substantial increase in proportional catch of black bream from the North Lagoon. In addition, 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) (C. Bice, 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 utilised. 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. This range extension likely reflected the increase in area of favorable salinities. This information combined with the positive relationship between annual discharge and the catch contribution from the southern part of the Coorong further supports that freshwater inflow plays a pivotal role in maintaining and extending favorable 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 3 and 9 year old fish, which persisted in the following years and were shown as 5 and 11 year olds in 2009/10, and 6 and 12 year olds in 2010/11, respectively. By 2011/12, a distinct 7 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 barrage discharge of 78 GL (July to November 2006). Although the majority of adult samples came 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 among all five 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 favorable 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 could not be examined in this study), there is evidence to suggest that the timing of flows, rather than volume of flows 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 respectively) 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 of those years. Given black bream spawning in the Coorong typically occurs during spring/summer (Ye *et al.* 2011b), 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 upper North Lagoon and improved habitat condition within the system, facilitating higher survivorship 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). 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. intensity, 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 25 and 31 years for females and males, respectively. Nevertheless, few individuals (3%) less than 12 years old were present in age structures 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; Ferguson *et al.* 2010; Ye *et al.* 2011b&c). 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 a distinct sign of recovery after the 2010/11 flows. 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 favorable. 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 and 2011/12 (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 some 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 have probably occurred at various times (most likely at Goolwa Barrage), which may 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 may have been partially attributed to the mismatch of incidental releases with the timing of spawning. In addition, the decline in population abundance may reflect 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 3 juveniles were collected in 2011/12 despite a significant increase in sampling effort (145 fyke net.nights) across 28 sites along the Coorong (between Goolwa Barrage and Robs Point) suggesting limited recent recruitment success. Possible explanations are that the high flow event 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. Nevertheless, the results should be interpreted with caution because nil or low catches of juvenile black bream in the last two years might also be an artifact of reduced sampling efficiency during the high flows (e.g. reduced fish density, dispersion or re-distribution, shifted location of favorable estuarine habitats). Interestingly, adult black bream had 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.* 2011a). 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 in subsequent years.

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 in the last ten years. 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 in the last three years (≤ 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). 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 to 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 sudden 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 due to increasing salinity throughout the North Lagoon. In 2010/11, although there were substantial inflows, fishery catches of flounder were still restricted to the Estuary subregion, suggesting an absence or 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 flow event in 2010/11 (Ye *et al.* 2011a) suggesting that flows may have had a positive influence on recruitment in that year. Based on growth estimates (J. Earl, unpublished data) and also the positive relationship between barrage discharge and the proportional catch from the southern part of the Coorong one year later, this new cohort of juvenile fish most likely recruited to the fishery 12-18 months later, i.e. throughout 2011/12. In fact, provisional commercial fishing statistics from the Lakes and Coorong Fishery for 2011/12 indicated a considerable increase in catch and CPUE for flounder in the North Lagoon, further corroborating the positive relationship between freshwater inflows and abundance of greenback flounder in that subregion.

4.3.2. Age and size 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.* 2010). 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.* 2012). Earlier studies suggested that greenback flounder sexually partitioned habitat 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 River 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 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 flounder in the nearshore habitats of the Southern Ocean adjacent to the Murray Mouth, there is some evidence to suggest that sex-related habitat partitioning may be occurring over a much larger scale than previously expected, i.e. male fish occupy offshore habitats, while females utilise habitats in the estuary.

Over the 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 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 has likely benefited from the 2010/11 flow event with an increase in productivity and food resources in the Coorong. 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 greenback flounder can live to more than 10 years of age (Sutton *et al.* 2010), the highly truncated age structures suggest that fishing has impacted on this species through the removal of the larger, older individuals (Hall 1984; Ferguson *et al.* 2010). However, the influence of emigration of fish in their second or third years of life from the estuary and subsequent role of the offshore habitats in the population dynamics of this species remains poorly understood and should be examined to better understand the factors driving this truncation.

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 four 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.* 2011a). Salinity is known to play a key role in the reproductive biology of greenback flounder, with optimum fertilisation rates at 35-45 ppt and an egg tolerance range of 14-45 ppt 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 ppt (Figure 3.2), excluding a large area of the Coorong as a favorable spawning ground, potentially impacting recruitment success. However, it is worth mentioning that juvenile greenback flounder are more tolerant to hyper saline conditions than eggs with the laboratory estimates of lethal concentration for 50% test fish (LC_{50}) ranging 79-88 ppt (Ye *et al.* 2012). Tolerance data therefore corroborates 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 2010/11 and 2011/12, recruitment response following freshwater inflows varied at different sampling sites within the Estuary, probably due to a strong flow effect on this subregion given its close proximity to the Murray Mouth. However, there has been a significant increase in new recruit abundance at Mark Point (North Lagoon), with higher catches in both 2010/11 and 2011/12 compared to the previous two drought years. The intervention monitoring also suggested a broader distribution of YOY greenback flounder in the North Lagoon following the 2010-2012 flow events (Ye *et al.* 2011a). These reflect a positive ecological response to the freshwater inflows, which have restored a large area of estuarine habitat and suitable nursery ground for greenback flounder, particularly in 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 ppt (Lui 1969), and an even greater tolerance range in natural conditions (e.g. hardyhead were present in small numbers up to 133.5 ppt in the Coorong, Noell *et al.* 2009). Despite its strong salinity tolerance, the extreme hypersaline conditions (>100 ppt) in recent years have restricted its southerly distribution in the Coorong. During 2008/09, no fish were collected at Jack Point and less than 2 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 ppt throughout the sampling season (November to February). The pattern of distribution and abundance of hardyhead was similar to that in 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 period.

In 2009/10, a significant increase in abundance of smallmouthed hardyhead was detected at some sites in the North Lagoon and at the southern end (i.e. Salt Creek) of the South Lagoon, compared to 2008/09. The highest catch rate was maintained at Noonameena even though there was a slight increase in salinity to 77-103 ppt. 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 -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). This may also partially explain the increase in hardyhead numbers at Mark Point. In contrast, the recovery of fish numbers at Salt Creek 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 favorable salinities and habitat for hardyhead. Flow discharges also have probably facilitated the dispersion of the abundant smallmouthed hardyhead from the Salt Creek inside creek (salinities 9-22 ppt) 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 Murray River. 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 area. Additional research is required to identify the flow characteristics (i.e. volume, duration, intensity and timing) that would facilitate an increase in recruitment for smallmouthed hardyhead and maintain the productivity of the ecosystem in the South Lagoon.

In 2010/11 and 2011/12, the barrage releases caused a substantial reduction in salinity throughout the Coorong. Hardyhead abundance increased significantly in 2010/11 and even more dramatically in 2011/12, particularly in the South Lagoon. The increases occurred following salinity reductions to below 100 ppt, 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 the Salt Creek (Salt Creek inside creek site) into the South Lagoon. Higher abundances 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). This is of particular ecological significance, given the important role this keystone species plays in the trophic ecology of the region.

4.4.2. Size structure

Length information of smallmouthed hardyhead collected using two gear types indicate that the small seine net is more effective in assessing the abundance of new recruits. Therefore this method was formally adopted in the quantitative sampling regime as of February 2009.

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 when no or very low numbers of hardyhead were present at sites within the South Lagoon, suggesting a recruitment failure. In contrast, size structures indicated successful recruitment in the later three years in both the North and South Lagoon.

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

4.4.3. Recruitment

Over the last four years, recruitment of smallmouthed hardyhead increased in the Coorong. In particular, after significant flow events in 2010/11 and 2011/12, there was a dramatic increase in the number of new recruits throughout an extensive area of the North and South Lagoons (between Noonameena and Salt Creek). The small seine net was an effective sampling gear type for quantitative assessment of new recruit abundance and the CPUE provided a recruitment index for hardyhead.

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 ppt) 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 ppt) for this species (Liu 1969). High salinity has been determined to impact the reproductive performance of other atherinids by several authors (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 ppt), it was suggested that salinity might limit their food resources (Molsher *et al.* 1994) and subsequently influence population ecology. 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 survivorship 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 favorable physiochemical conditions and habitats, such as *Ruppia tuberosa* beds, 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 declines in the Upper South East inflow and an increased evaporation in summer, leading to increases in salinity at the southern end of the South Lagoon from 29 ppt in October 2009 to 135 ppt in February 2010. Correspondingly, the distribution of the smallmouthed hardyhead population contracted southward toward Salt Creek and 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 hardyhead recruitment, which likely provides a source population for the South Lagoon when environmental conditions become favorable. On the other hand, recruitment success in the North Lagoon is no doubt important, which plays a key role in sustaining the core population in the Coorong.

In 2010/11 and 2011/12, significant freshwater inflows from the River Murray resulted in broadly reduced salinities throughout the Coorong region and salinities in the South Lagoon of <100 ppt. 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 dramatic 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 which benefits 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, therefore 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 the Icon Site Environmental Management Plan, Target F3 was met following the barrage releases in 2010/11 and 2011/12, 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 ppt) 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 (about 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. In 2010/11 and 2011/12, broadly decreased salinities after barrage releases, coupled with other freshwater induced environment changes, led to a dramatic increase in population abundance and enhanced recruitment in this species, especially in the southern part of the Coorong where salinities reduced to <100 ppt. 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 favorable conditions (i.e. salinity <100 ppt) 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 generally indicated that the management Target F4 was not met during the last four years (2008/09−2011/12). This was reflected, for both species, by:

- a continuation of significant declines in abundance (since the 1980s);
- historically low abundances from 2008–2011;
- a contraction of distributional range in recent years with black bream largely restricted to the Murray Estuary until 2009/10 and greenback flounder until 2010/11;
- heavily truncated age structures which may relate to over-exploitation of older fish by commercial and recreational fisheries, and/or emigration of adult fish (in the case of greenback flounder) during a period of poor environmental condition; and

- a decline in juvenile recruitment over the period 2008–2010 and uncertainty in recruitment success for black bream during the last two flow years.

Nevertheless, there have been positive responses to the 2010-2012 flow events, including an extended southward distribution for black bream following extensive salinity reductions, and enhanced recruitment for greenback flounder in the North Lagoon. Provisional fishing statistics for 2011/12 also suggest that the abundance and distributional range for greenback flounder in the North Lagoon increased relative to the four years prior.

The recent barrage releases are ecologically significant given the critical role of freshwater flows in facilitating successful spawning and recruitment in both black bream and greenback flounder and restoring/maintaining estuarine habitat with a favorable 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. For instance, the protection of black bream from commercial and recreational exploitation during small/medium barrage release periods may protect the spawning biomass and facilitate an increase in spawning opportunities for this species which would likely enhance recruitment success. In addition, conservation management should seek to protect the remnant populations of these species and rebuild the age structures to improve capacity for egg production and thus enhance 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 four 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 two significant flow years, which has established an excellent baseline by which future quantitative assessments can be made. 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 CLLMM region.

6. REFERENCES

Anderson, M. J. (2001) A new method for non-parametric multivariate analysis of variance. *Austral Ecology* **26**, 32-46.

Anderson, M. J., Gorley, R. N. & Clarke, K. R. (2008). 'PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods.' PRIMER-E, Plymouth, UK.

Beamish, R. J., McFarlane, G. A. & Benson, A. (2006). Longevity overfishing. *Progress in Oceanography* **68**, 289-302.

Bice, C. M. & Ye, Q. (2009) 'Risk assessment of proposed management scenarios for Lake Ale x andrina on the resident fish community.' SARDI Aquatic Sciences, Adelaide.

Bray, J. & Curtis, J. (1957) An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27**, 325-349.

Brookes, J.D., Lamontagne, S., Aldridge, K. T., Benger. S., Bissett, A., Bucater, L., Cheshire, A.C., Cook, P.L.M., Deegan, B.M., Dittmann, S., Fairweather, P.G., Fernandes, M.B., Ford, P.W., Geddes, M.C., Gillanders, B.M. , Grigg, N.J., Haese, R.R., Krull, E., Langley, R.A., Lester, R.E., Loo, M., Munro, A.R., Noell, C.J., Nayar, S., Paton, D.C., Revill, A.T., Rogers, D.J., Rolston, A., Sharma. S.K., Short, D.A., Tanner, J.E., Webster, I.T., Wellman, N.R. & Ye, Q. (2009) 'An Ecosystem Assessment Framework to Guide Management of the Coorong.' Final Report of the CLLAMMecology Research Cluster. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Carpelan, L. H. (1955) Tolerance of the San Francisco topsmelt, *Atherinops affinis affinis*, to conditions in salt producing ponds bordering San Francisco Bay. *California Fish and Game* **40**, 279-284.

Colburn, E. A. (1988). Factors influencing species diversity in saline waters of Death Valley, USA. *Hydrobiologia* **158,** 215-226.

Crawford, C. M. (1984a) 'An ecological study of Tasmanian flounder'. PhD thesis, University of Tasmania.

Crawford C. M. (1984b) Preliminary results of experiments on the rearing of Tasmanian flounders, *Rhombosolea tapirina* and *Ammotretis rostratus*. *Aquaculture* **42**, 75-81.

Crawford C. M. (1986) Development of eggs and larvae of the flounders *Rhombosolea tapirina* and *Ammotretis rostratus* (Pisces: Pleuronectidae). *Journal of Fish Biology* **29**, 325-334.

CSIRO (2008) 'Water availability in the Murray–Darling Basin.' Report to the Australian government from the CSIRO Murray–Darling Basin Sustainable Yields Project. CSIRO, Australia, 67pp.

DFW (2010) http://www.waterconnect.sa.gov.au

DFW (2012) http://www.waterconnect.sa.gov.au

DWLBC (2008) 'Fact sheet 23: Murray Mouth sand pumping project.' The Department of Water, Land and Biodiversity Conservation: Adelaide, South Australia.

Ferguson, G. J. (2010) 'Gear interaction of non-targeted species in the Lakes and Coorong commercial and recreational fisheries of South Australia.' Fisheries Research and Development Corporation Final report, SARDI Aquatic Sciences, Canberra.

Ferguson, G. & Ye, Q. (2008) 'Black bream'. Stock assessment Report for PIRSA Fisheries. South Australian Research and Development Institute, Aquatic Sciences, SSARDI Aquatic Sciences Publication No. F2008/000810-1, SARDI Research Report Series No: 310, Adelaide, SA.

Ferguson, G., Ward, T. M., Ye, Q., Geddes, M. C. & Gillanders, B. M. (2010) 'Impacts of drought, flow regime and fishing on the fish assemblage in southern Australia's largest temperate estuary.' Fishery Stock Assessment Report for PIRSA Fisheries. SARDI Publication No. F2010/000709-1. SARDI Research Report Series No. 498. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Frahn, K., Nicol, J. & Strawbridge, A. (2012). Current distribution and abundance of *Ruppia tuberosa* in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2012/000074-1. SARDI Research Report Series No. 615.

Geddes, M. C. (1987) Changes in salinity and in the distribution of macrophytes, macrobenthos and fish in the Coorong lagoons, South Australia, following a period of River Murray flow. *Transactions of the Royal Society of South Australia* **111**, 173-181.

Geddes, M. C. (2005) 'The ecological health of the North and South Lagoons of the Coorong in July 2004.' Report prepared for the Department of Water, Land and Biodiversity Conservation. South Australian Research and Development Institute (Aquatic Sciences): Adelaide, South Australia. SARDI Aquatic Sciences Publication No. RD03/0272-2.

Geddes, M. C. & Butler, A. J. (1984). Physicochemical and biological studies on the Coorong lagoons, South Australia, and the effect of salinity on the distribution of the macrobenthos. *Transactions of the Royal Society of South Australia* **108**, 51-62.

Gillanders, B. M. & Kingsford, M. J. (2002). Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. *Oceanography and Marine Biology: an Annual Review* **40,** 233-309.

Gillson, J., Scandol, J. & Suthers, I. (2009) Estuarine gillnet fishery catch rates decline during drought in eastern Australia. *Fisheries Research* **99**: 26-37.

Hall, D. (1984). The Coorong: biology of the major fish species and fluctuations in catch rates 1976-1983. *SAFIC* **8**(1), 3-17.

Hart, P. R. & Purser, G. J. (1995) Effects of salinity and temperature on eggs and yolk sac larvae of greenback flounder (*Rhombosolea tapirina* Günther, 1862). *Aquaculture* **136**, 221-230.

Hedgpeth, J. W. (1967) 'Ecological aspects of the Laguna Madre. A hypersaline estuary.' *In* G. H. Lauff (Ed.), 'Estuaries' Pp 408-419. (American Academy for the Advancement of Science, Publication 83, Washington).

Hilborn, R. & Walters, C. J. (1992) 'Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty'. London, Chapman and Hall.

Hobday, D. & Moran, M. (1983) 'Age, growth and fluctuating year-class strength of black bream in the Gippsland Lakes, Victoria'. West Australian Marine Research Laboratories, Department of Fisheries and Wildlife, Internal Report No. 20, Perth.

Hoeksema, S. D. & Potter, I. C. (2006) Diel, seasonal, regional and annual variations in the characteristics of the ichthyofauna of the upper reaches of a large Australian microtidal estuary. *Estuarine, Coastal and Shelf Science* **67,** 503-520.

Hughes, L. (2003). 'Climate change and Australia: Trends, projections and impacts.' Austral Ecology **28**: 423-443.

Ivantsoff, W. & Crowley, L. E. L. M. (1996). Family Atherinidae: Silversides or Hardyheads. **In:** McDowell, R.M., ed. *Freshwater Fishes of South-eastern Australia*. Page(s) 123-133. Chatswood, NSW: Reed Books.

King, J. R. & McFarlane, G. A. (2003) Marine fish life history strategies: applications to fishery management. *Fisheries Management and Ecology* **10**: 249-264.

Kurth, D. (1957) 'An investigation of the greenback flounder, *Rhombosolea tapirina* Günther'. PhD thesis, University of Tasmania, Hobart.

Lui, L. C. (1969) Salinity tolerance and osmoregulation in *Taenomembrus microstomus* (Gunther, 1861) (Pisces : Mugiliformes : Atherinidae) from Australian salt lakes. *Australian Journal of Marine and Freshwater Research* **20**, 157–162.

Maunsell Australia Pty Ltd. (2009) 'Lower Lakes, Coorong and Murray Mouth Icon Site condition monitoring plan.' South Australian Murray–Darling Basin Natural Resources Management Board, Adelaide.

MDBC (2006) 'The lower Lakes, Coorong and Murray Mouth Icon Site Management Plan2006-2007.'

Molsher, R. L., Geddes, M. C. & Paton, D. C. (1994) Population and reproductive ecology of the small-mouthed hardyhead Atherinosoma microstoma (Gunther) (Pisces: Atherinidae) along a salinity gradient in the Coorong, South Australia. *Transactions of the Royal Society of South Australia* **118**, 207-216.

Morison A. K., Coutin, P. C. & Robertson, S. G. (1998). Age determination of black bream, *Acanthopagrus butcheri* (Sparidae) from the Gippsland Lakes of south-eastern Australia indicates slow growth and episodic recruitment. *Marine and Freshwater Research* **49**, 491-498.

Newton, G. M. (1996) Estuarine icthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary. *Marine and Freshwater Research* **47**, 99-111.

Nicholson, G. and Gunthorpe, L. (2008) 'Western minor inlets fish habitats 2000'. Fisheries Victoria Assessment Report Series, Department of Primary Industries: 1-33.

Nicholson, G., Jenkins, G. P., Sherwood, J. & Longmore, A. (2008). 'Physical environmental conditions, spawning and early-life stages of an estuarine fish: climate change implications for recruitment in intermittently open estuaries'. *Marine and Freshwater Research* **59**: 735-749.

Noell, C. J., Ye, Q., Short, D. A., Bucater, L. B. & Wellman, N. R. (2009) 'Fish assemblages of the Murray Mouth and Coorong region, South Australia, during an extended drought period.' CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Norriss, J. V. Tregonning, J. E., Lenanton, R. C. J. & Sarre, G. A. (2002) 'Biological synopsis of the black bream, Acanthopagrus butcheri (Munroe) (Teleostei: Sparidae) in Western Australia with reference to information from other southern states: Fisheries Research report.' Department of Fisheries, Western Australia, Perth.

Paton, D. C. & Bailey, C. P. (2012). 'Annual monitoring of *Ruppia tuberosa* in the Coorong region of South Australia, July 2011.' Report for the Department of Environment and Natural Resources, University of Adelaide, Adelaide.

Phillips, W. & Muller, K. (2006) 'Ecological character of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance.' South Australian Department for Environment and Heritage.

Planque, B., Fomentin, J., Cury, P., Drinkwater, S., Jennings, S., Perry, R. I. & Kifani, S. (2010). How does fishing alter marine populations and ecosystems sensitivity to climate. *Journal of Marine Systems* **79**(3-4), 403-417.

Robins, J. & Ye, Q. (2007) 'Relationships between freshwater flow and fisheries (or secondary) production in Australian estuaries: a review.' Literature Review for e-Water CRC.

Roger, D. J. & Paton, D. C (2009) 'Spatiotemporal variation in the waterbird communities of the Coorong. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Sarre, G. A. & Potter, I. C. (2000). Variations in age compositions and growth rates of Acanthopagrus butcheri (Sparidae) among estuaries: some possible contributing factors. *Fishery Bulletin* **98**, 785-799.

Sherwood, J., Stagnitti, F., Kokkinn, M. & Williams, W. (1992) A standard table for predicting equilibrium dissolved oxygen concentrations in Salt Lakes dominated by sodium chloride. *International Journal of Salt Lake Research* **1**, 1-6.

Sutton, C. P., MacGibbon, D. J. & Stevens, D. W. (2010) Age and growth of greenback flounder (*Rhombosolea tapirina*) from southern New Zealand. *New Zealand Fisheries Assessment Report 2010/48.*

Vega-Cendejas, Ma. E. & Hernández de Santillana, M. (2004) Fish community structure and dynamics in a coastal hypersaline lagoon: Rio Lagartos, Yucatan, Mexico. *Estuarine, Coastal and Shelf Science* **60**, 285-299.

Walsh, C. T., Gray, C. A., West, R. J., van der Meulen, D. E., & Williams, L. F. G. (2010) Growth, episodic recruitment and age truncation in populations of a catadromous percichthyid, *Macquaria colonorum*. *Marine and Freshwater Research* **61**(4), 397-407.

Whitfield, A. K. (1994). Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. *Marine Ecology Progress Series* **105**, 257–267.

Winemiller, K. O. & Rose, K. A. (1992) Patterns of life-history diversification in North American fishes: implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* **49**, 2196-2218.

Ye, Q., Short, D.A., Green C. & Coutin, P.C. (2002). 'Age and growth rate determination of southern sea garfish.' In 'Fisheries Biology and Habitat Ecology of Southern Sea Garfish (*Hyporhamphus melanochir*) in Southern Australian Waters, pp 35-99.' (Eds KG Jones, Q Ye, S Ayvazian and P Coutin). FRDC Final Report Project 97/133. Fisheries Research and Development Corporation, Canberra, Australia.

Ye, Q., Bucater, L. & Short, D (2011a) 'Coorong fish intervention monitoring during barrage releases in 2010/11.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000309-1. SARDI Research Report Series No. 559. 57pp.

Ye, Q., Bucater, L., Ferguson, G. & Short, D. (2011b). 'Coorong fish condition monitoring 2008–2010: population and recruitment status of the black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*).' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000331-1. SARDI Research Report Series No. 572. 55pp.

Ye, Q., Bucater, L. & Short, D (2011c). 'Coorong fish condition monitoring 2008–2011: The black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-1. SARDI Research Report Series No. 582. 55pp.

Ye, Q., Earl, J., Bucater, L., Cheshire, K., McNeil, D., Noell, C. & Short, D. (2012). Flow related fish and fisheries ecology in the Coorong, South Australia. FRDC Project 2006/45 final report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Zampatti, B. P., Bice, C. M. & Jennings, P. R. (2010). Temporal variability in fish assemblage structure and recruitment in a freshwater-deprived estuary: The Coorong, Australia. *Marine and Freshwater Research* **61**, 1-15.

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 2011/12.

Gear Type	2008/09	2009/10	2010/11	2011/12	Total
Seine		47	37	5	89
Multi Panel Gill			8		8
Fyke Net	4	1			5
Fishway Trap			2		2
Line	1				1
Total	5	48	47	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 2011.

Gear Type	2009	2010	2011	Total
Seine	17	196	7	220
Multi Panel Gill Net	2		1	3
Fyke Net	8			8
Total	27	196	8	231