Coorong Fish Condition Monitoring 2008–2011:
The black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations

Dr Qifeng Ye, Luciana Bucater and David Short

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EXECUTIVE SUMMARY

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region is a recognised wetland of international importance listed 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 last decade, the Coorong ecosystem has become increasingly degraded following the protracted drought in the MDB, subsequent lack of freshwater inflows and considerable 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. An Icon Site Condition Monitoring Plan has been implemented to evaluate whether these targets have been achieved. This report presents the findings of the first three years (2008/09−2010/11) of a monitoring program for black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) in the Murray Estuary and North Lagoon, and for smallmouthed hardyhead (*Atherinosoma microstoma*) in the North and South Lagoons of the Coorong, in order to evaluate target F4: maintain or improve recruitment of black bream and greenback flounder in the Murray Mouth Estuary and North Lagoon; and target F3: provide optimum conditions to improve recruitment success of smallmouthed hardyhead in the South Lagoon.

Condition monitoring for smallmouthed hardyhead indicated that target F3 was met particularly following the barrage releases in 2010/11. Although smallmouthed hardyhead have a strong salinity tolerance, in 2008/09, the extremely hypersaline conditions (salinity up to 166 ppt) restricted their 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 inflows (~100 ML day^{-1}) from Salt Creek. This freshwater/brackish creek probably also served as a recruitment refuge for smallmouthed hardyhead, facilitating the population recovery in the South Lagoon. In 2010/11, broadly decreased salinities, coupled with other freshwater induced environment changes, led to a dramatic increase in population abundance and enhanced recruitment especially in the southern part of the Coorong when 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 the population recovery when favorable conditions (i.e. salinity) are restored and shows the resilience of the hardyhead population in the Coorong.

In contrast, for black bream and greenback flounder, condition monitoring did not indicate that target F4 was met during the first three years (2008/09−2010/11). This was reflected, for both species, by (i) truncated population age structures which indicate longevity overfishing and (ii) a general decline in juvenile recruitment from 2008/09 to 2009/10 and uncertainty in recruitment success for 2010/11. In addition, previous analysis of fisheries catch and effort data (1984/85−2009/10) indicated (i) a significant decline in population abundance, particularly over the past ten years, (ii) historically low levels of abundance in 2008/09 and 2009/10, and (iii) considerable contraction of distributional range to a reduced habitat in the Murray Estuary.

Nevertheless, the recent barrage flow event is deemed ecologically significant given the critical role of freshwater flows in facilitating successful spawning and recruitment in both black bream and greenback flounder and restoring or maintaining estuarine habitat and a favorable salinity gradient, as observed in 2010/11, in the Coorong. Ongoing monitoring will be required in subsequent years to continue to investigate the recruitment response of these commercially important estuarine species and evaluate how/whether they would benefit from the current and potentially future freshwater inflows to the Coorong. Environmental water management should also take into account flow regimes of small to moderate freshwater releases which could be linked to the strong recruitment of black bream as identified for 1997/98 and 2003/04 cohorts. 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 monitoring will be required to improve our understanding of primary environmental factors, including flow regimes, which influence the recruitment success of key estuarine species and fish habitat in the Coorong.

The first three years of condition monitoring have provided valuable information on the population age, size structures and recruitment ecology of black bream, greenback flounder and smallmouthed hardyhead in the Coorong, and have established a baseline by which future quantitative assessments can be made. The results of this study form an important basis for adaptive management to ensure the ecological sustainability of iconic estuarine fish species in the CLLMM region.

1. INTRODUCTION

1.1. Background

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 internationally as a Ramsar-listed wetland, providing an important breeding and feeding ground for waterbirds, and supporting significant populations of several species of fish and invertebrates (Phillips and Muller 2006; Bice and Ye 2009). The region is classified as an 'icon site' under the Murray-Darling Basin Authority's The Living Murray (TLM) program, based upon its unique ecological qualities, hydrological significance, economic and cultural values (Murray-Darling Basin Commission 2006).

The Coorong is a long (~110 km) and narrow (<4 km wide) estuary and 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). The estuarine influence 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 (~7 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 12 233 GL y^{-1} to 4 733 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 as well as ecological barrier between marine and freshwater systems. In recent years, the environmental condition of the Coorong has been exacerbated by severe drought in the Basin, with very low or no flow releases through the barrages between 2002/03 and 2009/10 (DFW 2010). Subsequently, the Murray Mouth was closed due to siltation, requiring a dredging operation to maintain its opening since 2002 (DWLBC 2008). The Coorong has transformed into a marine/hypersaline environment, with extreme hypersaline conditions in the South Lagoon which caused severe and continuing degradation of critical habitats for nationally listed bird species, and compromised the Ramsar ecological character of the system (Rogers and Paton 2009). Such changes have severely impacted on the regional ecology (Brookes *et al.* 2009). Many native fish species that depend on the Coorong estuary as a refuge, breeding, nursery and feeding ground have been negatively affected (Noell *et al.* 2009), and recruitment of diadromous fish has failed due to lack of connectivity between freshwater and marine environments (Zampatti *et al.* 2010).

In 2010/11, a significant increase in rainfall and flow in the River Murray led to the refill of the Lower Lakes which has resulted in barrage releases of more than 10,000 GL since September 2010. There has been a significant reduction in salinity in the Coorong (Ye *et al.* 2011a). Broadly decreased salinities, coupled with other freshwater induced environment changes, such as increased nutrient input and elevated primary productivity (Aldridge and Brookes 2011), have elicited significant ecological responses in fish assemblages in the region during 2010/11, including an increase in the diversity and abundance of freshwater species, enhanced recruitment and subsequent abundances 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).

Given that 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), species specific monitoring has been instigated 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.

The current report presents the findings of the Coorong fish condition monitoring from the first three years (2008–2011), particularly for the population age/size structures and recruitment status of black bream, greenback flounder and smallmouthed hardyhead.

1.2. Objectives

The aim of the monitoring program, in reference to targets F3 and F4, was to assess the population status, particularly the level of recruitment, of the three key species (black bream, greenback flounder and smallmouthed hardyhead) in the Coorong. Specific objectives for the black bream and greenback flounder (F4) were to:

- Determine their population size/age structures; and
- Assess their level of recruitment in the Murray Estuary and North Lagoon of the Coorong.

Specific objectives for smallmouthed hardyhead (F3) were to:

- Determine their relative abundance and distribution;
- Determine their population size structure; and
- Assess their level of recruitment in the North and South Lagoons of the Coorong.

2. METHODS

2.1. Sampling

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 2010/11 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 (Figure 2.1) and adult greenback flounder were collected during winter each year from the Goolwa channel and near Mark Point in the North Lagoon (Figure 2.2). In addition, fishery-independent samples of both species were also used. Sample sizes for adult black bream and greenback flounder are shown in Table 2.1 and Table 2.2, respectively.

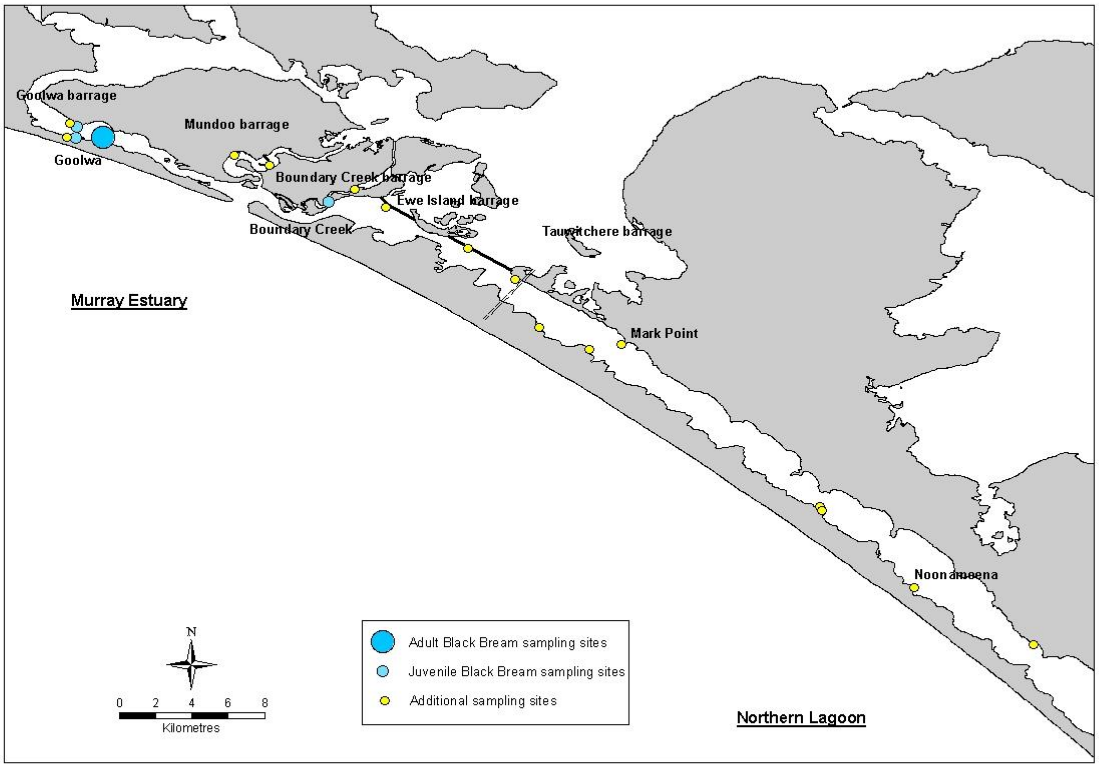


Figure 2.1. Icon site condition monitoring sampling sites for adult and juvenile black bream in the Coorong.

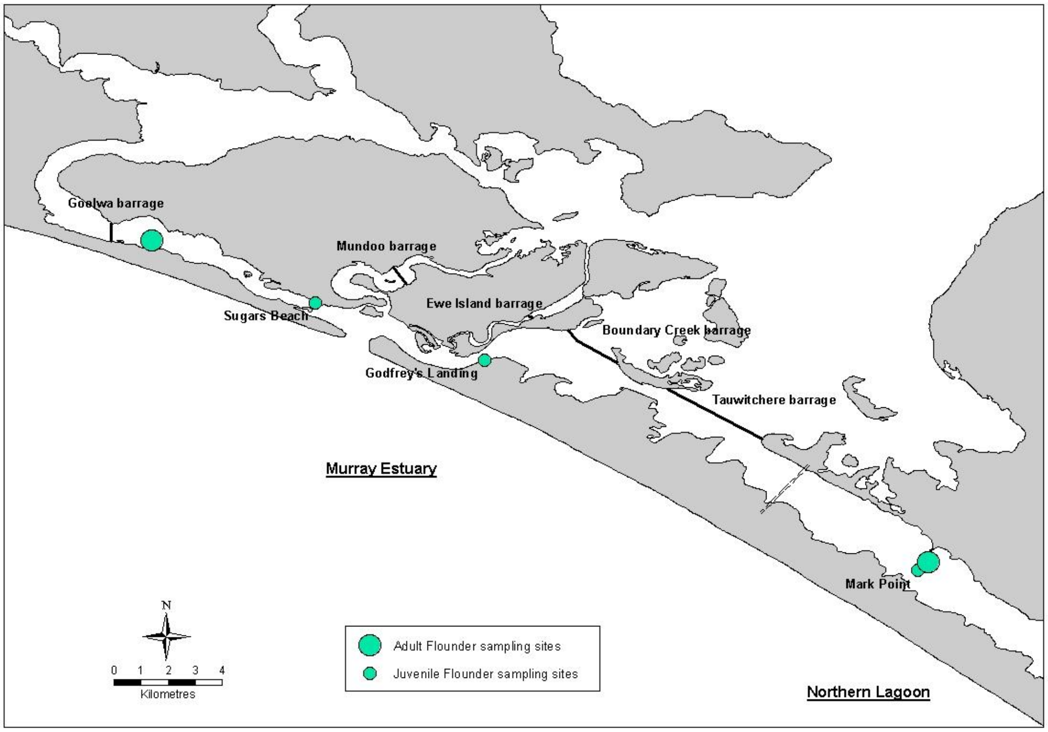


Figure 2.2. Icon site condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong.

Table 2.1. Numbers of adult black bream collected from commercial fishery and fishery-independent sampling during 2008/09, 2009/10 and 2010/11.

	2008/09			2009/10			2010/11		
Month	Commercial	Fishery-Independent.	Total	Commercial	Fishery-Independent	Total	Commercial	Fishery-Independent	Total
Sep				50		50	36	30	66
Oct	15		15	46		46	27		27
Nov				37		37		1	1
De	20		20	25	1	26		4	4
Jan	45	1	46	6		6			
Feb	2		2		23	23		2	2
Mar	16		16		1	1			
May					14	14			
Jun					9	9			
Jul								9	9
Overall	98	1	99	164	48	212	63	46	109

Table 2.2. Numbers of adult greenback flounder collected from commercial fishery and fishery-independent sampling during 2009 and 2010.

	2009			2010		
Month	Commercial	Fishery- Independent	Total	Commercial	Fishery- Independent	Total
January						0
February		17	17			0
May	13		13	37	47	84
June	24	1	25		46	46
July	38		38		38	38
August	29		29	14	32	46
November					5	5
Overall	104	18	122	51	168	219

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 2.1) 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. at the freshwater side of Goolwa Barrage, Mundoo and Tauwitchere Barrages, Pelican Point, Mark Point). 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 2.2) using a standard seine net during spring/early summer each year (*n*=3 trips/year). The standard 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 ~592 m^2. Sampling was replicated (i.e. 3 standard shots) at each site. A summary of effort for juvenile greenback flounder is presented in Table 2.4.

Table 2.3. Sampling effort used to collect juvenile black bream using single-wing fyke nets at regular and additional sites in the Coorong for 2008/09, 2009/10 and 2010/11.

Total number of fyke nets set per year Location	2008/09	2009/10	2010/11
Regular sampling sites			
Goolwa Barrage salt water side HI	21	24	28
Goolwa Barrage salt water side SRP	31	24	20
Boundary Creek	31	24	
Additional sampling sites			
Boundary Creek Barrage	4		
Cattle Point			4
Ewe Island Causeway	4	16	
Goolwa Barrage freshwater side HI	4		
Goolwa Barrage freshwater side SRP	2	4	
Long Point			8
Long Point sand dune			4
Mark Point	8		8
Mundoo Barrage	4		24
Mundoo Channel	8		
Noonameena			4
Pelican Point	4		
Pelican Point YHP	8		
Robs Point			4
Tauwitchere Barrage	3	4	
Overall	132	96	104

Table 2.4. Sampling effort used to collect juvenile greenback flounder using standard seine net at in the Coorong for 2008/09, 2009/10 and 2010/11.

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

The standard seine net was also used for quantitative sampling of smallmouthed hardyhead at six sites along the North and South Lagoons of the Coorong (Figure 2.3). Sampling was conducted at each site during spring/summer in 2008/09, 2009/10 and 2010/11 (*n*=4 trips/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 sweeping an area of 100 m^2. At the end of the transect, it was closed up and carried to the beach, whereupon it was laid flat and the catch removed. 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.

On each sampling occasion at each site, all fish species were identified and the numbers of juvenile black bream, greenback flounder and smallmouthed hardyhead from each net were counted. The relative abundance was defined as the number of fish per fyke net or per seine net shot. Additionally, a random subsample of up to 50 individuals of each targeted species from each gear type were measured (total length (TL), mm) with 20 individuals from each species kept for laboratory processing.

Water quality parameters (i.e. salinity, temperature, dissolved oxygen, pH) were recorded using a TPS water quality meter and turbidity were measured using a Secchi disc at each site on each fish sampling occasion. See Table 2.6 for a list of sites, gear types used and fish targeted at each location.

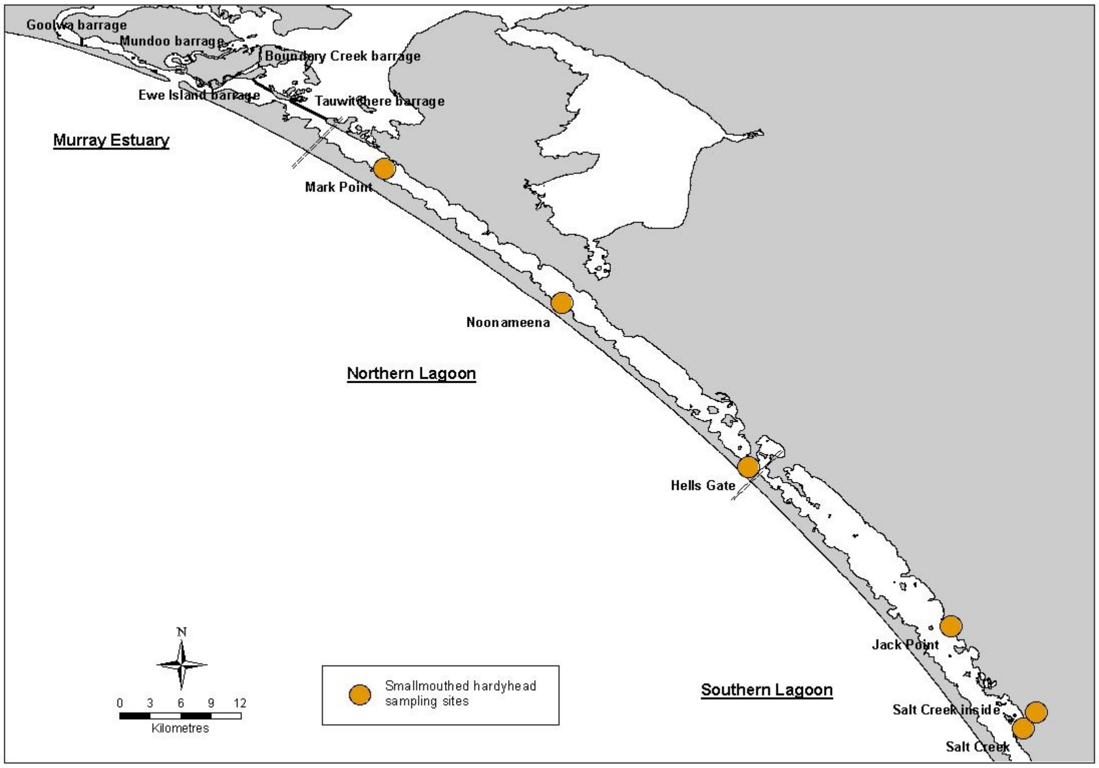


Figure 2.3. Icon site condition monitoring sampling sites for smallmouthed hardyhead in the Coorong.

Table 2.5. Sampling effort used to collect juvenile and adult smallmouthed hardyhead using large and small nets in the Coorong for 2008/09, 2009/10 and 2010/11.

Total number of seine net shots per year Location	2008/09	2009/2010	2010/11
Large seine net			
Hells Gate	12	12	12
Jack Point	12	12	12
Mark Point	12	12	12
Noonameena	12	12	12
Salt Creek	12	12	12
Salt Creek inside creek	3	12	12
Overall	63	72	72
Small seine net			
Hells Gate	0	12	12
Jack Point	0	12	12
Mark Point	3	9	12
Noonameena	3	9	12
Salt Creek	0	12	12
Salt Creek inside creek	3	12	12
Overall	9	66	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
Boundary Creek	E3	Black Bream	Fyke net
Sugars Beach	E4	Greenback Flounder	Standard seine net
Godfrey's Landing	E5	Greenback Flounder	Standard seine net
Mark Point	N1	Greenback Flounder/Smallmouthed Hardyhead	Standard and small seine nets
Noonameena	N2	Smallmouthed Hardyhead	Standard and small seine nets
Hells Gate	N3	Smallmouthed Hardyhead	Standard and small seine nets
Jack Point	S1	Smallmouthed Hardyhead	Standard and small seine nets
Salt Creek	S2	Smallmouthed Hardyhead	Standard and small seine nets
Salt Creek inside creek	S3	Smallmouthed Hardyhead	Standard and small seine nets

2.2. Laboratory Processing

To assess the population age structures for the black bream and greenback flounder, annual bands in sagittal otoliths were analysed for age determination. Otoliths were extracted from fish of both species 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 taken from the otoliths (Ye *et al.* 2002). The 2007-2008 data of age/size of these two species from a previous study, i.e. the CLLAMMecology fish study (Noell *et al.* 2009), are also presented in this report for comparison. The age structures established also allow for the identification of strong year classes that may have recruited in the fish populations.

For juvenile fish, otoliths from a subsample of each species were extracted for age determination to confirm the proportion of the YOY fish. In order to obtain thin transverse sections, the small juvenile otoliths were prepared by grinding and polishing techniques in the following manner: the otolith was first mounted on a microscope slide using thermoplastic glue (Crystalbond) such that its anterior half protruded beyond the edge of the slide. Using the slide to hold and orientate the otolith, the anterior half was hand-ground away using 600 grit wet/dry sand paper. Upon approaching the level of the otolith's primordium two grades of imperial lapping film (9μ and 3μ) were used to finely polish the ground face. The slide was then heated and the remaining otolith half removed and remounted in the centre on another microscope slide polished face down. The posterior half of the otolith was then ground and polished until a transverse section of otolith remained which was approximately 250μ thick and contained the primordium. The sections were smeared with immersion oil when read to clear surface irregularities. They were examined and counted for opaque rings with a binocular microscope at x20 magnification under transmitted light.

2.3. Data Analysis

Catch per unit effort (CPUE) data 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 of smallmouthed hardyhead from the standard seine net were used to compare population abundance between years at key sites. Because the data did not meet assumptions of univariate normality and homogeneity of variance, analysis was done using permutational analysis of variance (PERMANOVA) (Anderson 2001). CPUE data for juveniles 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 if differences between years could be detected at each site (i.e. sampling station). 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 one-year life cycle of this species (Molsher *et al.* 1994).

3. RESULTS

3.1. Freshwater inflow

The Murray Estuary and Coorong, similarly to the upper reaches of the River Murray, has been experiencing fluctuations in the water flow regime. Between 1989/90 and 1993/94, the freshwater inflows to the Estuary were among the highest with annual discharges ranging between 10 500 and 12 500 GL.year^{-1} and the peak monthly flow in spring above 2 000 GL month^{-1} (Figure 3.1). After 1993/94, inflows to the Coorong generally declined. The annual discharges were around 9 000 GL, 3 000 GL and 5 000 GL in 1996/97, 1998/99 and 2000/01, respectively. Between 2001/02 and 2009/10, annual inflows were less than 800 GL, and no barrage releases were made in the last three years (2007/08 – 2009/10). However in 2010/11, a significant increase in rainfall and flow in the River Murray led to the refill of the Lower Lakes and barrage releases of approximately 13 000 GL with a monthly peak of 2 400 GL in January 2011 (Figure 3.1).

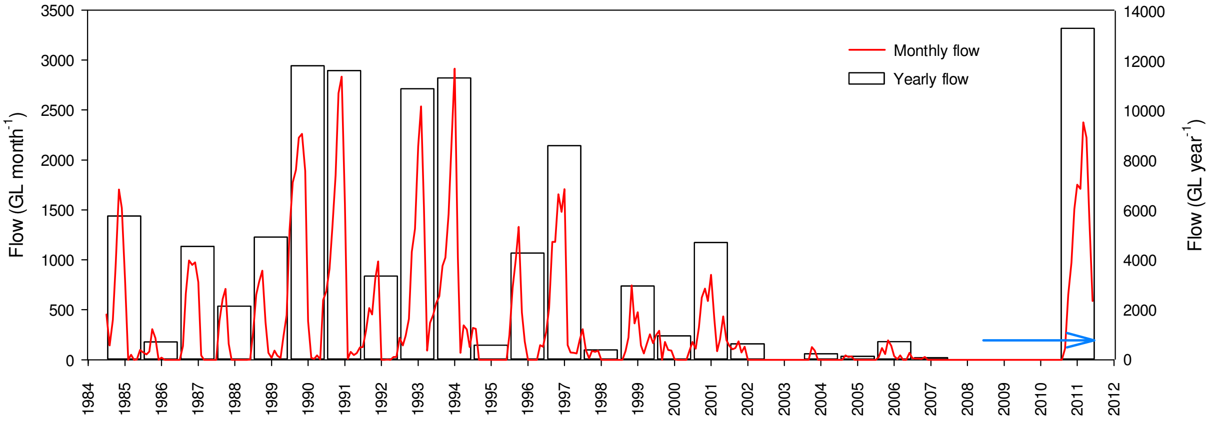


Figure 3.1. Average annual and monthly freshwater inflows across the barrages from July 1986 to June 2011 (source: MDBC, 2008 except that 2010/11 data were the estimates by the SA Department for Water). Blue arrow indicates time period of fish condition monitoring.

3.2. Water Quality

The averages of key water quality parameters, temperature, salinity, dissolved oxygen (DO), pH and turbidity (Secchi disk depth) at each sampling site are presented in Figure 3.2. There was a remarkable reduction in salinities at all sampling sites during the barrage releases in 2010/11, while the north to south increasing salinity gradient remained in the Coorong. In 2008/09 and 2009/10, average salinities ranged from 37-44 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, salinities reduced to 1-5 ppt in the Murray Estuary, 9-76 ppt in the North Lagoon, and 54-98 ppt in the South Lagoon. With the River Murray inflows in 2010/11, an increase in turbidity was observed in the Estuary subregion compared to those in previous years. There was no substantial change in other parameters.

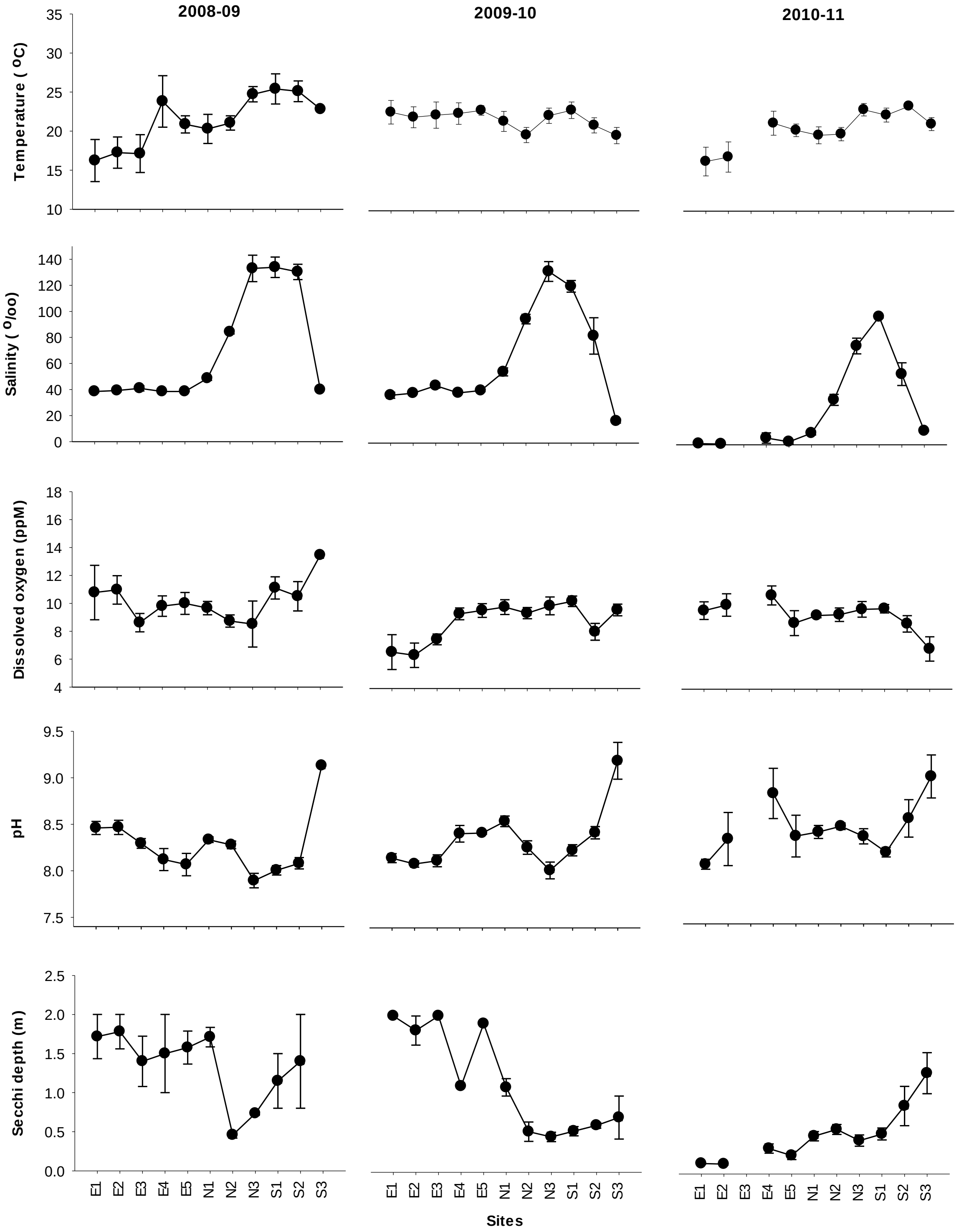


Figure 3.2. Mean values ± S.E. for water temperature, salinity, dissolved oxygen, pH and Secchi depth for each sampling site (sampling occasions pooled) within the Murray Mouth and Coorong region during 2008/09, 2009/10 and 2010/11.

3.3. Black Bream

3.3.1. Size and age structures

Size and age structures of female and male black bream in the last four years are shown in Figure 3.3. 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 the 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 an 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 the 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 the dominant mode at 6 years (27% females and 32% males) and a secondary mode at 12 years (20% females and 25% 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. 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.

Size structures for black bream did not reflect the distinct modal progression in age structures (Figure 3.3). All size structures were unimodal with a modal size of 320 – 359 mm TL for both females and males in all four years.

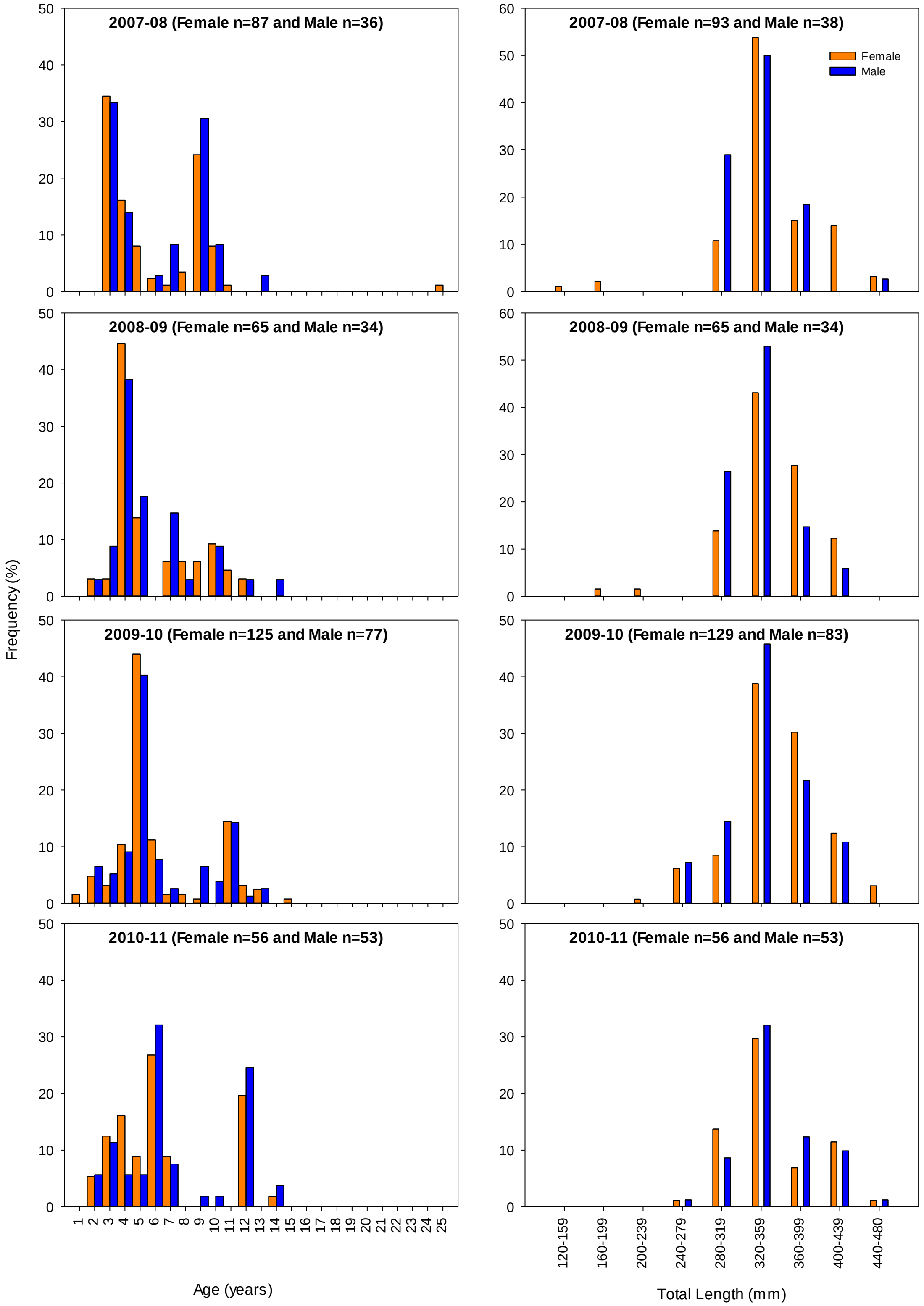


Figure 3.3. Age (left) and size (right) structures of black bream from the Murray Estuary and Coorong between 2007/08 and 2010/11 (most of the samples were from commercial catches).

3.3.2. Recruitment

Abundance and distributional range of juvenile black bream showed a general decline from 2008/09 to 2010/11 across all sites (Table 3.1, Figure 3.4). In 2010/11, no black bream were collected in any samples at either regular or additional sampling sites, although one regular site, Boundary Creek was not sampled due to excessive barrage releases.

PERMANOVA detected a significant interaction (*p*=0.002) when comparing CPUE of juvenile black bream between three years (2008/09- 2010/11) across three regular sites (Boundary Creek, Goolwa Barrage (Saltwater side, Hindmarsh Island end) and Sir Richard Peninsula end) (Table 3.2). Pairwise comparisons revealed that there was a significant spatial difference in all years, with an exception of the Goolwa barrage sites in 2008/09 (*p*=0.144). The analysis also revealed a significant difference between years in juvenile CPUE at the Goolwa Barrage (Hindmarsh Island end) (*p*<0.005); while the CPUE's did not differ significantly between 2008/09 and 2009/10 at the Goolwa Barrage (Sir Richard Peninsula end) (*p*=0.233) and at Boundary Creek (*p*=0.379). In 2010/11, however, the juvenile CPUE was significantly lower at Goolwa Barrage than previous years (*p*<0.003).

Length frequency distributions of juvenile black bream from all sites combined are presented for each year in Figure 3.5. 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.

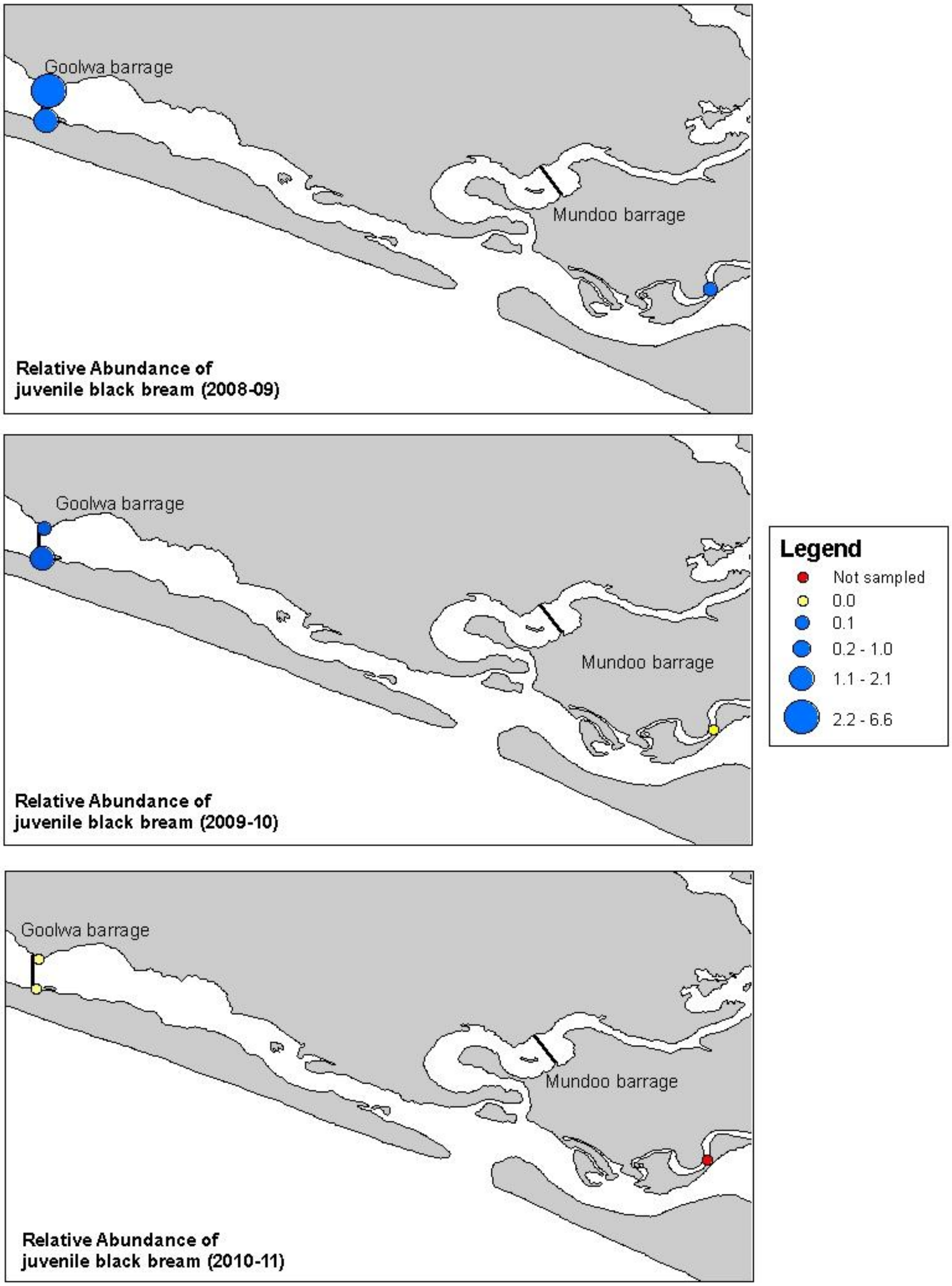


Figure 3.4. Murray Estuary map showing juvenile black bream relative abundance and distribution from 2008/09 to 2010/11 (top to bottom).

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 2010/11. (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**	
Regular sites	Mean	SE	Mean	SE	Mean	SE
Goolwa Barrage saltwater side HI	6.6	2.1	0.4	0.2	0.0	0.0
Goolwa Barrage saltwater side SRP	2.1	0.4	1.3	0.3	0.0	0.0
Boundary Creek	0.1	0.1	0.0	0.0		
Additional sites						
Boundary Creek Barrage	0.8	0.3				
Cattle Point					0.0	0.0
Ewe Island Causeway	0.0	0.0	0.0	0.0		
Goolwa Barrage freshwater side HI	0.0	0.0				
Goolwa Barrage freshwater side SRP	0.0	0.0	0.0	0.0		
Long Point					0.0	0.0
Long Point sand dune					0.0	0.0
Mark Point	0.1	0.1			0.0	0.0
Mundoo Barrage	0.3	0.3			0.0	0.0
Mundoo Channel	0.0	0.0			0.0	0.0
Noonameena					0.0	0.0
Pelican Point	0.0	0.0				
Pelican Point YHP	0.1	0.1				
Robs Point					0.0	0.0
Tauwitchere Barrage	1.3	1.3	0.0	0.0		
Average across sites	1.6	0.4	0.4	0.1	0.0	0.0

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	2	16863	**0.001**
Site	2	13822	**0.001**
Year x Site	3	2496.2	**0.002**

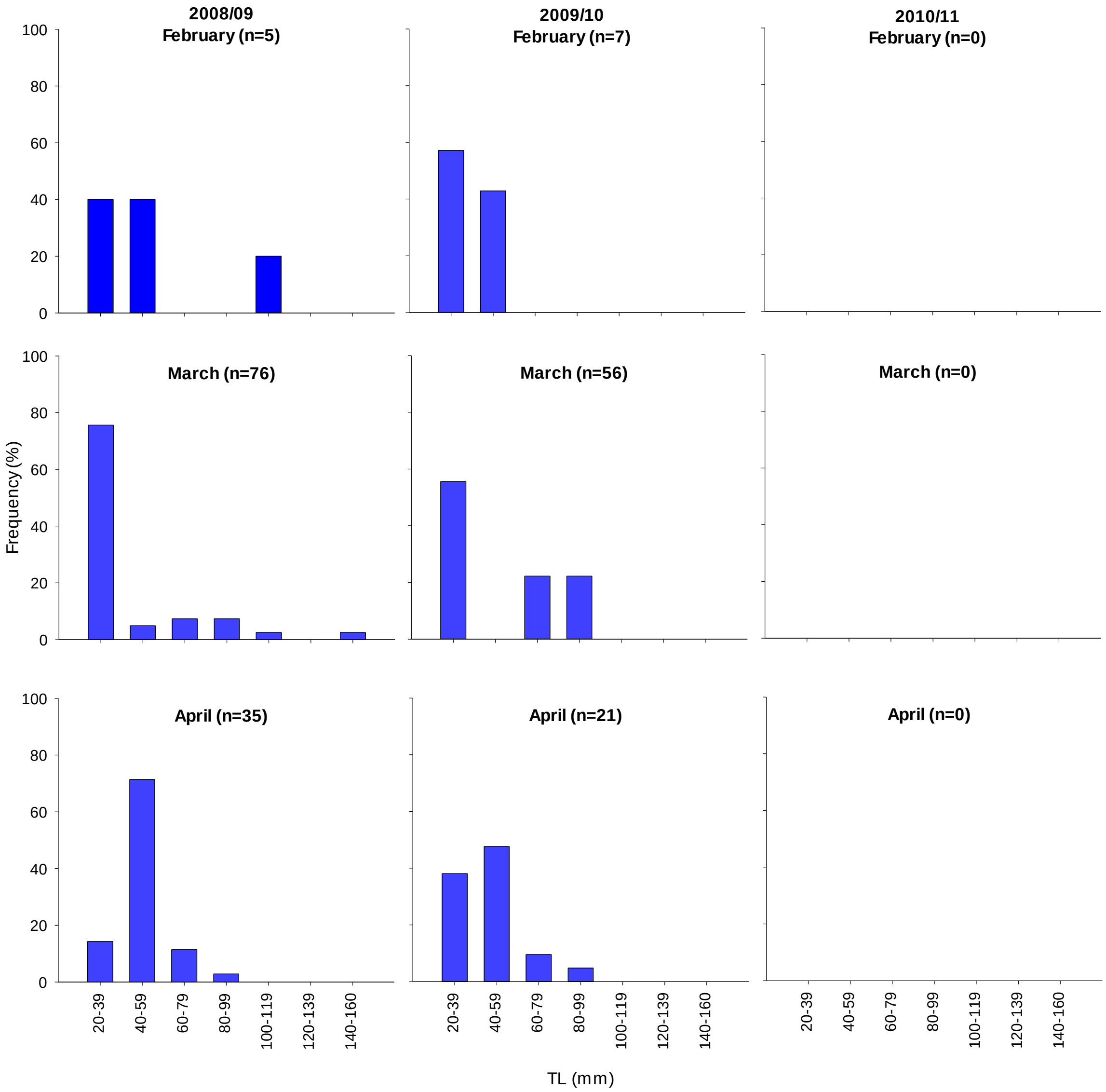


Figure 3.5. Length frequency distributions of juvenile black bream from fyke net samples in the Murray Estuary and Coorong from February to April between 2008/09 and 2010/11.

3.4. Greenback flounder

3.4.1. Size and age structures

Age structures of female and male greenback flounder are shown in Figure 3.6. In 2007, fish were dominated by 2 and 3 year old females, consisting of 87.3% of the total catch. Age of females ranged from 1 to 3 years, and males were 2 or 4 years old, although only three males were sampled. 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, females of 1 and 2 years olds continued to dominate the catch, however 66% were 1 year olds; age of females ranged from 1 to 3 years and three male fish collected were either 1 or 2 year olds. Most of the 2010 samples of greenback flounder were from fishery-independent sampling therefore the age structure difference was more likely attributed to gear selectivity.

In 2007, the size distribution of female flounder was bimodal with distinct modes at 260-279 and 340-359 mm TL (Figure 3.6). The size distribution of females, in 2009, was unimodal with 82% between 240 and 339 mm TL. In 2010, however, the size distribution of females was bimodal, with 28.5% of the fish ranging between 220 to 239 mm and approximately 14% between 280-299 mm. Only three and five males were collected in 2007 and 2010 with sizes ranging from 260 to 359 mm and 220 to 359 mm TL, respectively; whilst no males were collected in 2009.

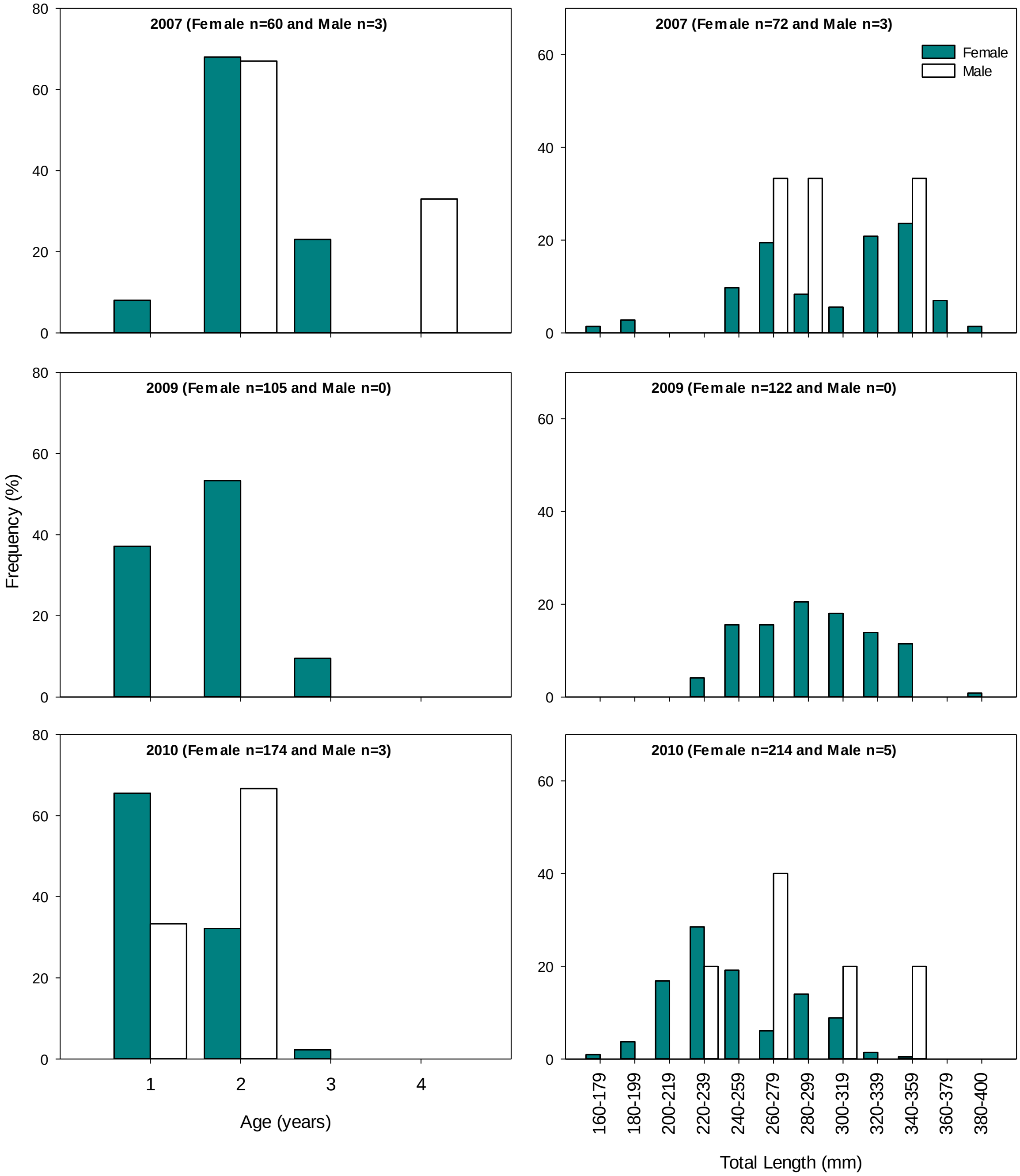


Figure 3.6. Age (left) and size (right) structures of greenback flounder from the Murray Estuary and Coorong in 2007, 2009 and 2010 (most of the samples were from commercial catches in 2007 and 2009 whilst 2010 samples were mainly from fishery-independent sampling).

3.4.2. Recruitment

The relative abundance of juvenile greenback flounder varied greatly across sites between years (2008/09-2010/11) in the Murray Estuary and Coorong (Table 3.3, Figure 3.7). PERMANOVA detected a significant interaction (*p*=0.001) between three years across three sites (Sugar beach, Godfrey's landing and Mark Point) (Table 3.4). Pairwise comparisons revealed that, at Godfery's Landing, CPUE declined significantly from 2008/09 to 2009/10 (*p*=0.002), but then increased slightly in 2010/11 although the level was not significantly different from those in 2008/09 or 2009/10 (Table 3.5). At Sugars Beach, CPUE had no difference between 2008/09 and 2009/10 (*p*=0.128), however, it reduced significantly in 2010/11 compared to previous years (*p*<0.003) (Table 3.5). At Mark Point, there was no difference in CPUE between the first two years, but a near significant increase (*p*=0.059) in 2010/11 compared to 2009/10.

Length frequency distributions of juvenile fish from three sites combined are presented in Figure 3.8. In 2008/09, fish collected ranged from 20 to 129 mm TL. Length distributions for each month indicated multiple size modes (e.g. 30-39, 50-59 and 80-89 mm TL in November 2008). Several modes persisted from November to December and January, indicating fish growth. There is evidence of the smallest length classes (20-29 and 30-39 mm) emerging again in January 2009, suggesting recent spawning events. No fish greater than 90 mm were sampled during this period.

In 2009/10, fish size ranged from 20 to 170 mm TL. Similarly to the previous year, monthly modal progression of length frequency distributions was identifiable for at least two size classes, which were 40-49 and 90-99 mm in November 2009 (Figure 3.8). These size classes can be tracked in the following two months in 2009/10.

In 2010/11, fish size ranged from 20 to 170 mm TL. In December 2010 and January 2011, there was no evidence of continued recruitment of small fish (20-29 mm); size distribution was represented by more larger-fish than in the previous year (Figure 3.8).

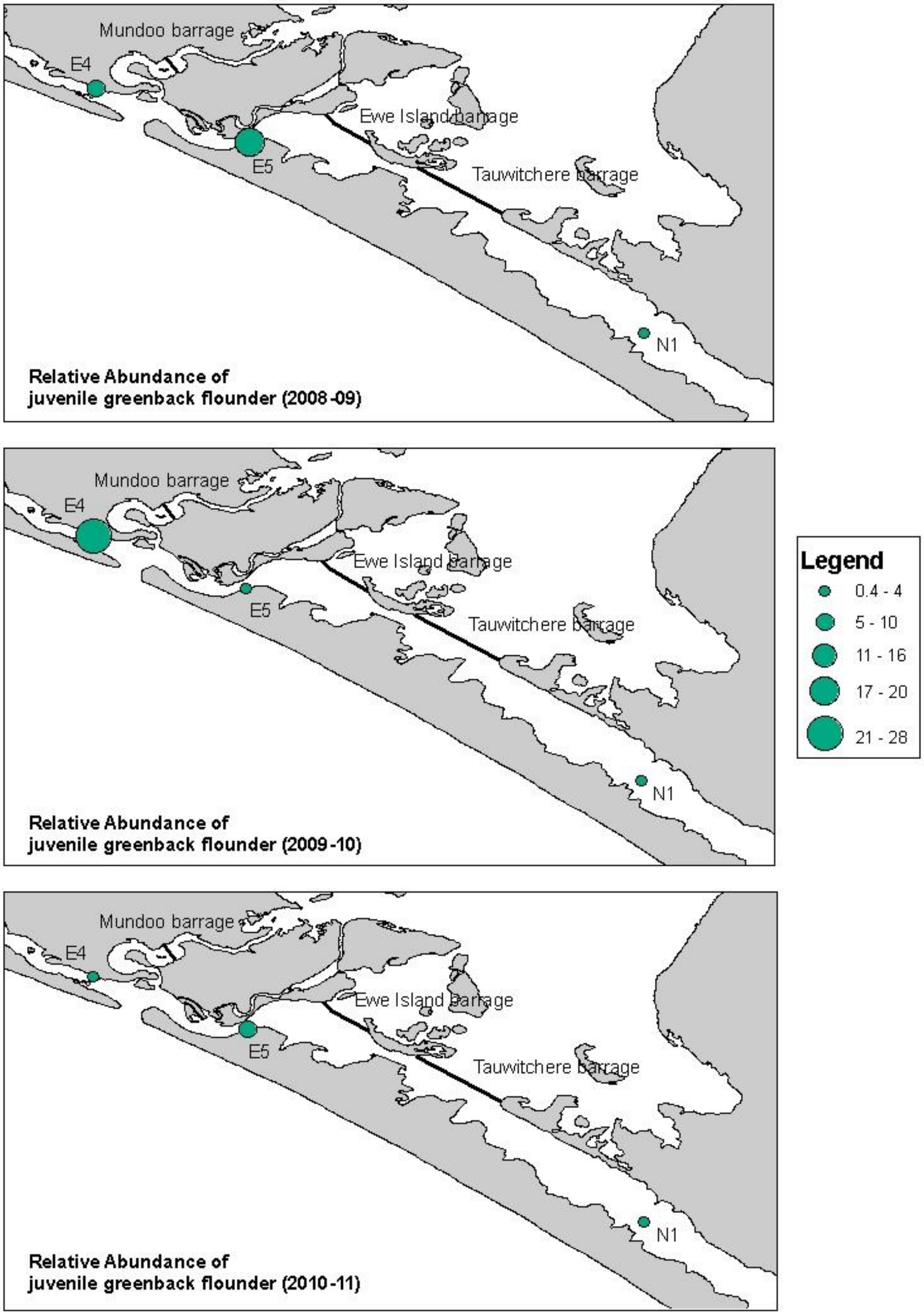


Figure 3.7. Coorong map showing juvenile greenback flounder relative abundance and distribution from 2008/09 to 2010/11 (top to bottom).

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 2010/11.

CPUE (fish per net.shot)	**2008/09**		**2009/10**		**2010/11**	
Regular Site	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Sugars Beach	10.8	3.1	27.7	8.8	0.7	0.4
Godfrey's Landing	17.4	3.2	4.3	1.1	5.3	2.0
Mark Point	0.4	0.2	0.4	0.2	1.8	0.5
Average across sites	8.8	1.8	9.1	3.1	3.0	0.8

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	2	3295.1	**0.017**
Site	2	18533	**0.001**
YearxSite	4	7895.7	**0.001**

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.

Sugras beach	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	1.4707	0.128
	2008/09x2010/11	3.7118	**0.002**
	2009/10x2010/11	4.9856	**0.001**
Godfrey's landing	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	2.667	**0.002**
	2008/09x2010/11	1.6945	0.071
	2009/10x2010/11	0.8870	0.454
Mark Point	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	0.2852	1
	2008/09x2010/11	1.9629	0.084
	2009/10x2010/11	1.9658	0.059

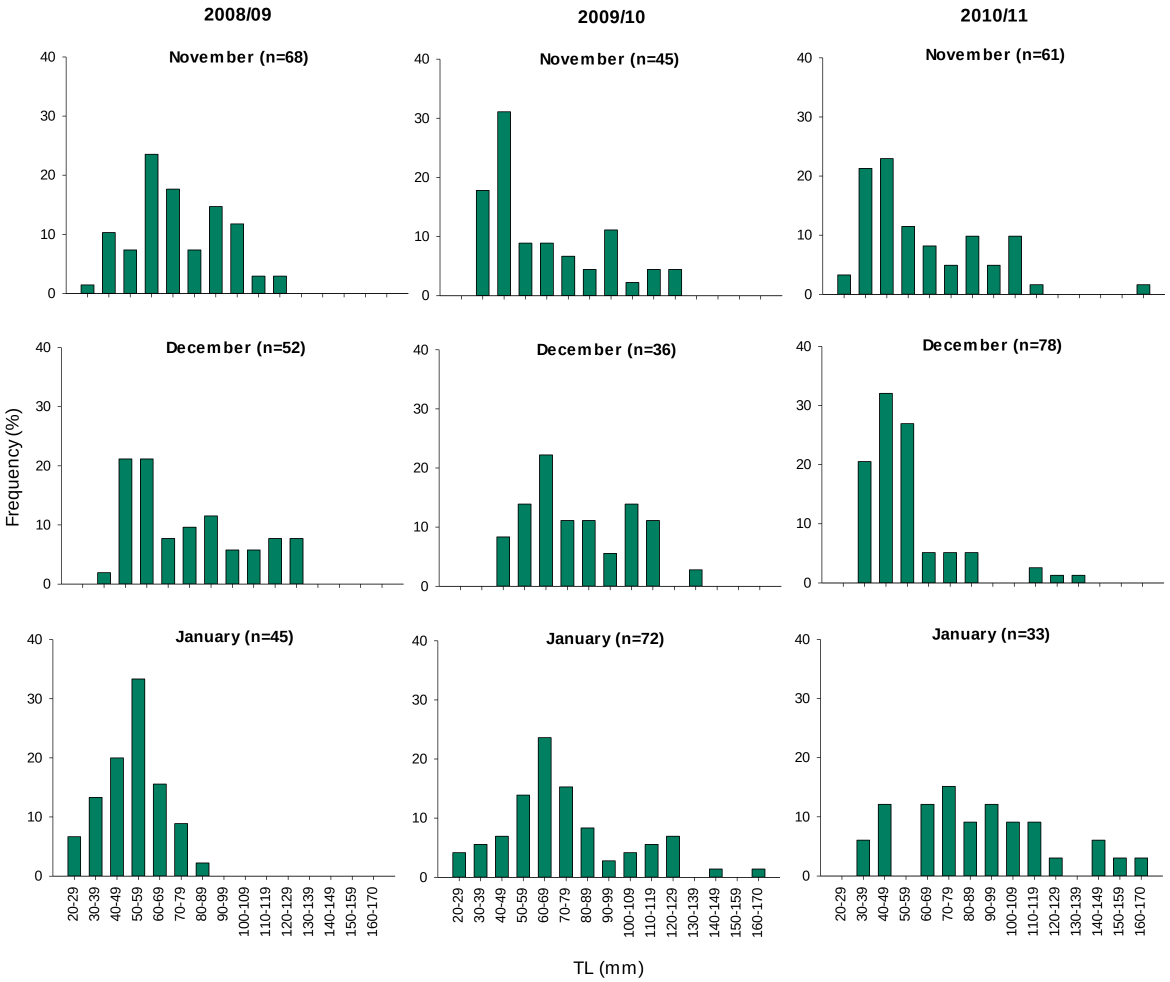


Figure 3.8. Length frequency distributions of juvenile greenback flounder from seine net samples in the Murray Estuary and Coorong from November to January between 2008/09 and 2010/11.

3.5. Smallmouthed Hardyhead

3.5.1. Relative abundance and distribution

Overall, there was an increase in abundance of smallmouthed hardyhead (Table 3.6, Figure 3.9). The distributional range of this species also expanded in the South Lagoon in 2009/10 and 2010/11 compared to that in 2008/09 (Figure 3.9).

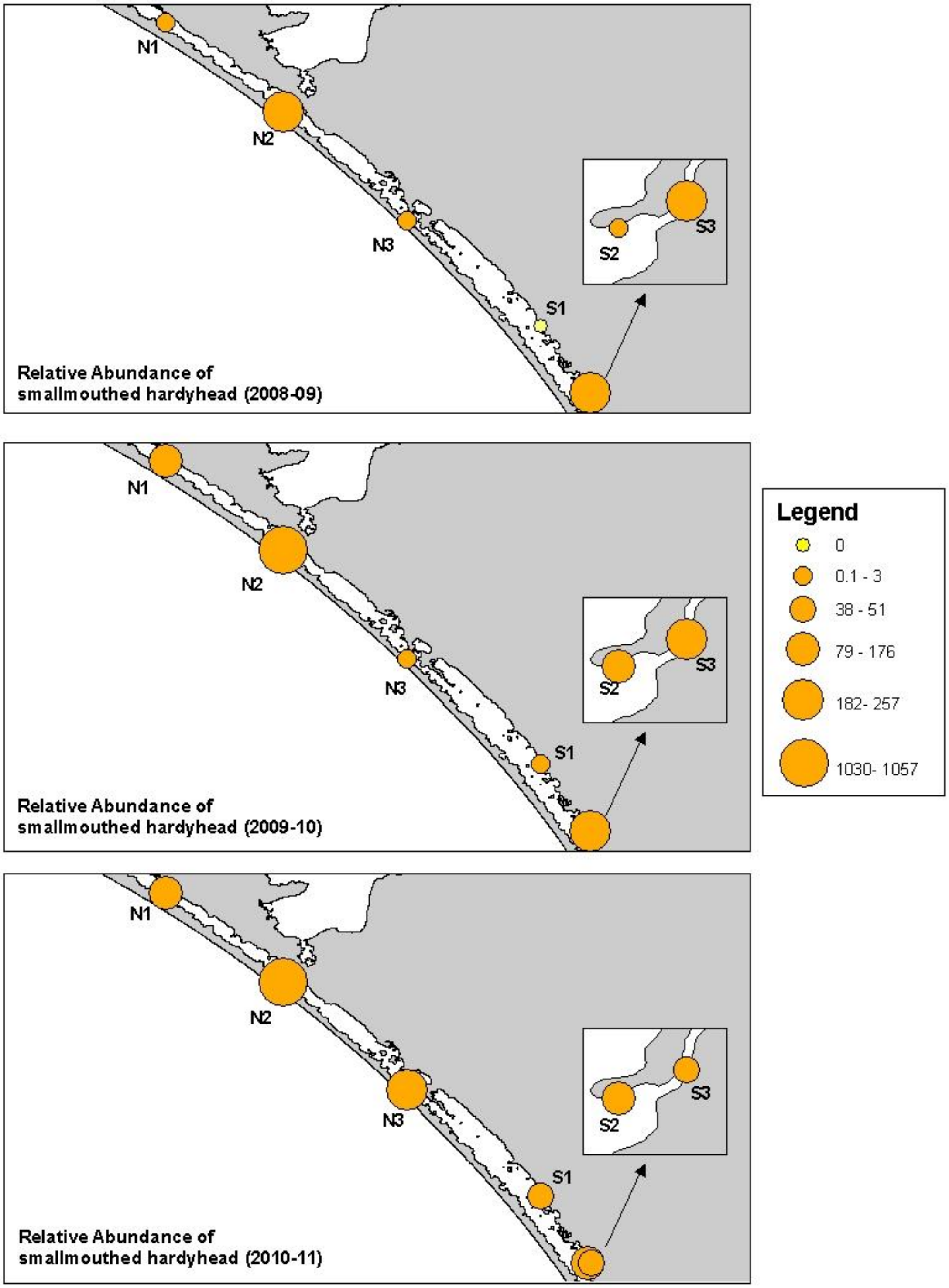
A significant interaction (*p*=0.001) when comparing CPUE between years (2008/09-2010/11) across sites in the North Lagoon (Mark Point, Noonameena and Hells Gate) and the South Lagoon (Jack Point, Salt Creek and Salt Creek inside creek) indicated that the spatiotemporal pattern varied (Table 3.7). Pairwise comparisons revealed that, there was a significant increase in CPUE from 2008/09 to 2009/10 at Mark Point (*p*=0.008), Noonameena (*p*=0.002) and Salt Creek (*p*=0.004), but no change was detected at the other sites between the first two years (Tables 3.6 and 3.8). From 2009/10 to 2010/11, CPUE increased significantly at Hells Gate (*p*=0.001) and Jack Point (*p*=0.003) and remained the same level at the other sites except for a significant reduction at Salt Creek (inside creek) (*p*=0.001).

Table 3.6. 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 2010/11.

CPUE (fish per net.shot)	**2008/09**		**2009/10**		**2010/11**	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Mark Point	2.3	1.9	176.0	48.6	120.0	33.2
Noonameena	248.0	37.6	1057.0	259.2	1029.8	604.4
Hells Gate	1.8	1.2	0.1	0.1	252.3	78.0
Jack Point	0.0	0.0	0.4	0.3	38.3	15.4
Salt Creek	0.4	0.4	79.7	30.1	168.1	60.3
Salt Creek inside creek	182.0	61.0	256.7	38.1	50.1	13.0
Average across sites	56.8	14.7	261.6	61.3	276.4	106.7

Table 3.7. 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	2	12641	**0.001**
Site	5	13992	**0.001**
YearxSite	10	3466.5	**0.001**



Relative Abundance of smallmouthed hardyhead (2008-09)

Relative Abundance of smallmouthed hardyhead (2009-10)

Relative Abundance of smallmouthed hardyhead (2010-11)

Figure 3.9. Coorong map showing relative abundance and distribution of smallmouthed hardyhead sampled using standard seine net from 2008/09 to 2010/11 (top to bottom). Inset map shows Salt Creek and Salt Creek inside creek sites.

Table 3.8. 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)**
	2008/09x2009/10	3.345	**0.008**
	2008/09x2010/11	8.5036	**0.001**
	2009/10x2010/11	1.678	0.098
Noonameena	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	3.8096	**0.002**
	2008/09x2010/11	1.0532	0.314
	2009/10x2010/11	1.4137	0.168
Hells Gate	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	2.0192	0.105
	2008/09x2010/11	7.4926	**0.001**
	2009/10x2010/11	14.806	**0.001**
Jack Point	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	1.4694	0.487
	2008/09x2010/11	4.8417	**0.002**
	2009/10x2010/11	3.5344	**0.003**
Salt Creek	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	3.7123	**0.004**
	2008/09x2010/11	6.1077	**0.001**
	2009/10x2010/11	1.1146	0.286
Salt Creek inside creek	**Groups**	**t**	**P(perm)**
	2008/09x2009/10	0.50551	0.652
	2008/09x2010/11	2.188	**0.023**
	2009/10x2010/11	4.3467	**0.001**

3.5.2. Size structure

The length frequency distributions of smallmouthed hardyhead collected from the North and South Lagoons throughout the sampling months are presented in Figure 3.10 and Figure 3.11. In the North Lagoon, fish size ranged from 10 to 89 mm TL in all years, except for 2010/11, when larger fish were collected (100 mm TL). No modal progression was identified between the 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 till February. 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 for 2009/10, 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 shown in 2009/10. In 2010/11, a considerable reduction of larger fish occurred in December, followed by a modal progression in standard 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.

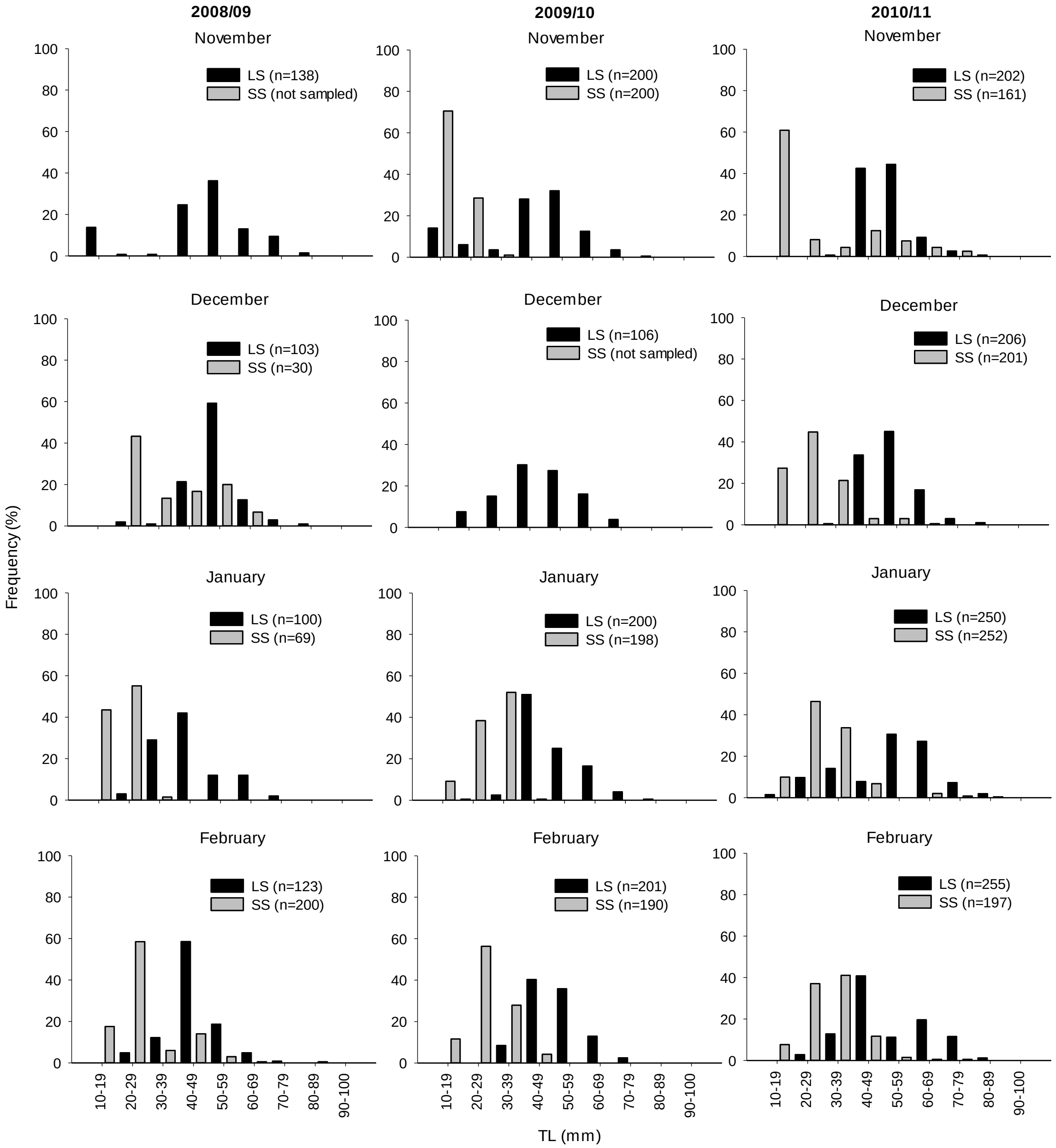


Figure 3.10. Length frequency distributions of smallmouthed hardyhead from standard (LS) and small (SS) seine nets in the North Lagoon sites from November to February between 2008/09 and 2010/11.

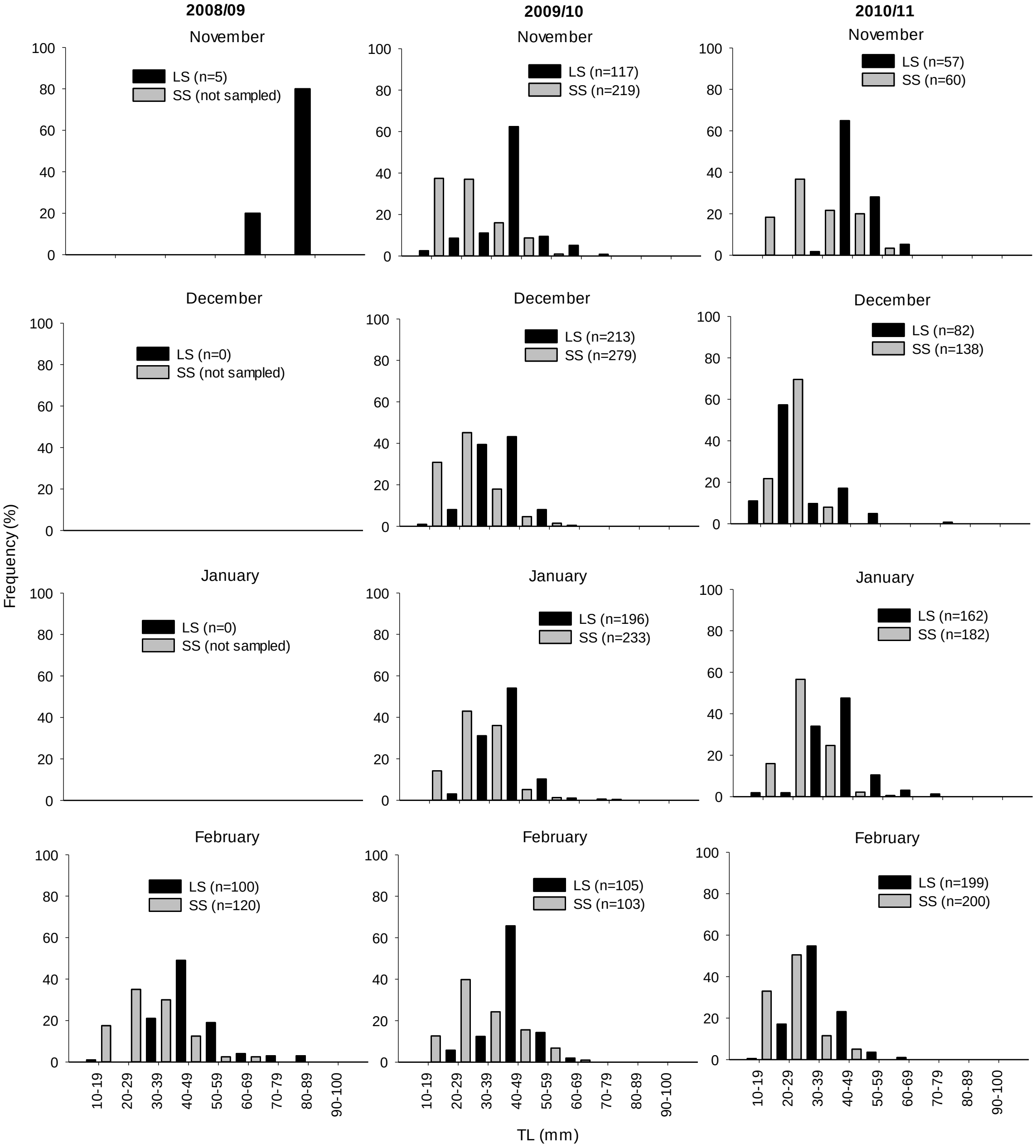


Figure 3.11. Length frequency distributions of smallmouthed hardyhead from standard (LS) and small (SS) seine nets in the South Lagoon sites from November to February between 2008/09 and 2010/11.

3.5.3. Recruitment

Overall, there was an increase in abundance of juvenile smallmouthed hardyhead in 2010/11 in the North and South Lagoons of the Coorong compared to previous years (Table 3.9, Figure 3.12). Salt Creek inside creek was the only site, where juvenile CPUE was higher in 2009/10 compared to both years (2008/09 and 2010/11) (Table 3.9).

A significant interaction (*p*=0.001) was detected when comparing CPUE of juvenile smallmouthed hardyhead between years across sites (Table 3.10), indicating that spatiotemporal pattern was not consistent in all years and sites. From 2008/09 to 2009/10, there was a significant increase in juvenile CPUE at Mark Point (*p*=0.004) and Salt Creek inside creek (*p*=0.004), but no difference at Noonameena (*p*=0.8) (Tables 3.9 and 3.11). The other three sites were not sampled using the small seine net (i.e. only standard seine net was used) in 2008/09. From 2009/10 to 2010/11, there was a significant increase in juvenile CPUE at Noonameena (*p*=0.003), Hells Gate (*p*=0.001) and Jack Point (*p*=0.003), whilst no difference was detected at Mark Point and Salt Creek and there was a reduction at Salt Creek inside creek (*p*=0.001) (Tables 3.9 and 3.11).

Table 3.9. 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 2010/11.

CPUE (fish per net.night)	**2008/09**		**2009/10**		**2010/11**	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Mark Point	114.3	43.6	396.9	46.0	407.9	166.4
Noonameena	175.3	41.1	195.9	28.3	2541.7	808.9
Hells Gate			0.3	0.2	1122.1	288.3
Jack Point			8.8	3.8	72.6	14.5
Salt Creek			238.0	129.3	290.5	60.8
Salt Creek inside creek	59.0	18.2	520.0	75.8	60.0	12.9
Average across sites	116.2	24.7	220.3	36.3	749.1	175.2

Table 3.10. 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	2	4824.9	**0.001**
Site	5	4959.4	**0.001**
YearxSite	7	3598.2	**0.001**

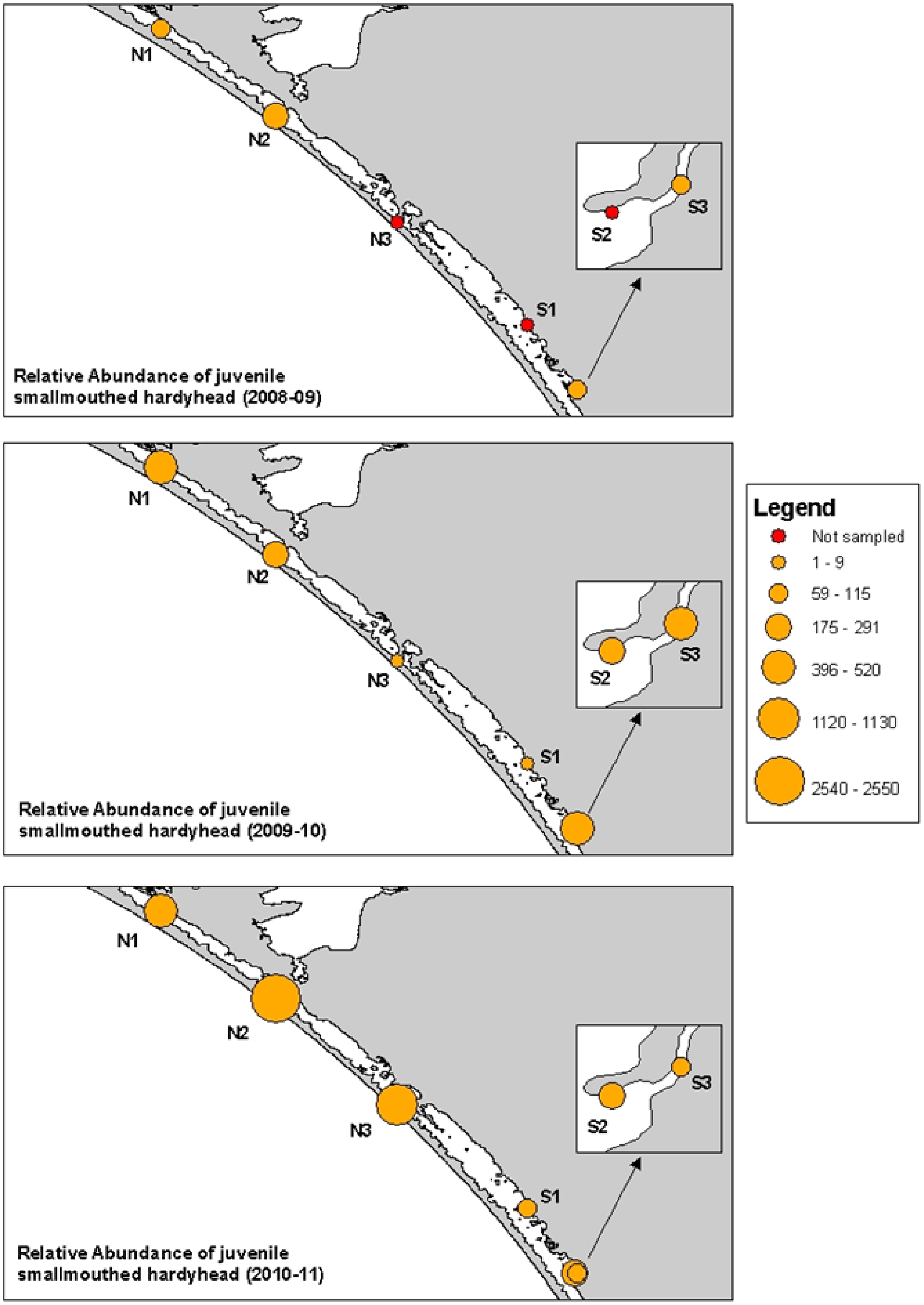


Figure 3.12. Coorong map showing relative abundance and distribution of juvenile smallmouthed hardyhead sampled using small seine net from 2008/09 to 2010/11 (top to bottom). Inset map shows Salt Creek and Salt Creek inside creek sites.

Table 3.11. 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)**
	2009/10x2010/11	1.5241	0.126
	2009/10x2008/09	4.6308	**0.004**
	2010/11x2008/09	0.9551	0.35
Noonamena	**Groups**	**t**	**P(perm)**
	2009/10x2010/11	4.7501	**0.003**
	2009/10x2008/09	0.20913	0.8
	2010/11x2008/09	2.9054	**0.006**
Hells Gate	**Groups**	**t**	**P(perm)**
	2009/10x2010/11	9.4107	**0.001**
Jack Point	**Groups**	**t**	**P(perm)**
	2009/10x2010/11	3.2098	**0.003**
Salt Creek	**Groups**	**t**	**P(perm)**
	2009/10x2010/11	1.565	0.125
Salt Creek inside creek	**Groups**	**t**	**P(perm)**
	2009/10x2010/11	7.2328	**0.001**
	2009/10x2008/09	4.8403	**0.004**
	2010/11x2008/09	0.33279	0.773

4. DISCUSSION

4.1. Freshwater inflow and salinity

Over the last decade, extensive drought in the Murray-Darling Basin, combined with extensive river regulation and water abstraction, has resulted in a significant reduction in annual freshwater flow to the Coorong, with discharges less than 1 000 GL y^{-1} since 2000/01. Between 2007/08 and 2009/10, there were no barrage releases. During 2010/11, a significant increase in rainfall and flow in the River Murray led to the refill of the Lower Lakes and barrage releases of more than 10 000 GL since September 2010.

Salinities in the Coorong are highly variable, mainly driven by freshwater flows from the River Murray and tidal seawater exchanges 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, with almost no barrage release, the Coorong essentially became a marine/hypersaline environment. Mean salinities during 2008-2010 ranged from 37-44 ppt in the Murray Estuary, 49-133 ppt in the North Lagoon and 82-134 ppt in the South Lagoon. These values are higher than those recorded during the 1982 drought, which included a 16-month period of no freshwater inflows (Geddes and Butler 1984), resulting in salinities reaching 80 ppt in the North Lagoon and 90-100 ppt in the South Lagoon. The increased salinities throughout the Murray Mouth and Coorong had a profound impact on fish assemblages in the region, with negative implications for several estuarine and diadromous species including TLM targeted species (black bream, greenback flounder and congolli) (Noell *et al.* 2009; Zampatti *et al.* 2010; Ye *et al.* 2011b).

During 2010/11, freshwater input caused a significant reduction in salinity; between November 2010 and June 2011, mean salinities were 1-5 ppt in the Murray Estuary, 9-76 ppt in the North Lagoon, and 54-98 ppt in the South Lagoon. These levels were somewhat comparable to those in the 1983/84 flow year, when, 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) (Geddes 1987). With broadly decreased salinities coupled with other freshwater induced environmental changes in the Coorong during 2010/11, intervention monitoring for fish assemblages found a significant change in assemblage structure compared to that of the drought years, mainly attributed to an increase in the diversity and abundance of freshwater species, and increased abundances of small-bodied estuarine/opportunist species and catadromous species (congolli) (Ye *et al.* 2011a).

4.2. Black Bream

4.2.1. 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 (Norriss *et al.* 2002; Winemiller and Rose 1992). Age structures of both females and males from 2007/08 were dominated by 3 and 9 year olds, 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. 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). 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 ages/sizes was consistent among four years and two strong cohorts persisted in samples over multiple years (at least 9 years for 1997/98 cohort and 4 years for 2003/04 cohort). Additionally, for species such as black bream which may be entangled as well as meshed in gill nets, selectivity over a wide length range is common (Hamley 1975; Bjordal 2002; Ferguson 2010).

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 or 2003/04 were major flows or flood events in this study, suggesting that the recruitment of black bream may benefit from below-average inflows from the River Murray. A study in Western Australia also indicated that recruitment of juveniles was the greatest in moderate flow years (Hoeksema *et al.* 2006). Flow regime is likely important to facilitate recruitment success of black bream. Further research is required to determine the flow characteristics 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 reported age of black bream from the Coorong population is 25 and 14 years for females and males, respectively, in this study. Nevertheless, few individuals (2%) greater than 12 years old were present in age structures from 2007/08 to 2010/11. Such truncation of age structures had previously been reported for this population in 2002, 2003, 2004 and 2007 (Ferguson and Ye 2008). Given it is unlikely that black bream leave the Coorong, 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 on this species (Sarre 2000; Ferguson and Ye 2008; Ferguson *et al.* 2010; Ye *et al.* 2011b). The commercial catch of black bream from the Coorong also showed a substantial reduction since the mid 1980's, reaching a historical low in 2008/09 and 2009/10 (Ye *et al.* 2011b). Truncated age structures indicate longevity in overfishing which suggests that capacity for egg production may be compromised (Beamish *et al.* 2006). Rebuilding and maintaining age structures is critically 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 especially 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 climate change predictions indicate further flow reduction (Hughes 2003).

4.2.2. 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 the environmental deterioration due to the continued lack of flow conditions in 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 no barrage releases were made for the Coorong from 2007/08 to 2009/10 (The Living Murray Coorong fish condition monitoring commenced in 2008/09), some unintentional releases or leakage of freshwater have probably occurred at various times (e.g. SA Water 2009), which may have facilitated fish 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 from a low in 2008/09 to an even lower level in 2009/10 may reflect a reduced spawning biomass, thus compromising recruitment capacity of this species (Ye *et al.* 2011b).

In 2010/11, with a substantial increase in barrage discharge, salinities reduced significantly in the Murray Estuary and Coorong. However, no new recruits (YOY) were collected during this year, which might suggest recruitment failure possibly due to the current high flow event not providing environmental conditions conducive to black bream recruitment in the Coorong or the further reduced spawning biomass failed to respond to the flow event with detectable new recruits. Nevertheless, the results should be interpreted with caution because no collection of juvenile black bream in 2010/11 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, the adult black bream did have a southward range expansion into the North Lagoon following the flow event in 2010/11 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 cohort in subsequent years.

4.3. Greenback Flounder

4.3.1. Age and size structures

Greenback flounder is a fast-growing species, and may attain >6 years of age; fish mature early at about one year old and fecundity is high (Kurth 1957; Crawford 1986; Stevens *et al.* 2005). 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. Dominance of females in samples has been reported previously for fishery catches from the Coorong (Cheshire *et al.* 2011). Studies suggested that greenback flounder sexually partitioned habitat and spawning aggregations of females formed in deeper habitats (Kurth 1957; Crawford 1984a), which probably makes them more susceptible to netting.

Over the years of this study, the dominant age class in age structure of females showed a general shift toward younger fish although, in 2010, the dominance of smaller and younger fish in the catch may be attributed to gear selectivity given most of the samples came from fishery-independent sampling. Nevertheless the general consistency of size structures of greenback flounder in this study with those from a previous study suggests age/size structures are representative of the population in the Coorong (Ferguson 2010). Given that greenback flounder can live to more than 6 years (Stevens *et al.* 2005), and they rarely leave the Coorong (Hall 1984), the most likely explanation for the highly truncated age structures is that fishing has impacted on this species (Ferguson *et al.* 2010). Annual commercial fishery catch of this species also showed a substantial decline in the Coorong particularly in the last ten years, reaching a historical low level in 2008/09 and 2009/10 (Ye *et al.* 2011b).

4.3.2. 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 three 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 are likely to be affected by freshwater flows to estuaries (Robins and Ye 2007). As this species spawns during winter (Crawford 1984b) before the high flow season, larval and juvenile growth would potentially take advantage of any enhanced biological productivity (i.e. food availability) related to freshwater flows to estuaries, which might result in faster growth rates (and therefore survival rates) thus higher levels of recruitment success (Robins and Ye 2007). In addition, freshwater flow is the key influence on salinity regimes in the Coorong (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 a tolerance range of 14-45 ppt after fertilisation (Hart and Purser 1995). During 2008/09 and 2009/10, with no barrage releases, the 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 thus impacting on recruitment success of greenback flounder. However, it is worth mentioning that juvenile greenback flounder are more tolerant to hyper saline conditions with the laboratory estimates of lethal concentration for 50% test fish (LC_{50}) ranging 79-88 ppt (McNeil *et al.* 2011). Therefore they were still collected in the mid to northern part of the North Lagoon during drought years (Noell *et al.* 2009).

In 2010/11, freshwater inflows caused a significant reduction in salinity, restoring a large area of estuarine habitat and suitable nursery ground for greenback flounder particularly in the North Lagoon. Despite the fact that new recruits collected were less abundant at Sugars Beach in 2010/11 than in the previous two years and this might be due to a strong flow effect for this site given its close proximity to the Murray Mouth. At Godfrey's Landing and a few other sites within the Estuary subregion (intervention monitoring, Ye *et al.* 2011a), the catch of new recruits appeared to be slightly greater in 2010/11 than previous years although not all were statistically different. A near significant increase in new recruit abundance at Mark Point was probably a response to the freshwater inflows and freshening of the North Lagoon. The intervention monitoring also suggested a broader distribution of YOY greenback flounder in the North Lagoon following the 2010/11 flow event (Ye *et al.* 2011a), which reduced the salinities to less than 76 ppt in this subregion.

4.4. Smallmouthed hardyhead

4.4.1. Relative abundance and distribution

Smallmouthed hardyhead is an 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 maintained between 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 smallmouth 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 & Hernández de Santillana 2004). This may also partially explain the increase in hardyhead numbers at Mark Point, where salinity rose from 48-52 ppt in 2008/09 to 56-62 ppt in 2009/10. In contrast, the recovery of fish numbers at Salt Creek was most likely attributed to the increased inflow from the Upper South East through the Salt Creek (Figure 3.13), freshening the southern end of the Coorong thus restoring suitable salinities and habitats for hardyhead (Figure 3.2). 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. However, this positive biological response was only at a local scale (limited to the southern end of the South Lagoon).

In 2010/11, the barrage releases caused a substantial reduction in salinity throughout the Coorong. The dramatic increase in smallmouthed hardyhead abundance in the South Lagoon following salinity reductions (to <100 ppt) was 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 the Salt Creek inside creek into the South Lagoon. This is of particular ecological significance, given the important role this keystone species plays in the trophic ecology of the region.

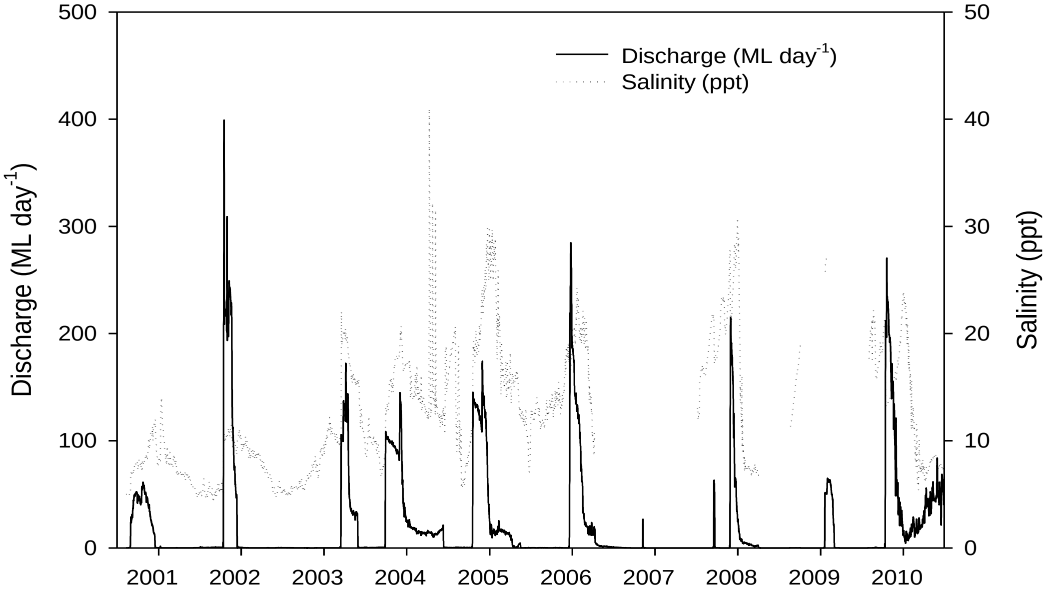


Figure 3.13. Daily flow discharge through the Salt Creek with salinity levels (DFW 2010, Surface Water Archive, Station A2390568).

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 since February 2009.

The spatial and temporal pattern of length frequency distributions provides a useful indication of recruitment dynamics of this species. 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 Hells Gate, Jack Point and Salt Creek sites, suggesting a recruitment failure. In contrast, size structures indicated successful recruitment in later two years in both North and South Lagoons, although the small seine net catch indicated the 2010/11 cohort was much stronger.

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 of this species (Molsher *et al.* 1994). The maximum total lengths recorded during the first two years in this study was similar to that found by Molsher *et al.* (1994) in the Coorong (i.e. 85 mm TL). However, in 2010/11 the maximum size was larger (i.e. 96 mm TL), and fish appeared to grow faster in the North Lagoon as indicated by a more distinct modal progression in size distribution. This was possibly attributed to an increase in food resources following freshwater inflows from the River Murray and lower salinities which reduced osmoregulatory stress.

4.4.3. Recruitment

Over the last three years, recruitment of smallmouth hardyhead increased in the Coorong. In particular, after the significant Murray flow event in 2010/11, there was a dramatic increase in the number of new recruits throughout an extensive area of the North and South Lagoons (between Noonameena and Jack Point). The small seine net was an effective gear for quantitative assessment of new recruit abundance and the CPUE provided a recruitment index for hardyhead.

In 2008/09, fish recruitment was likely spatially restricted to the northern part of the North Lagoon and within the Salt Creek (i.e. Salt Creek inside creek with a salinity level of 40 ppt). The constant high salinities (>109 ppt) during the reproductive season presented a limiting factor for fish recruitment at the southern end of the North Lagoon (i.e. Hells Gate) and in the South Lagoon. Such salinity levels were higher than the laboratory tolerance (i.e. LC_{50} 108 ppt) of this species (Liu 1969). The effect of high salinity on the reproductive performance of atherinids has been evidenced in several studies (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) hence affect population ecology.

In 2009/10, small amounts of inflows from the South East significantly reduced the salinity in the southern end of the South Lagoon (i.e. Salt Creek). Restoration of suitable physiochemical environment and habitats probably led to the 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, such effect appeared to be short-lived. With a decline in the Upper South East inflow and an increase in evaporation during summer, salinities rose steeply at the southern end of the South Lagoon from 29 ppt in October 2009 to 135 ppt in February 2010. Correspondingly, smallmouthed hardyhead populations contracted southward toward

Salt Creek, and essentially 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 a strong hold 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, significant freshwater inflows from the River Murray resulted in broadly reduced salinities throughout the Coorong region. These, coupled with other freshwater induced environmental changes, have restored extensive suitable habitat and facilitated spawning and recruitment of smallmouthed hardyhead, thus leading to a dramatic increase in new recruit abundance across a large area in the Coorong (from Noonameena to Jack Point). Seasonal reduction of salinity by freshwater influence has been 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 young fish, therefore benefiting smallmouthed hardyhead recruitment (Whitfield 1994; Gillanders and Kingsford 2002).

5. CONCLUSIONS

Condition monitoring of the populations of smallmouthed hardyhead in the North and South Lagoons of the Coorong for the first three years (2008/09−2010/11) indicated that management target F3, as defined in the CLLMM Icon Site EMP (i.e. Provide optimum conditions to improve recruitment success of smallmouthed hardyhead in the South Lagoon), was met particularly following the barrage releases in 2010/11. Although smallmouthed hardyhead has a strong salinity tolerance, in 2008/09, the extremely 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 inflows (~100 ML day^{-1}) from Salt Creek. This freshwater/brackish creek probably also served as a recruitment refuge for smallmouthed hardyhead, facilitating the population recovery in the South Lagoon. In 2010/11, broadly decreased salinities, coupled with other freshwater induced environment changes, led to a dramatic increase in population abundance and enhanced recruitment for 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) are restored and shows the resilience of the hardyhead population in the Coorong.

In contrast, for black bream and greenback flounder, condition monitoring in the Murray Estuary and North Lagoon of the Coorong did not indicate that management target F4, as defined in the CLLMM Icon Site EMP (i.e. Maintain or improve recruitment of black bream and greenback flounder in the Murray Mouth estuary and North Lagoon), was met during the first three years (2008/09−2010/11). This was reflected, for both species, by: (i) truncated population age structures which indicate longevity overfishing and (ii) a general decline in juvenile recruitment from 2008/09 to 2009/10 and uncertainty in recruitment success for 2010/11. In addition, analysis of fisheries catch and effort data (1984/85−2009/10) (Ye *et al.* 2011b) indicated (i) a significant decline in population abundance, particularly over the past ten years, (ii) historically low level of abundance in 2008/09 and 2009/10, and (iii) considerable contraction of distributional range to a reduced habitat in the Murray Estuary.

Nevertheless, the recent barrage flow event is deemed 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 and a favorable salinity gradient, as observed in 2010/11, in the Coorong. Ongoing monitoring will be required in subsequent years to continue to investigate the recruitment response of these important large-bodied estuarine species and evaluate how/whether they would benefit from the current and potentially future freshwater inflows to the Coorong. 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. 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 regimes, which influence the recruitment success of key estuarine species and fish habitat.

The first three years of condition monitoring in the Coorong has provided valuable information on the population age, size structure and recruitment ecology of black bream, greenback flounder and smallmouthed hardyhead, and has established a baseline by which future quantitative assessment can be made. The results of this study form an important basis for the adaptive management to ensure ecological sustainability of the iconic estuarine fish species in the CLLMM region.

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APPENDIX

Appendix I. Monthly sampling effort used to collect juvenile black bream using single-wing fyke nets at regular and additional sites in the Coorong for 2008/09, 2009/10 and 2010/11.

Sampling Effort	2008/09						2009/10				2010/11				
(number of fyke nets x nights)	Feb	Mar	Apr	May	Jun	T	Feb	Mar	Apr	T	Feb	Mar	Apr	Jun	T
Regular sampling sites															
Goolwa Barrage sw side HI		8	6		7	21	8	8	8	24	8	8	8	4	28
Goolwa Barrage sw side SRP	7	8	8		8	31	8	8	8	24	8		8	4	20
Boundary Creek	7	8	8		8	31	8	8	8	24					
Additional sampling sites															
Boundary Creek Barrage			4			4									
Cattle Point														4	4
Ewe Island Causeway				4		4		8	8	16					
Goolwa Barrage fw side HI		4				4									
Goolwa Barrage frw side SRP		2				2	4			4					
Long Point											4			4	8
Long Point sand dune														4	4
Mark Point					8	8					4			4	8
Mundoo Barrage				4		4					8	8	8		24
Mundoo Channel					8	8									
Noonameena														4	4
Pelican Point				4		4									
Pelican Point YHP					8	8									
Robs Point														4	4
Tauwitchere Barrage				3		3	4			4					
Overall						132				96					104

Appendix II. Monthly sampling effort used to collect juvenile greenback flounder using standard seine net at in the Coorong for 2008/09, 2009/10 and 2010/11.

Sampling Effort	2008/09				2009/10				2010/11			
(number of seine net shots)	Nov	Dec	Jan	Total	Nov	Dec	Jan	Total	Nov	Dec	Jan	Total
Sugars Beach	3	3	3	9	3	3	3	9	3	3	3	9
Godfrey's Landing	3	3	3	9	3	3	3	9	3	3	3	9
Mark Point	3	3	3	9	3	3	3	9	3	3	3	9
Overall				27				27				27

Appendix III. Monthly sampling effort used to collect juvenile and adult smallmouthed hardyhead using large and small nets in the Coorong for 2008/09, 2009/10 and 2010/11.

Sampling Effort	2008/09					2009/10					2010/11				
(number of seine net shots)	Nov	Dec	Jan	Feb	T	Nov	Dec	Jan	Feb	T	Nov	Dec	Jan	Feb	Total
Large seine net															
Hells Gate	3	3	3	3	12	3	3	3	3	12	3	3	3	3	12
Jack Point	3	3	3	3	12	3	3	3	3	12	3	3	3	3	12
Mark Point	3	3	3	3	12	3	3	3	3	12	3	3	3	3	12
Noonameena	3	3	3	3	12	3	3	3	3	12	3	3	3	3	12
Salt Creek	3	3	3	3	12	3	3	3	3	12	3	3	3	3	12
Salt Creek inside creek				3	3	3	3	3	3	12	3	3	3	3	12
Overall					63					72					72
Small seine net															
Hells Gate					0	3	3	3	3	12	3	3	3	3	12
Jack Point					0	3	3	3	3	12	3	3	3	3	12
Mark Point				3	3	3		3	3	9	3	3	3	3	12
Noonameena				3	3	3		3	3	9	3	3	3	3	12
Salt Creek					0	3	3	3	3	12	3	3	3	3	12
Salt Creek inside creek				3	3	3	3	3	3	12	3	3	3	3	12
Overall					9					66					72