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Coorong Fish Condition Monitoring 2008–2010: Population and Recruitment Status of the Black Bream (*Acanthopagrus butcheri*) and Greenback Flounder (*Rhombosolea tapirina*)

Qifeng Ye, Luciana Bucater, Greg Ferguson and David Short

SARDI Publication No. F2011/000331-1
SARDI Research Report Series No. 572

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

2011

Government of South Australia
South Australian Murray-Darling Basin Natural Resources Management Board

Australian Government
MURRAY–DARLING BASIN AUTHORITY

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This Publication may be cited as:
Ye, Q., Bucater, L., Ferguson, G. and Short, D (2011). 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.

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Printed in Adelaide: September 2011

SARDI Publication No. F2011/000331-1
SARDI Research Report Series No. 572

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Date:	9 September 2011
Distribution:	SAMDB NRM Board, Murray-Darling Basin Authority, DENR, DFW, SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library
Circulation:	Public Domain

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ACKNOWLEDGEMENTS

This project was funded by the Living Murray Initiative of the Murray-Darling Basin Authority through the South Australian Murray-Darling Basin Natural Resources Management Board (SAMDB NRMB). The authors would like to thank the Coorong commercial fishers, Darren Hoad, Dingles, Garry Hera-Singh, Matt Hoad and Tim Hoad for supplying fish samples. SARDI staff Neil Wellman, Dave Fleer, Katherine Cheshire and Jason Earl provided assistance with fieldwork and/or laboratory analyses. Thanks to Adrienne Frears and Glynn Ricketts for support and management of this project. Also thanks to Adrienne Frears, Karl Hillyard and Jason Earl who reviewed and provided comments on this report; and to John Middleton and Annie Vainickis for managing the review process.

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 The Living Murray program. Over the last decade under the protracted drought conditions, the Coorong ecosystem has become increasingly degraded due to lack of freshwater inflows and significant increases in salinity as a result of extensive river regulation and over abstraction. In order to restore and enhance the environmental values of the CLLMM region, an Icon Site Environmental Management Plan was developed, within which preliminary targets were set for fish in the Coorong. Condition monitoring has been implemented to evaluate whether these targets have been achieved. This report presents the findings of the first two years of a monitoring program for black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) in 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.

Commercial fishery catch and CPUE were used as an indicator of the relative abundance of both species. Catches reported by spatial fishing blocks provided an indicator of fish distribution along the Coorong. Additional research sampling was conducted to quantitatively assess the recruitment of juveniles in 2008/09 and 2009/10. Results from the first two years indicated that management target F4 was not met in 2008/09 or 2009/10. This was reflected, for both species, by (i) a significant decline in population abundance, particularly over the last ten years, (ii) historically low level of abundance in the last two years, (iii) considerable contraction of distributional range to a reduced habitat in the Murray Estuary, (iv) truncated population age structures which indicate longevity overfishing, and (v) a decline in juvenile recruitment from 2008/09 to 2009/10.

Freshwater inflows are important for the recovery of depleted populations of black bream and greenback flounder given their critical role in facilitating successful spawning and recruitment and maintaining estuarine fish habitat in 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. 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, including flow regimes, that influence the recruitment success of key estuarine species and fish habitat.

The first two years of condition monitoring in the Coorong have provided valuable information on the population ecology of black bream and greenback flounder and have 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.

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, the Coorong region has been heavily impacted by river regulation and water abstraction since European settlement. The average annual flow at the Murray Mouth has declined by 61% (from 12,333 GL y^{-1} to 4,733 GL y^{-1}, CSIRO 2008). The construction of five tidal barrages in the 1940s significantly reduced the area of the original Murray Estuary establishing an abrupt physical 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, continuing degradation of critical habitats for nationally listed bird species, and compromised the 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 the freshwater and the sea (Zampatti *et al.* 2010).

In order to restore and enhance the environmental values of the CLLMM region, the Murray-Darling Basin Commission (MDBC, now Murray-Darling Basin Authority) developed an Icon Site Environmental Management Plan (EMP), within which preliminary targets were developed for fish in the Coorong:

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.

Relevant condition monitoring, as described in the Icon Site Condition Monitoring Plan (Maunsell Australia Pty Ltd. 2009), was instigated in 2008/09 to assess whether these targets have been achieved. The current report presents the findings of the condition monitoring for black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) (target F4) in the Murray Mouth Estuary and North Lagoon of the Coorong during the first two years (i.e. 2008/09 and 2009/10).

1.2. Objectives

The aim of the condition monitoring, linked to target F4, was to assess the population, reproductive and recruitment status of black bream and greenback flounder in the Murray Estuary and the North Lagoon of the Coorong. Specific objectives were to:

- determine the relative abundance, distribution and size/age structures of black bream and greenback flounder;
- assess reproductive development during the spawning season for each species; and
- establish recruitment indices and assess recruitment success for both species.

2. METHODS

2.1. Catch, effort, CPUE and freshwater inflows

2.1.1. Data

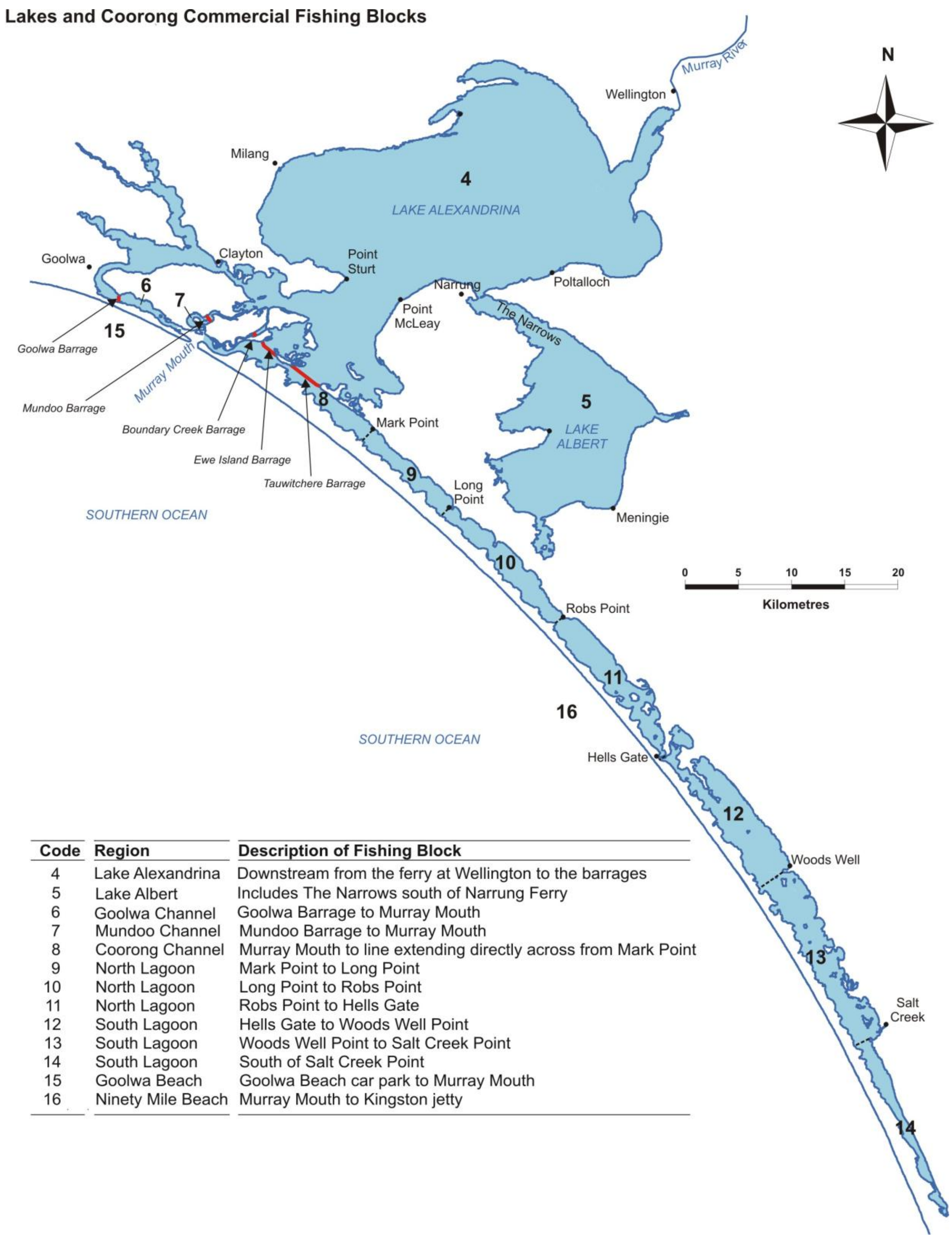
Commercial catch and effort data for black bream and greenback flounder from the Lakes and Coorong Fishery were available for the years 1984/85 to 2009/10 from the SARDI Statistics and Information Unit). Data included catch (kg), effort (fisher days, net days), and spatial reporting block (Figure 2.1).

Annual and monthly freshwater discharges across the barrages were available for the period from July 1984 to June 2010 from the regression based Murray hydrological model (MDM, BIGMOD, MDBA).

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. 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 commercial catches of black bream and greenback flounder was conducted in the Murray Estuary and North Lagoon of the Coorong. Adult black bream were collected during spring/early summer, mainly from the Goolwa channel (Figure 2.2) and greenback flounder during winter from the Goolwa channel and near Mark Point in the North Lagoon (Figure 2.3). Supplemental samples from fishery-independent sampling were also included when necessary. Sample sizes for adult black bream and greenback flounder are shown in Table 2.1 and Table 2.2 respectively. 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.

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

Number of fish	**2008/09**			**2009/10**			Grand Total
Month	Commercial	Fishery-independent	*Total*	Commercial	Fishery-independent	*Total*	
September				50		*50*	50
October	15		*15*	46		*46*	61
November				37		*37*	37
December	20		*20*	25	1	*26*	46
January	46	1	*47*	6		*6*	53
February	2		*2*		23	*23*	25
March	16		*16*		15	*15*	31
Overall	*99*	*1*	*100*	*164*	*39*	*203*	303

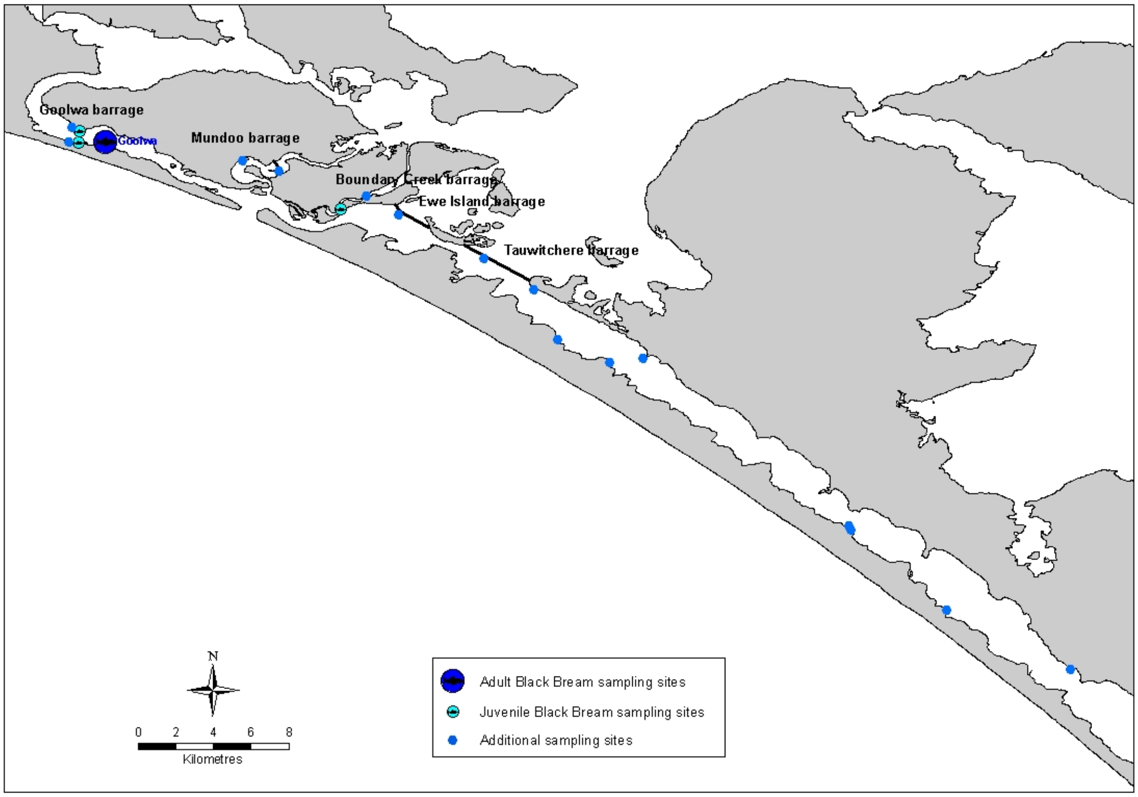


Figure 2.2. Icon site condition monitoring sampling sites for black bream in the Murray Estuary and Coorong.

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

Number of fish	**2009**		
Month	Commercial	Fishery-independent	*Total*
May	14		*14*
June	24	1	*25*
July	38		*38*
August	29		*29*
Overal	*105*	*1*	*106*

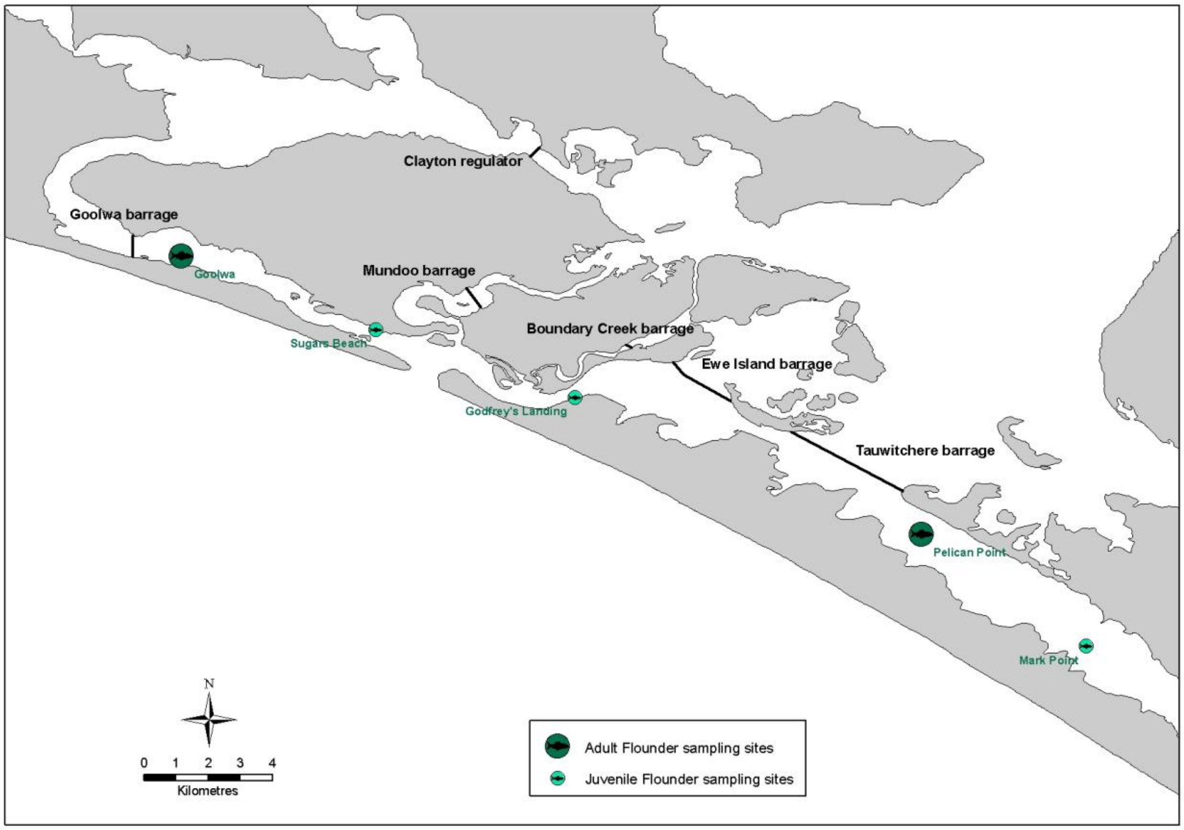


Figure 2.3. Icon site condition monitoring sampling sites for greenback flounder in the Murray Estuary and Coorong.

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 sagittal 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).

To test for differences in size and age composition between adult female and male black bream Kolmogorov-Smirnov goodness of fit (K-S) tests were applied to length or age data for each year. The K-S tests were also used to examine differences in size and age structures between years for female greenback flounder.

2.3. Reproduction

2.3.1. Samples

Fish samples collected during the age/size study for black bream and greenback flounder (Tables 2.1 and 2.2) were also used for the reproductive development assessment.

2.3.2. Laboratory processing and analysis

Individual fish were measured, weighed, and dissected to remove their gonads. Sex, macroscopic gonad stage and gonad weight were also recorded. Gonado-somatic indices (GSI) were calculated as: GSI = $[W_g/W_f]*100\%$, where, W_g = gonad weight, W_f = gonad-free fish weight. Ovaries were classified macroscopically to one of five developmental stages, based on size, colour and visibility of oocytes (Fowler *et al.* 1999) (Appendix I). Males were staged macroscopically and testes were classified to one of three developmental stages (Appendix I). However, assignment of developmental stages for males was less clear than females thus the results for these should be interpreted with caution.

Additionally, a subsample of ovaries was collected for each species during each season for histological preparation and microscopic examination. Detailed methods followed those of Fowler *et al.* 1999. Histological (microscopic) analysis of ovaries allows identification of spawning fish, whose ovaries were characterized by the presence of hydrated oocytes, post-ovulatory follicles and/or oocytes with a migratory nucleus. Microscopic examination also allows the separation of regressing fish from spent fish based on presence/absence of post-ovulatory follicles and the level of atresia (Fowler *et al.* 1999).

2.4. Recruitment

2.4.1. Sampling

Additional research 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) during late summer/early autumn using single-wing fyke nets (3 trips). Other suitable sites for sampling juveniles were assessed during the season (e.g. at Goolwa Barrage freshwater side, Mundoo and Tauwitchere Barrages, Pelican Point, Mark Point). On each sampling occasion, eight fyke nets were set overnight at each site. A summary of effort is presented in Table 2.3. In contrast, for greenback flounder, juvenile sampling was conducted at Sugars Beach, Godfrey's

Landing and Mark Point (Figure 2.3) using a standard seine net during spring/early summer (3 trips). 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 m². Sampling was replicated (i.e. 3 standard shots) at each site. A summary of effort is presented in Table 2.4.

Table 2.3. A summary of sampling effort for black bream juveniles in the Coorong using single-wing fyke nets during 2008/09 and 2009/10. (Regular sampling sites and months are in bold. HI-Hindmarsh Island; SRP-Sir Richard Peninsula; YHP-Young Husband Peninsula).

Sampling Effort (number of fyke nets x nights)	**2008/09**						**2009/10**				
	February	**March**	**April**	May	June	Subtotal	**February**	**March**	**April**	Subtotal	Total
Regular sites:											
Boundary Creek	**8**	**8**	**8**		8	32	**8**	**8**	**8**	24	56
Goolwa Barrage HI		**8**	**8**		8	24	**8**	**8**	**8**	24	48
Goolwa Barrage SRP	**8**	**8**	**8**		8	32	**8**	**8**	**8**	24	56
Other sites:											
Boundary Creek Barrage			4			4				0	4
Ewe Island Causeway				4		4		8	8	16	20
Goolwa Barrage freshwater HI		4				4				0	4
Goolwa Barrage freshwater SRP		4				4	4			4	8
Mundoo Barrage				4		4				0	4
Mundoo Channel					8	8				0	8
Pelican Point				4		4				0	4
Pelican Point YHP					8	8				0	8
Tauwitchere Barrage				4		4	4			4	8
Mark Point					8	8				0	8
Overall	*16*	*32*	*28*	*16*	*48*	*140*	*32*	*32*	*32*	*96*	*236*

Table 2.4. A summary of sampling effort for greenback flounder juveniles in the Coorong using seine net during 2008/09 and 2009/10.

Sampling Effort (number of seine net shots)	2008/09 November	December	January	Subtotal	2009/10 November	December	January	Subtotal	Total
Sampling sites:									
Sugars Beach	3	3	3	9	3	3	3	9	18
Godfrey's Landing	3	3	3	9	3	3	3	9	18
Mark Point	3	3	3	9	3	3	3	9	18
Overall	*9*	*9*	*9*	*27*	*9*	*9*	*9*	*27*	*54*

The number of juvenile black bream and greenback flounder from each net were counted. A random subsample of up to 50 individuals was also measured (Total Length, mm) with 20 individuals collected for laboratory processing. Fish were measured and weighed and otoliths from a sub-sample of fish were extracted for age determination to confirm the proportion of the YOY fish.

On each fish sampling occasion at each site, water quality parameters (i.e. salinity, temperature, dissolved oxygen, pH) were recorded using a TPS water quality meter and turbidity measured using a Secchi disc. A summary of environmental data collected during 2008/09 and 2009/10 is provided in Appendices II to VI.

2.4.2. Analysis

Catch per unit effort (CPUE) of juveniles was used to compare recruitment between years at key sites for each species. 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) except for the greenback flounder data from Sugars Beach because there was no catch at this site. A one-way design was used, with Year as a random factor, 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).

The feasibility of using catch rates of YOY (number per net or per shot) as recruitment indices for each species was investigated. 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. For both black bream and greenback flounder, recruitment success could also be corroborated using year class strength in the age structures from the commercial fishery.

3. RESULTS

3.1. Black Bream

3.1.1. Fishery catch, effort and CPUE

In the Lakes and Coorong Fishery, most of the commercial catch of black bream were from the Coorong (overall 93%) in the past 26 years. The total annual catch from the Coorong was 46.7 t in 1984/85, which was the highest on record (Figure 3.1). Catch declined steeply to 2.6 t in 1992/93 then remained below 5 t y^{-1} until 1999/00. Annual catches increased to 11.6 t in 2002/03 before declining to historical lows of 1.8 t and 1.1 t in 2008/09 and 2009/10 respectively. The dominant gear in all years was the large mesh gill net, accounting for more than 75% of annual catches of black bream (Figure 3.1).

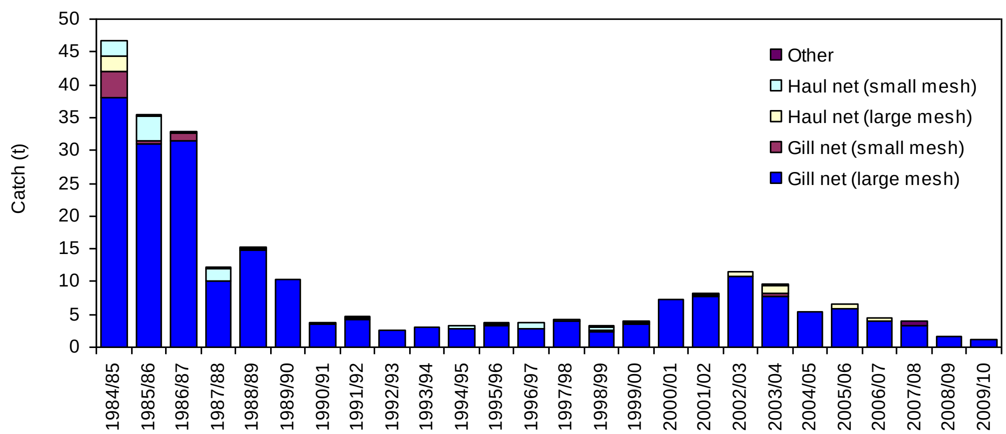


Figure 3.1. Annual catches of black bream taken by gear type in the Coorong.

Catches of black bream were highly seasonal, with most of the annual catch taken between August and October (i.e. 54% in the years 2005/06 to 2009/10; and 45% in the years 1984/85 to 2009/10). In most years the peak monthly catch was in September (Figure 3.2).

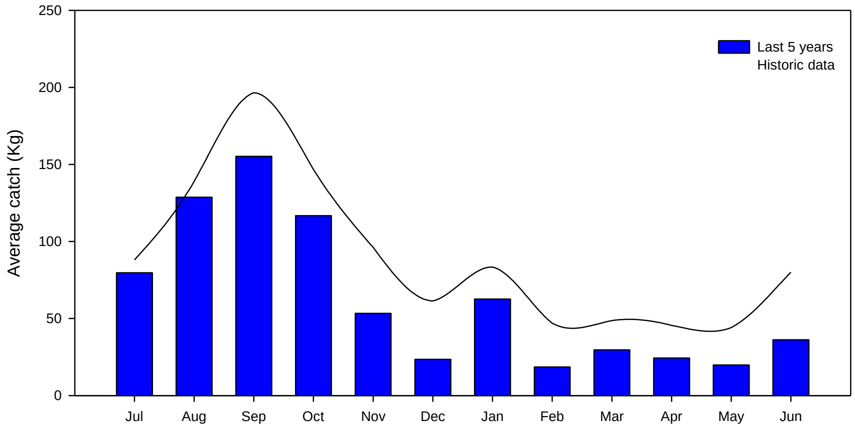


Figure 3.2. Long-term average monthly catches of black bream from the Coorong Fishery (1984/85 to 2009-10) and average monthly catches from the last five years (2005/06 to 2009/10).

Annual targeted catch, effort, and CPUE for black bream caught in large mesh gill nets is shown in Figure 3.3. The highest targeted catch of black bream was 30.6 t in 1984/85 (Figure 3.3 A). The catch then declined dramatically to 0.2 t in 1991/92. Targeted catch remained below 1 t y^{-1} from 1990/91 to 2001/02 then increased to 5.9 t in 2002/03 before declining to less than 1 t in 2008/09 (catch amount cannot be presented due to confidentiality the targeted catches were from less than five fishers) and there was no reported targeted catch in 2009/10. The contribution of targeted catch to total catch varied greatly between years, peaking in 1989/90 at 84% of total catch. The proportion of targeted catch ranged between 4 and 34% from 1990/91 to 2001/02, then rose to between 45 and 65% from 2002/03 to 2007/08. In 2008/09, targeted catch comprised 32% of the total catch, however all catch of black bream was non-targeted in 2009/10 in the Coorong.

Trends in targeted effort (fisher days) were similar to those for targeted catch. Effort peaked at 1 376 and 1 361 fisher days in 1984/85 and 1985/86, respectively (Figure 3.3 B). Effort then declined steeply to a historic low of 18 fisher days in 1991/92. After this, the highest targeted effort was 276 fisher days in 2002/03. Targteted effort then declined to 198 fisher days in 2005/06 and was < 100 fisher days in 2008/09 (value cannot be presented due to confidentiality). There was no effort targeted at black bream in 2009/10.

Trends in targeted effort measured in fisher days or net days were similar and effort (fisher days) and effort (net days) were linearly related (LR: R^2=0.97, $F_{1,24}$=661.830, p<0.001) (Figure 3.3 B). Variability in targeted effort (fisher days) explained 91% of the variability in targeted catch (LR: R^2=0.91,

$F_{1,24}$=306.236, p<0.001), while effort (net days) exaplained 93% of the variability in targeted catch (LR: R^2=0.93, $F_{1,24}$=243.339, p<0.001).

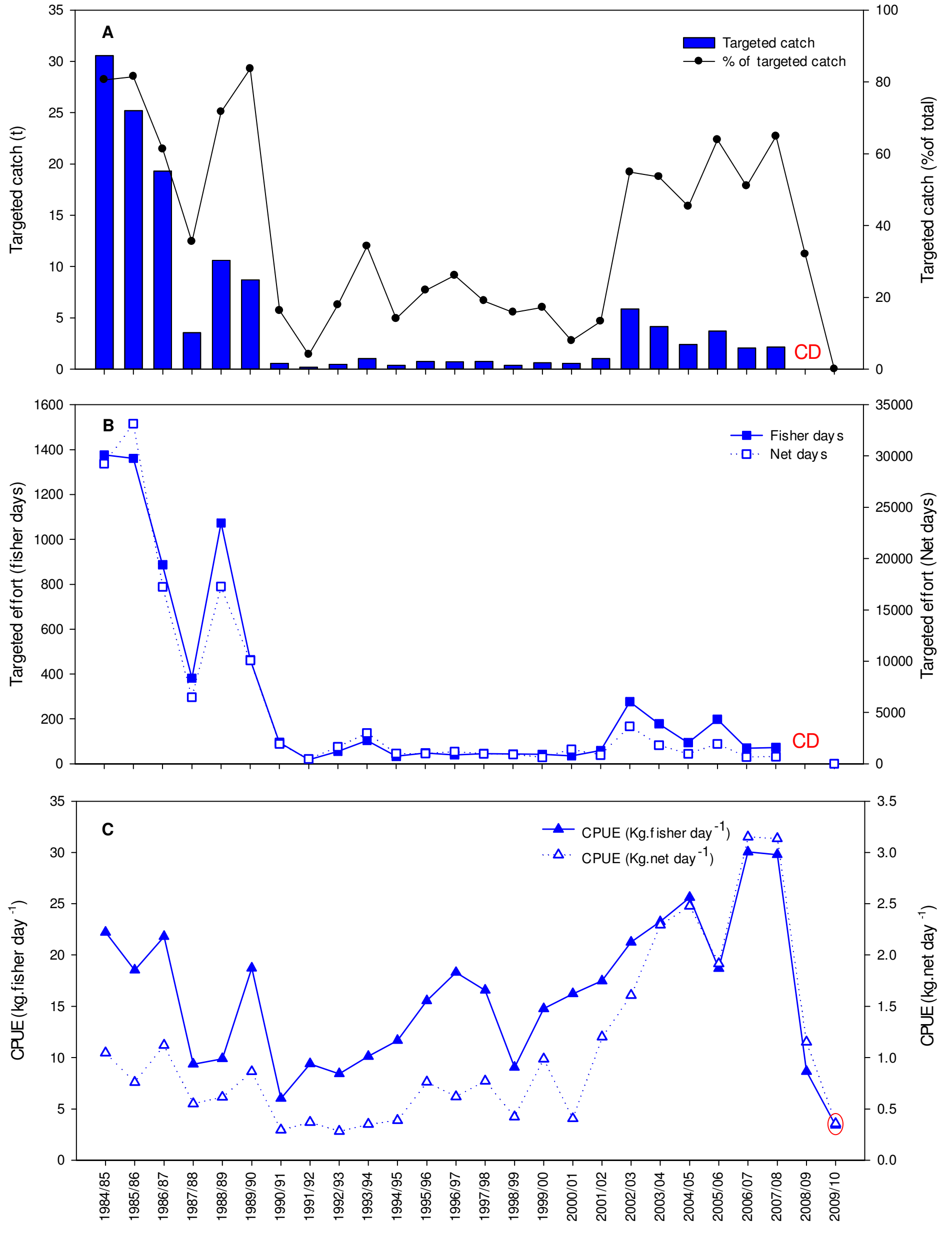


Figure 3.3. Annual targeted catch and effort for black bream caught in large mesh gill nets. (A) Targeted catch shown in tonnes, and as a percentage of total catch, (B) Comparison of two measures of effort, and (C) Comparison of two estimates of CPUE. CD: confidential data; red circle: estimated CPUE based on catch and effort when targeting any species.

CPUE was approximately 20 kg.fisher day^{-1} from 1984/85 to 1986/87, then declined to 6.0 kg.fisher day^{-1} in 1990/91(Figure 3.3.C). The CPUE increased to 18.3 kg.fisher day^{-1} in 1996/97 before declining to 9.0 kg.fisher day^{-1} in 1998/99. Historical peaks of ~30 kg.fisher day^{-1} occurred in 2006/07 and 2007/08, followed by a steep decline to 8.7 kg.fisher day^{-1} in 2008/09. In 2009/10, CPUE for black bream catch when no target species was specified was 3.4 kg.fisher day^{-1}, which was less than the lowest record of targeted CPUE in 1990/91. Trends in CPUE (kg.net day^{-1}) generally followed those of CPUE (kg.fisher day^{-1}).

3.1.2. Spatial distribution of catches, and influence of freshwater inflow

Fishery catch and effort from the Murray estuary and Coorong lagoons is 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 3.4 A).

After 1997/98, the catch 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 3.4 B). Since 2001/02, catches from the Estuary have contributed more than 90% of the total catch. In the last five years, most catches were from the Estuary (i.e. ≥ 98%).

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 3.4 B). However, they contributed less than 2% in all other years. Since 1997/98, there have been no recorded catches of black bream from the South Lagoon except for 2001/02 when a small catch (1% of the total) was reported.

Mean annual and monthly freshwater inflow to the Murray River Estuary is shown in Figure 3.5. The highest freshwater inflows to the Estuary occurred between 1989/90 and 1993/94 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 3.5). After 1993/94, inflows to the Murray Estuary and Coorong generally declined. The annual discharges were 9 000 GL, 3 000 GL and 5 000 GL in 1996/97, 1998/99 and 2000/01, respectively. Since 2001/02, annual inflows have been less than 800 GL. In the last three years (2007/08 – 2009/10), there have been no barrage releases.

There was a positive relationship 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 3.6). Freshwater inflow explained 45% of the variability in the catch contribution from south of Mark Point to the total catch in the Coorong (LR: R^2=0.45, $F_{1,24}$=19.254, p=0.0002). This suggests that the extent of the fishing area is reduced when freshwater inflow to the Coorong declines. Reduction in the number of spatial reporting blocks fished over the last ten years 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).

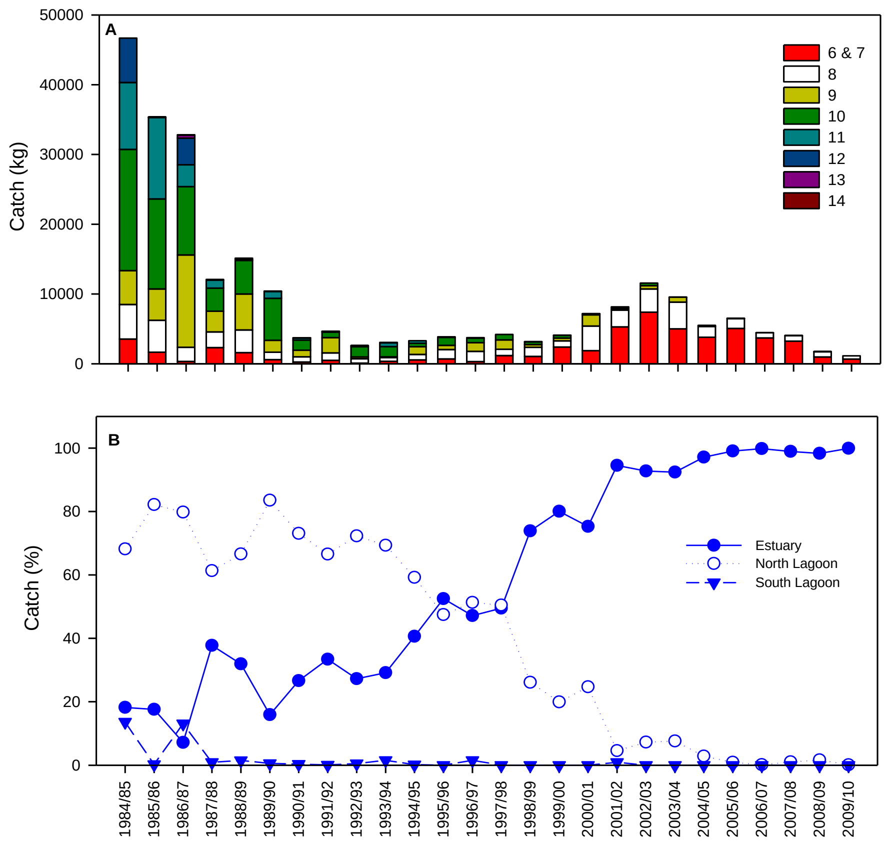


Figure 3.4. Black bream catches from (A) reporting blocks within the Coorong lagoons, and (B) contribution to total catch by areas in the Estuary, North and South lagoons.

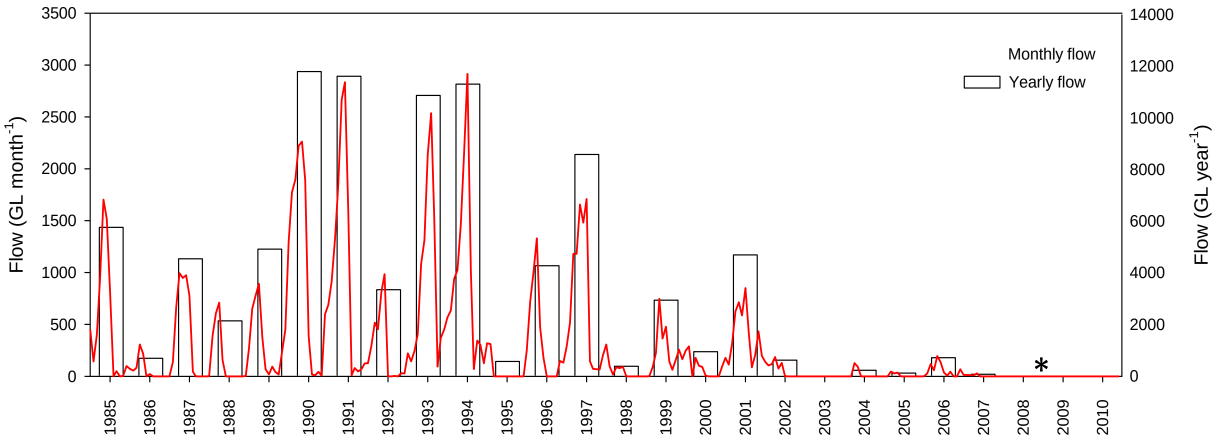


Figure 3.5. Average annual and monthly freshwater inflows across the barrages from July 1984 to June 2010 (source: MDBC, 2008). Asterisk (*) indicates commencement of fish condition monitoring.

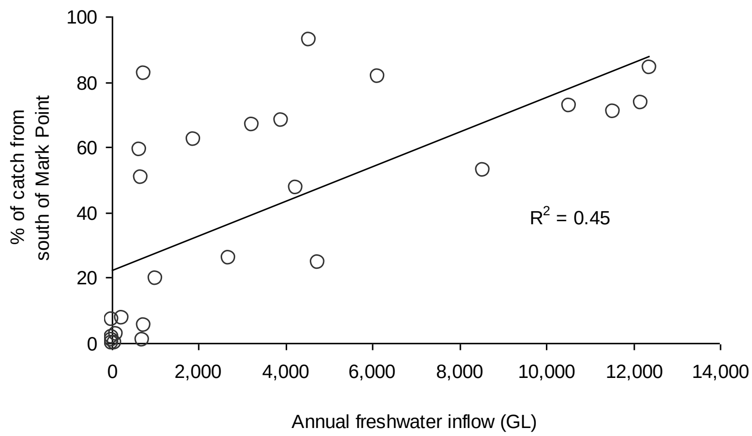


Figure 3.6. The relationship between freshwater inflows to the Coorong and the contribution of black bream catch from the area south of Mark Point to the total catch.

3.1.3. Size and age structures

Age structures of female and male black bream in the last three years are shown in Figure 3.7. In 2007/08, ages ranged from 3 to 25 years and 3 to 13 years for females and males, respectively. The age structures for females and males were from the same bimodal distribution (K-S: D=0.114, p=1), 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. The age structures for females and males represented the same unimodal distribution (K-S: D=0.116, p=1), 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. The age structures for females and males were from the same bimodal distribution (K-S: D=0.070, p=1), with the dominant mode at 5 years (44% for females and 40% for males) and a secondary mode at 11 years (14% for both sex).

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 and 5 year olds in samples from 2008/09 and 2009/10, respectively. The second strongest cohort originated in 1997/98, and persisted as 9 and 11 year olds in 2007/08 and 2009/10, respectively.

Size structures for black bream do not reflect the distinct modal progression in age structures (Figure 3.7). All size structures were unimodal with a modal size of 320 – 360 mm TL for both females and males in all three years. There was no difference in size distribution between females and males in 2007/08 (K-S: D=0.150, p=0.597), 2008/09 (K-S: D=0.194, p=0.372) or 2009/10 (K-S: D=0.136, p=0.340).

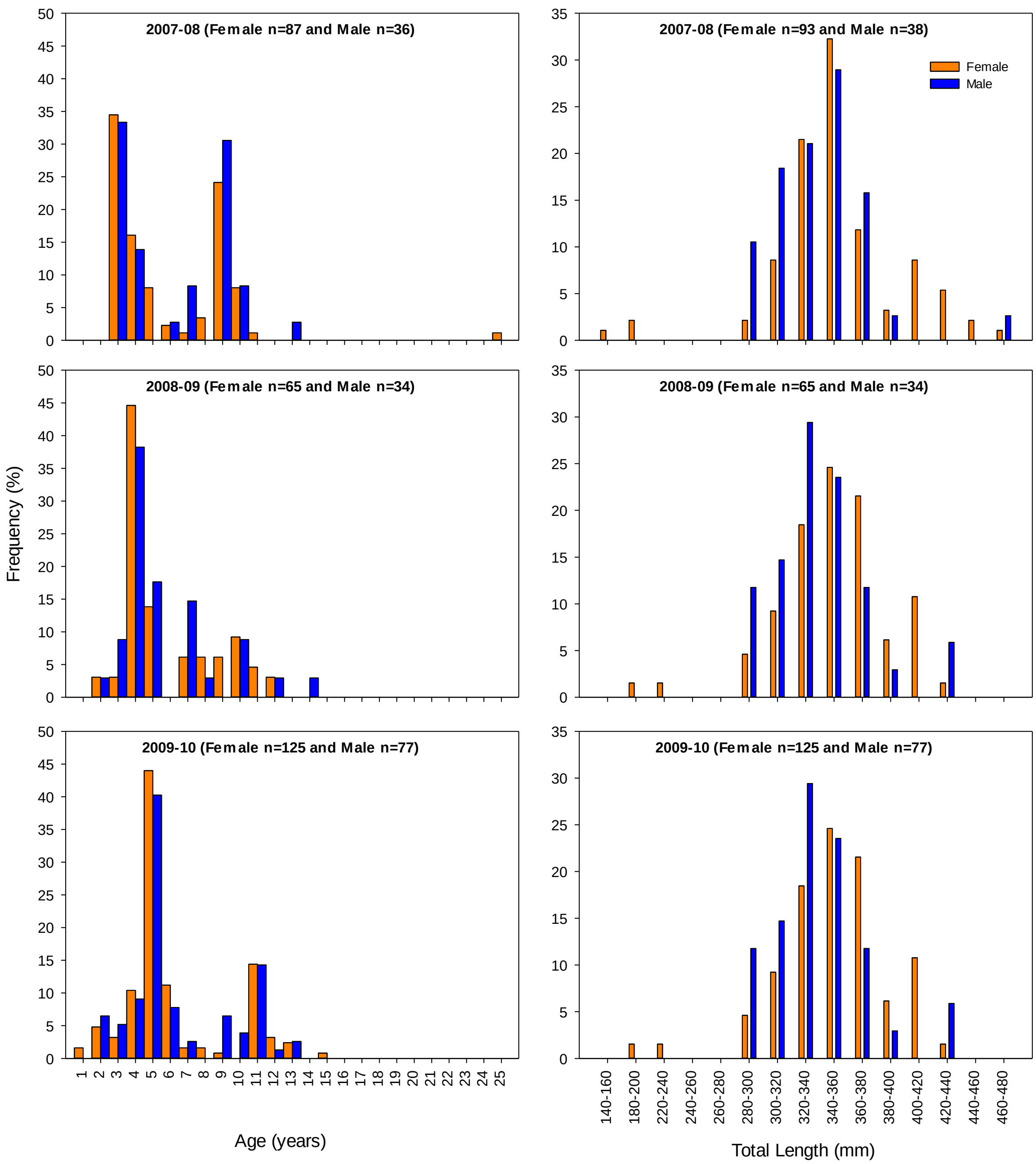


Figure 3.7. Age (left) and size (right) structures of black bream from the Murray Estuary and Coorong in 2007/08, 2008/09 and 2009/10 (most of the samples were from commercial catches).

3.1.4. Reproductive development

Sex ratios

Catches of black bream from the Murray Estuary and Coorong were generally dominated by females (overall percentage for spring/summer) during 2008/09 and 2009/10 (Figure 3.8). Exceptions were October 2009 when there were more males than females, and March 2009 when 50% of fish collected were males.

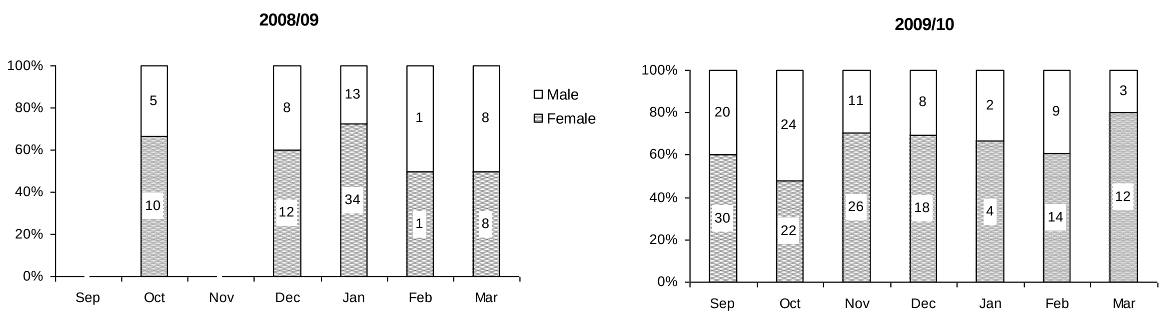


Figure 3.8. Temporal trends in sex ratios (%) of black bream in the Murray Estuary and Coorong between September and March during 2008/09 and 2009/10. (Fish numbers are labeled).

Gonado-somatic indices (GSI)

The monthly trend in GSI's was a general decline from spring/early summer to lat summer/autumn, although in 2008/09 data were available for fewer months. In 2009/10 the monthly GSI's for females declined from September to March (Figure 3.9). Peak GSI was 8.1% in October, declined to 3.9% in November, then was <2% from January to March. Peak GSI for males occurred in September and was 7.1%. Otherwise, the monthly trend in GSI was similar to that for females.

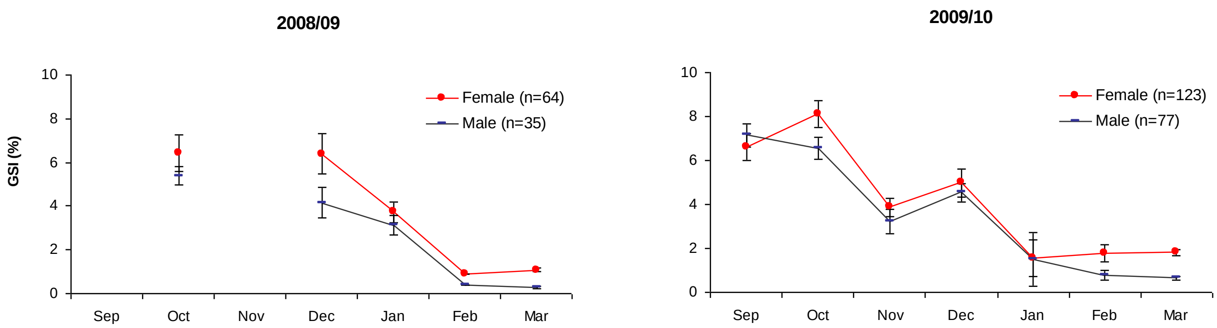


Figure 3.9. Temporal trends in gonado-somatic indices (GSI) between September and March for female and male black bream in the Murray Estuary and Coorong during 2008/09 and 2009/10 (Vertical lines represent standard error).

Macroscopic gonad stages

Mature females (≥ stage 3) were present in all samples collected during spring/summer in both years except that in February 2009 only one female (stage 2) was collected (Figure 3.10). The temporal pattern in gonad development was similar in 2008/09 and 2009/10 although data were available for fewer months in the first year.

Between September and December 2009, the majority of female fish (90%) had developed (stage 3) or ripe/hydrated (stage 4) ovaries. From January to March 2010, the percentage of females (≥ stage 3) declined to <30% although ripe/hydrated fish were present in samples until March. Similarly, for males, fish with developed testes (stage 3, milt present) dominated the samples (≥73%) between September and November 2009, whilst they dropped to ≤ 33% in the following four months

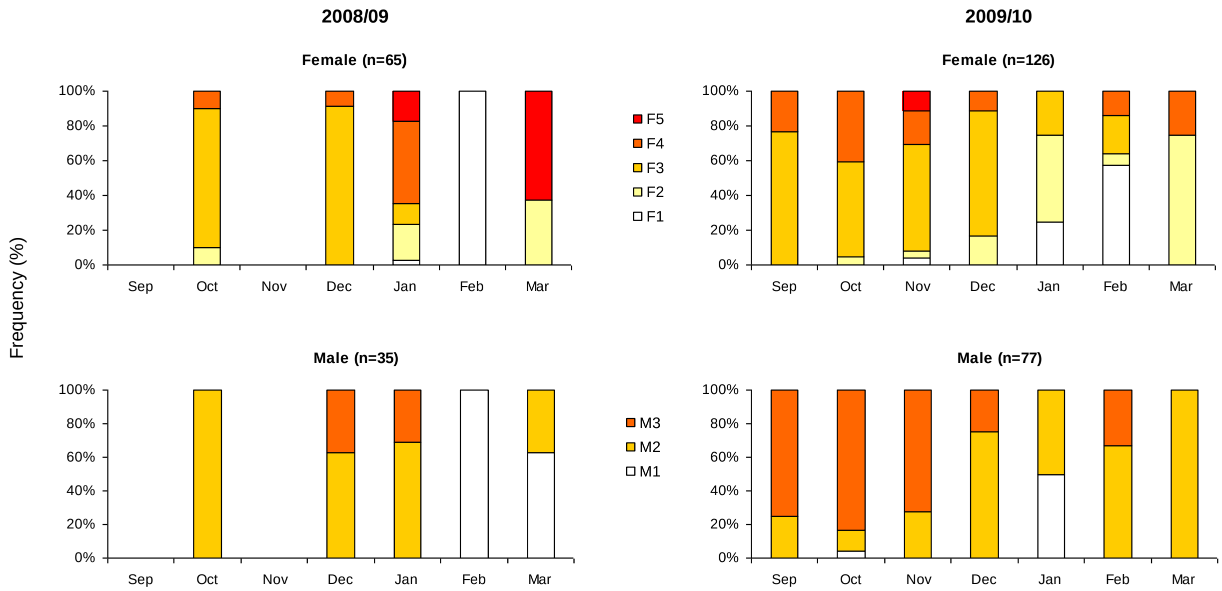


Figure 3.10. Temporal trends in macroscopic stages of gonad development (frequency %) for female and male black bream in the Murray Estuary and Coorong between September and March during 2008/09 and 2009/10.

Histological examination of ovaries

Fish in spawning condition were found throughout the sampling period in 2009/10, but only occurred in January during 2008/09. These included fish that had spawned recently (with post-ovulatory follicles) or in which spawning was imminent (with hydrated oocytes and/or migratory nuclei). However, sample sizes were small and data were available for fewer months in 2008/09 (Figure 3.11).

High levels of atresia (>50% atretic oocytes relative to advanced yolk) indicate that ovaries may have developed to an advanced stage but then regressed without spawning having occurred. In November 2009 and February 2010 a significant percentage of females (about 30%) had high levels of atresia in their ovaries, suggesting that they were regressing (Figure 3.12). In other months of 2009/10, and October and January 2008/09, less than 5% of fish showed high levels of atresia..

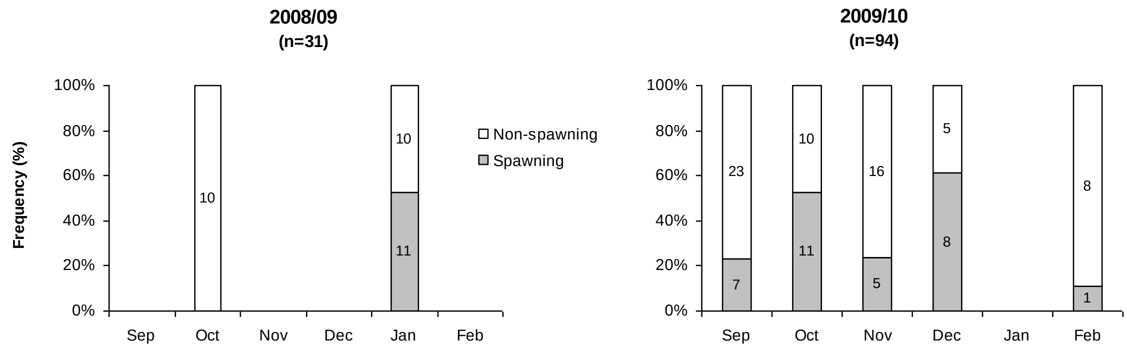


Figure 3.11. Percentage of black bream from the Murray Estuary and Coorong during spring and summer of 2008/09 and 2009/10 in spawning condition from histological analysis of ovaries. (Numbers are sample sizes).

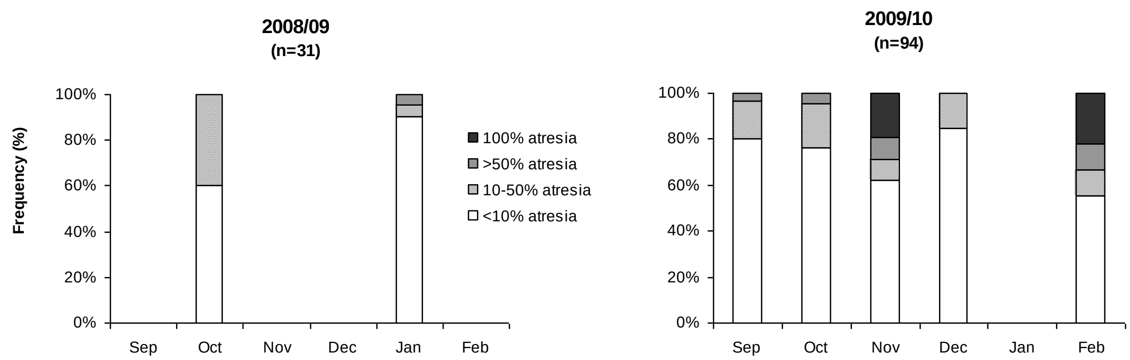


Figure 3.12. Percentage of black bream from the Murray Estuary and Coorong during spring and summer of 2008/09 and 2009/10 with ovaries exhibiting several levels of atresia, identified by histological examination.

3.1.5. Recruitment

A total of 261 black bream were collected using fyke nets to target new recruits (i.e. juveniles) from the Murray Estuary and Coorong, of which 221 fish were sampled during 2008/09 and 40 fish during 2009/10 (Table 3.1). Most fish sampled were less than 110 mm (TL) (Figure 3.13).

Table 3.1. The number of black bream juveniles sampled in the Murray Estuary and Coorong using single-wing fyke nets during 2008/09 and 2009/10. (Regular sampling sites and months are in bold. HI-Hindmarsh Island; SRP-Sir Richard Peninsula; YHP-Young Husband Peninsula).

Number of fish	**2008/09**						**2009/10**				
	February	**March**	**April**	May	June	Subtotal	**February**	**March**	**April**	Subtotal	Total
Regular sites:											
Boundary Creek	**0**	**0**	**2**		0	2	**0**	**0**	**0**	0	2
Goolwa Barrage HI		**52**	**84**		7	143	**4**	**4**	**2**	10	153
Goolwa Barrage SRP	**5**	**28**	**12**		21	66	**4**	**7**	**19**	30	96
Other sites:											
Boundary Creek Barrage			3			3					3
Ewe Island Causeway				0		0		0	0	0	0
Goolwa Barrage freshwater HI		0				0					0
Goolwa Barrage freshwater SRP		0				0	0			0	0
Mundoo Barrage				1		1					1
Mundoo Channel					0	0					0
Pelican Point				0		0					0
Pelican Point YHP					1	1					1
Tauwitchere Barrage				4		4	0			0	4
Mark Point					1	1					1
Overall	*5*	*80*	*101*	*5*	*30*	*221*	*8*	*11*	*21*	*40*	*261*

Length frequency distributions

Length frequency distributions of juvenile black bream from all sites combined in 2008/09 and 2009/10 are presented in Figure 3.13. In 2008/09, a modal progression across several months was identified for two distinct size classes, which were 20-29 and 30-39 mm TL in March 2009 (Figure 3.13). The modes of 40-49 and 50-59 mm TL fish in April samples likely persisted as modes of 60-69 and 80-89 mm in June 2009. The modal progression indicates fish growth throughout the season.

In 2009/10, progression of length frequency modes was also identifiable between months (Figure 3.13). A distinct size class appeared at 20-29 mm TL in February then progressed to 30-39 mm and 40-49 mm TL in March and April, respectively. In addition, a size of 40-49 mm TL in February likely had grown to 60-69 mm TL in March 2010. However, the results should be interpreted with caution given the small sample size in 2009/10.

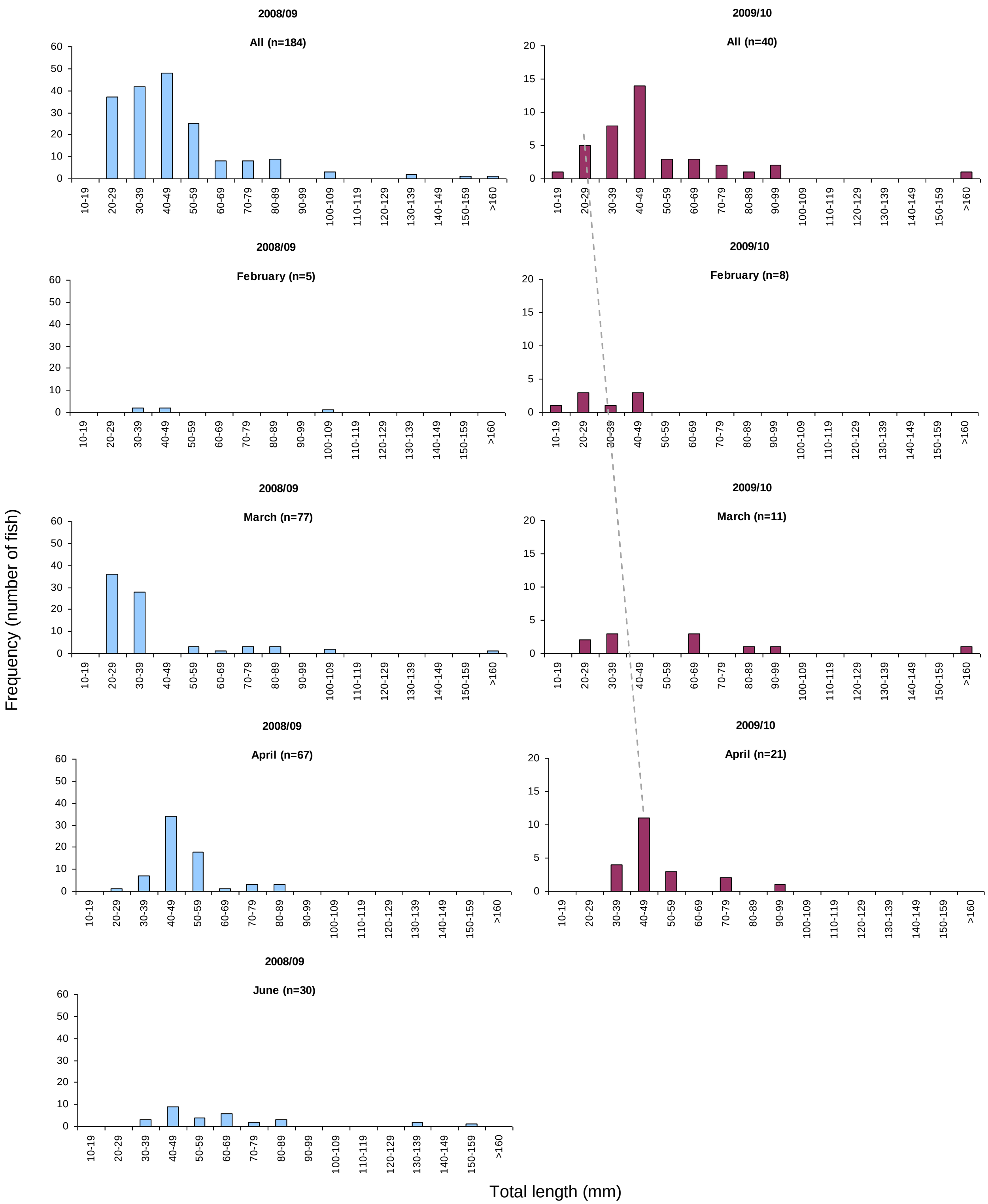


Figure 3.13. Length frequency distributions of black bream sampled using fyke nets from the Murray Estuary and Coorong during 2008/09 and 2009/10 (note the scale difference on y-axes).

Recruitment index

Catch per unit effort of juvenile black bream caught in fyke nets provides an estimate of relative abundance of new recruits and thus provides a recruitment index for this species in the Murray Estuary and Coorong. Estimates of CPUE varied between sampling sites and months (Table 3.2), but were generally higher in 2008/09 than in 2009/10. Comparison among sampling sites (Boundary Creek and two sites below Goolwa Barrage) for the period February to April showed higher CPUE in 2008/09 than in 2009/10 at Goolwa Barrage HI (p=0.001), but no difference at Goolwa Barrage SRP (p=0.497) or Boundary Creek (p=1) (Figure 3.14).

Table 3.2. catch per unit effort (CPUE) for black bream juveniles by single-wing fyke nets in the Murray Estuary and Coorong during 2008/09 and 2009/10. (Regular sampling sites and months are in bold. HI-Hindmarsh Island; SRP-Sir Richard Peninsula; YHP-Young Husband Peninsula; *SE*= standard error).

CPUE	**2008/09**												**2009/10**							
(fish per net.night)											average								average	
	February		**March**		**April**		May		June				**February**		**March**		**April**			
	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*	Mean	± *SE*
Regular sites:																				
Boundary Creek	**0.0**	*0.0*	**0.0**	*0.0*	**0.3**	*0.3*			0.0	*0.0*	0.1	*0.1*	**0.0**	*0.0*	**0.0**	*0.0*	**0.0**	*0.0*	0.0	*0.0*
Goolwa Barrage HI			**6.5**	*3.7*	**10.5**	*3.7*			0.9	*0.3*	6.0	*1.9*	**0.5**	*0.4*	**0.5**	*0.3*	**0.3**	*0.2*	0.4	*0.2*
Goolwa Barrage SRP	**0.6**	*0.3*	**3.5**	*1.0*	**1.5**	*0.8*			2.6	*0.8*	2.1	*0.4*	**0.5**	*0.3*	**0.9**	*0.4*	**2.4**	*0.8*	1.3	*0.3*
Other sites:																				
Boundary Creek Barrage					0.8	*0.3*					0.8	*0.3*								
Ewe Island Causeway							0.0	*0.0*			0.0	*0.0*			0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
Goolwa Barrage freshwater HI			0.0	*0.0*							0.0	*0.0*								
Goolwa Barrage freshwater SRP			0.0	*0.0*							0.0	*0.0*	0.0	*0.0*					0.0	*0.0*
Mundoo Barrage							0.3	*0.3*			0.3	*0.3*								
Mundoo Channel									0.0	*0.0*	0.0	*0.0*								
Pelican Point							0.0	*0.0*			0.0	*0.0*								
Pelican Point YHP									0.1	*0.1*	0.1	*0.1*								
Tauwitchere Barrage							1.0	*1.0*			1.0	*1.0*	0.0	*0.0*					0.0	*0.0*
Mark Point									0.1	*0.1*	0.1	*0.1*								
Average across sites	0.3	*0.2*	2.5	*1.0*	3.6	*1.3*	0.3	*0.3*	0.6	*0.2*	1.6	*0.4*	0.3	*0.1*	0.3	*0.1*	0.7	*0.3*	0.4	*0.1*

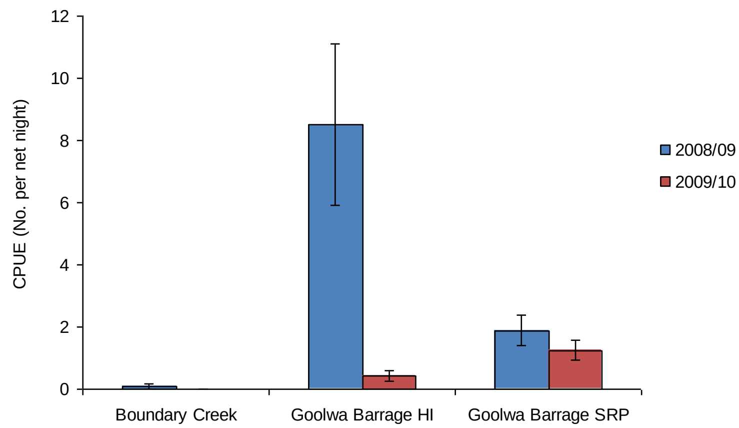


Figure 3.14. Catch per unit effort (CPUE) for juvenile black bream by single-wing fyke nets at regular sampling sites in the Coorong between February and March during 2008/09 and 2009/10 (Vertical lines represent standard error).

3.2. Greenback Flounder

3.2.1. Fishery catch, effort and CPUE

Almost all of the Lakes and Coorong Fishery catch of the greenback flounder have come from the Coorong (overall average 99.7%) in the past 26 years (Figure 2.1). 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 3.15). The annual catches remained stable from 1995/96 to 2001/02 then declined to less than 10% of the peak catch in 2002/03. Catches of 0.5 and 1.0 t in 2008/09 and 2009/10 respectively represented an historical low. The dominant gear was the large mesh gill net, accounting for more 95% of the catch from the Coorong over 26 years (Figure 3.15).

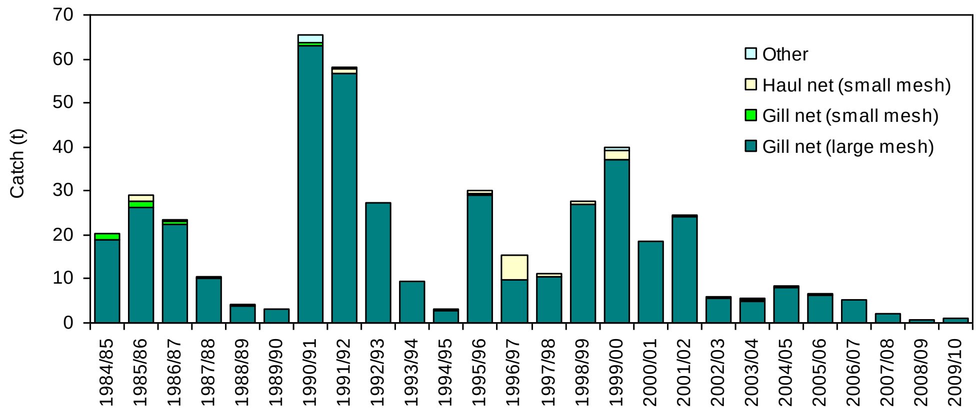


Figure 3.15. Annual catches of greenback flounder taken by gear type in the Coorong.

Historically, catches of greenback flounder were highly seasonal, with 78 % of the annual catch taken between October and April, since 1984/85. However such seasonality of catches was less defined from 2005/06 to 2009/10 (Figure 3.16).

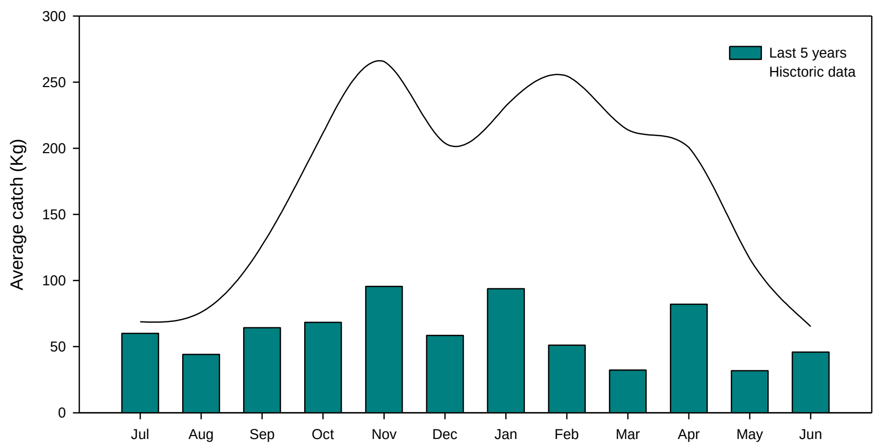


Figure 3.16. Average monthly catches of greenback flounder taken from the Coorong based on historical fishery data (1984/85 to date) and the last five years data (from 2005/06 to 2009/10).

Targeted catch, effort, and CPUE for greenback flounder caught in large mesh gill nets are shown in Figure 3.17. The highest targeted catch was 45.8 t in 1990/91 (Figure 3.17 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). The contribution of targeted catch to total catch varied greatly between years, from 3% in 1988/89 to 82% in 1992/93. In the last five years, the proportion of targeted catch declined consistently from 60% (2005/06) to 14% (2009/10).

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 they were 1398, 1562 and 1272 fisher days, respectively (Figure 3.17 B). Targeted effort declined steeply to 60 fisher days in 1994/95, before rising to 797 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.

Trends in effort defined by fisher days and net days were similar with both measures linearly related (LR: R^2=0.96, $F_{1,24}$=579.678, p<0.001). Variability in targeted effort (fisher day) explained 87% of the variability in targeted catch (LR: R^2=0.87, $F_{1,24}$=160.920, p<0.001), while effort (net days) explained 89% of the catch (LR: R^2=0.89, $F_{1,24}$=202.283, p<0.001).

CPUE (kg.fisher day^{-1}) increased from 12.9 kg.fisher day^{-1} in 1984/85 to 32.8 kg.fisher day^{-1} in 1990/91 (Figure 3.17 C). In 1994/95, CPUE (kg.fisher day^{-1}) declined to an historical low of 7.6 kg.fisher day^{-1}. An historical peak of 36.6 kg.fisher day^{-1} occurred in 1999/2000, before declining to 10.4 kg.fisher day^{-1} in 2007/08. CPUE was 26.3 and 14.7 kg.fisher day^{-1} in 2008/09 and 2009/10, respectively. Trends in CPUE (kg.net day^{-1}) were generally similar to those for CPUE (kg.fisher day^{-1}). However, CPUE was estimated from low levels of fishing effort in 2008/09 and 2009/10 and may not provide a good estimate of relative abundance for those years. Consequently, estimates of CPUE for the last two years should be interpreted with caution.

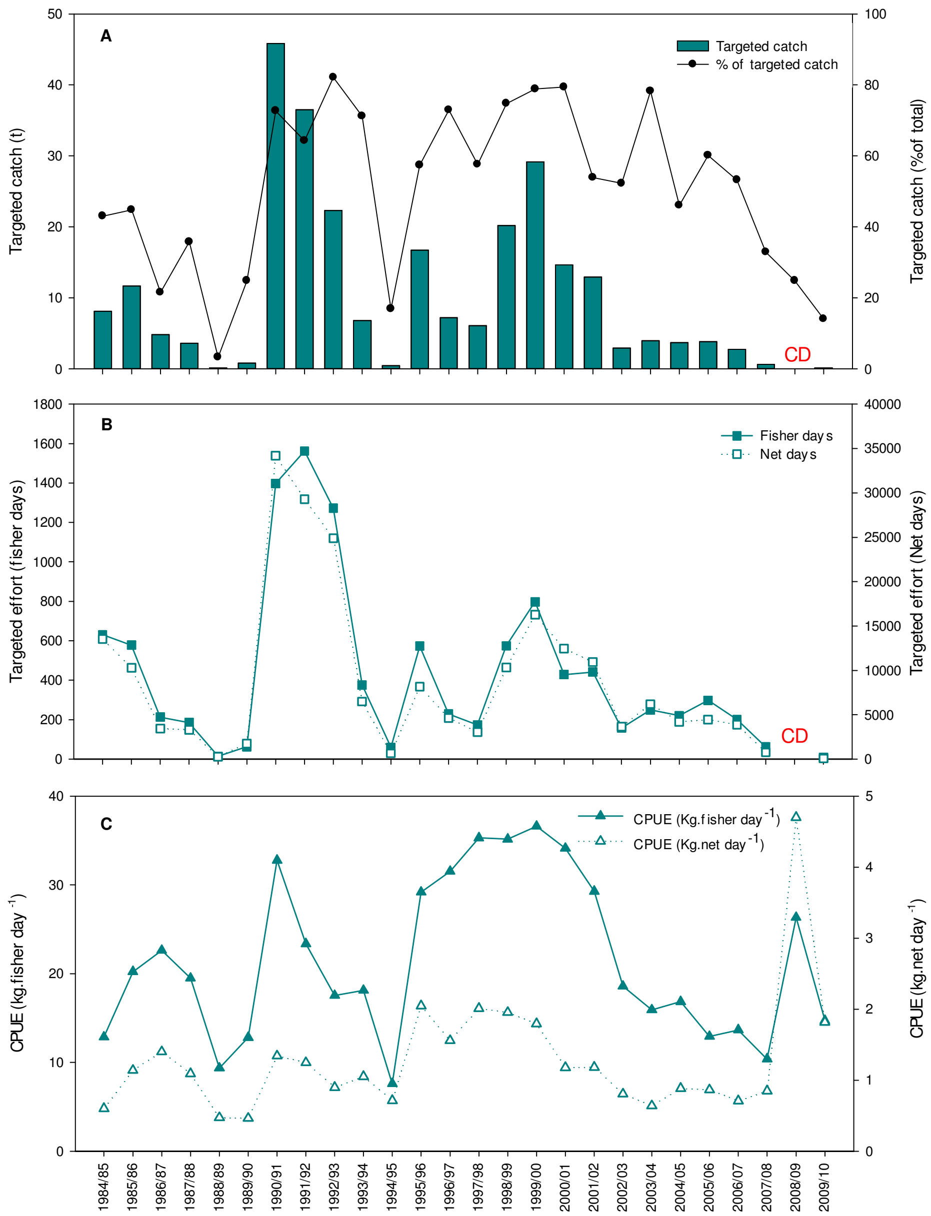


Figure 3.17. Annual targeted catch and effort for greenback flounder caught in large mesh gill nets. (A) Targeted catch shown in tonnes, and as percentage of total catch, (B) Comparison of two measures of effort, and (C) Comparison of two estimates of CPUE. CD: confidential data

3.2.2. Spatial distribution and 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 3.18 A). Since 2006/07, the proportional catch from the North Lagoon has reduced significantly, as 98% and 100% of the total annual catches were from the Estuary (Blocks 6, 7, 8) in 2008/09 and 2009/10, respectively (Figure 3.18 B).

Annual catches of flounder from the South Lagoon (Blocks 12, 13, 14) were small, contributing less than 0.3% to the total annual catches except for 1993/94 when 4% of the catch came from this sub-region (Figure 3.18 B). Since 2002/03, there has been no record of greenback founder catch in the South Lagoon.

There was a positive relationship between freshwater inflow to the Coorong and proportional catch of greenback flounder from the area south of Mark Point (circa North and South lagoons) (Figure 3.19). However, freshwater inflow explained only 25% of the variability in the catch contribution from south of Mark Point to the total catch in the Coorong (LR: R^2=0.25, $F_{1,24}$=7.878, p=0.01), suggesting that there were other factors influencing the amount and extent of flounder catch toward the southern area of the Coorong.

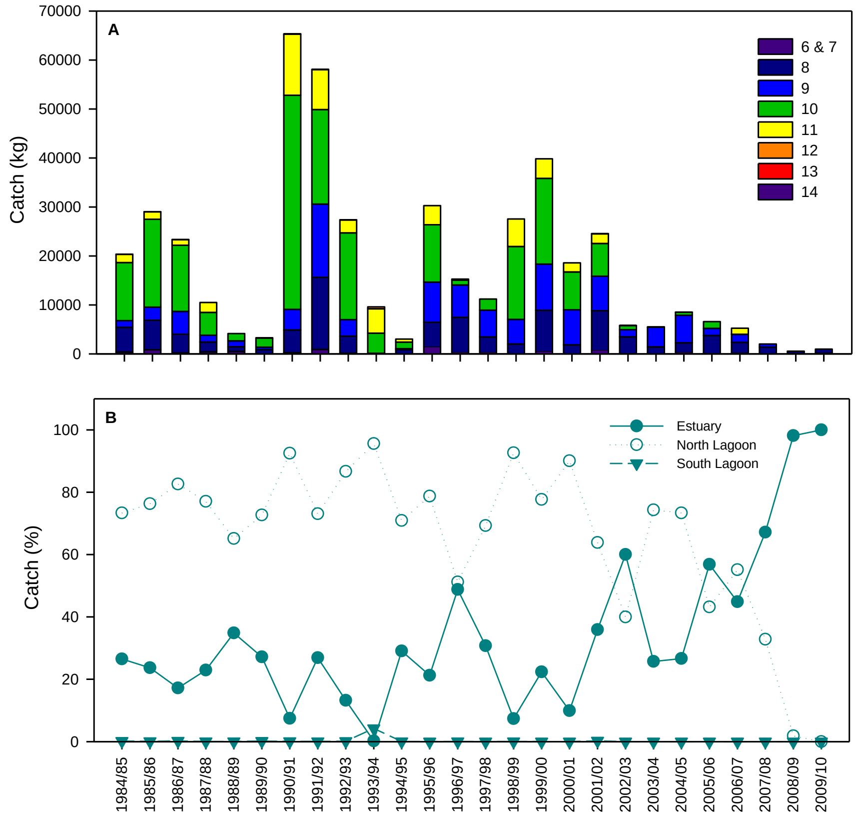


Figure 3.18. Greenback flounder catches from (A) reporting blocks within the Coorong lagoons, and (B) contribution to total catch by areas in the Estuary, North and South lagoons.

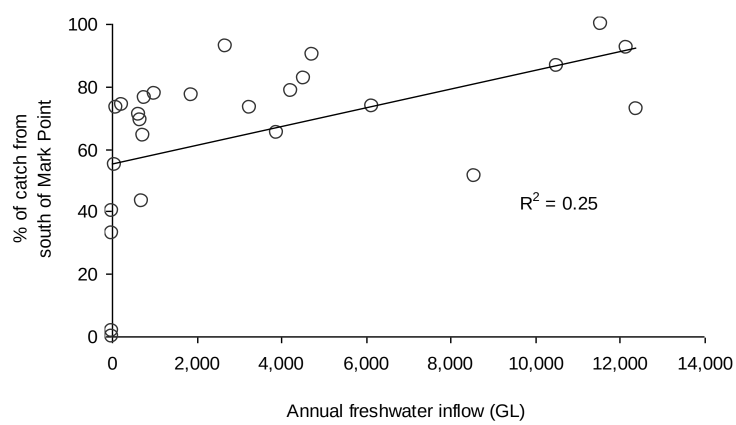


Figure 3.19. The relationship between freshwater inflows to the Coorong and contribution of greenback flounder catch from the area south of Mark Point to the total catch.

3.2.3. Size and age structures

Age structures of female and male greenback flounder are shown in Figure 3.20. In 2007, fish samples were dominated by 2 and 3 year old females, representing 87.3% of the total catch. Age of females ranged from 1 to 3 years, and males were 2 or 4 year olds although only three males were sampled. In 2009, all fish collected were females, ranging from 1 to 3 years with 93% being 1 and 2 year olds. Age structure of females differed significantly between the two years (K-S: D=0.364, p=0.0002).

In 2007, the size distribution of female flounder was bimodal with distinct modes at 260-279 and 340-359 mm TL (Figure 3.20). In 2009, there was no distinct modes in size distribution of females with 82% of fish ranging between 240 and 339 mm TL. There was a significant difference in size distribution of females between 2007 and 2009 (K-S: D=0.287, p=0.002). Only three males were collected in 2007 and sizes ranged from 260 to 359 mm TL. No males were collected in 2009.

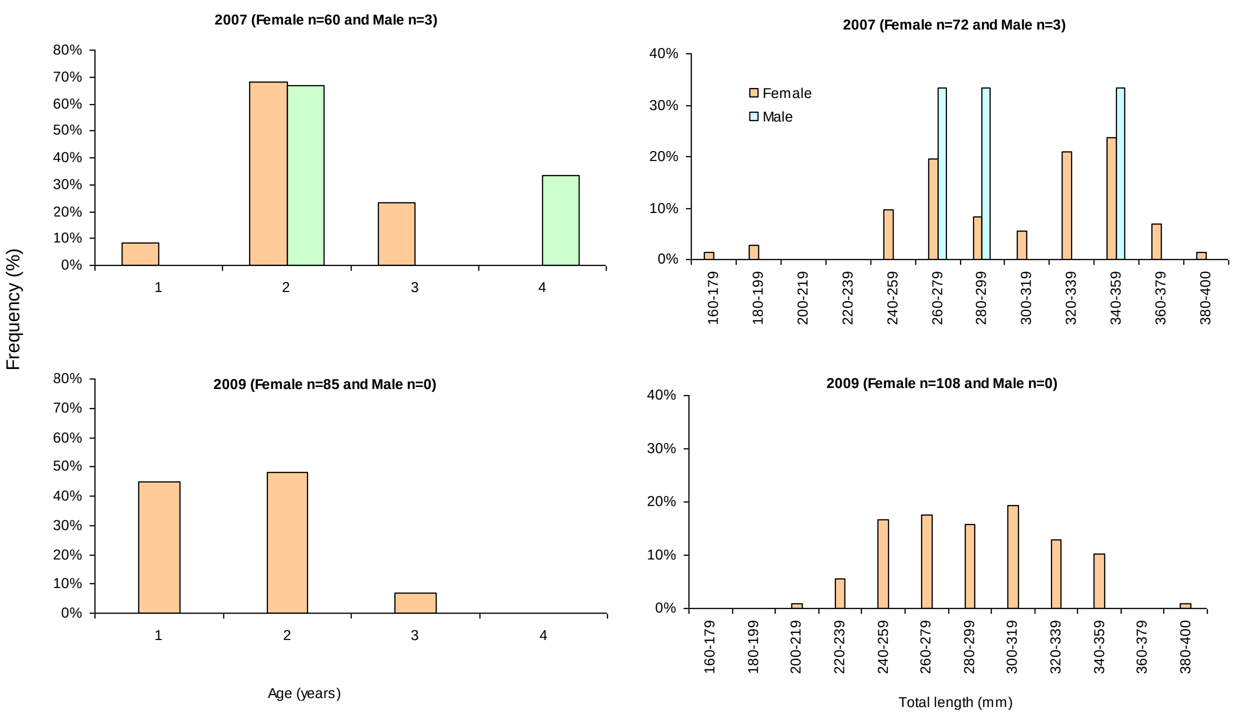


Figure 3.20. Age (left) and size (right) structures of greenback flounder from Coorong during 2007 and 2009.

3.2.4. Reproductive development

Sex ratios

A total of 106 adult greenback flounder were collected between May and August 2009 to assess spawning condition during the peak reproductive season for this species. All samples were from commercial catches except for one individual from research sampling. No males were collected.

Gonado-somatic indices (GSI)

GSI's for females was between 10 to 13% from May to July in 2009 then declined to 8.6% in August (Figure 3.21).

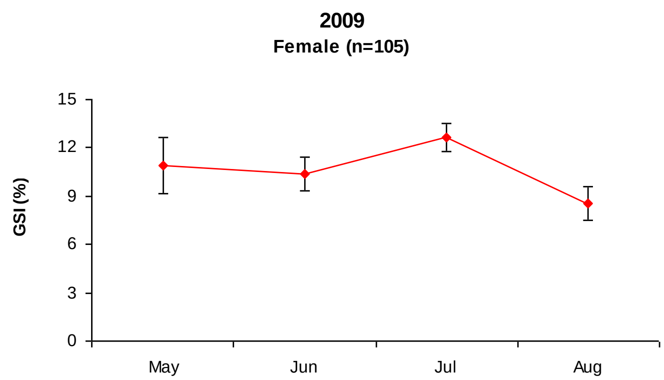


Figure 3.21. Temporal trends in gonado-somatic indices (GSI) between May and August 2009 for female greenback flounder in the Murray Estuary and Coorong (Vertical lines represent standard error).

Macroscopic gonad stages

More than 70% of the female fish had ovaries at advanced stages (stage 3, 4 or 5) throughout the sampling period (Figure 3.22). Spent and ripe/hydrated fish were found from June to August, suggesting that fish were spawning during this period.

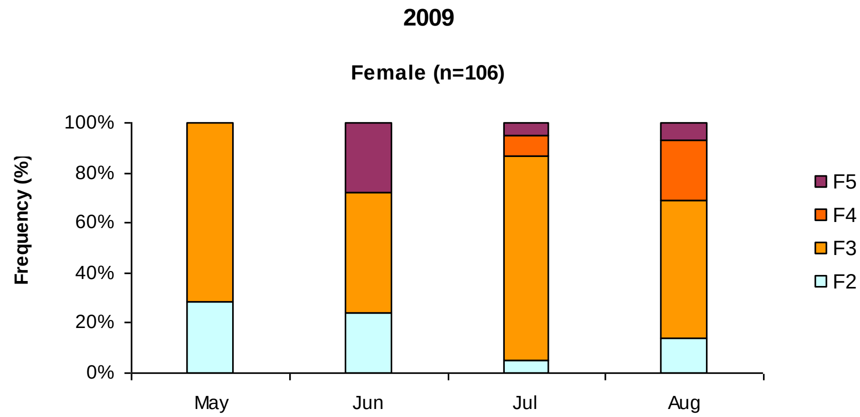


Figure 3.22. Temporal trends in macroscopic stages of gonad development (frequency %) for female greenback flounder in the Murray Estuary and Coorong between May and August 2009.

Microscopic ovarian histology

Microscopic examination of ovarian histology of female greenback flounder showed that in July and August 2009, 8% and 52% of fish were in spawning condition, respectively (Figure 3.23). These included fish that had spawned recently (with post-ovulatory follicles) or in which spawning was imminent (with hydrated oocytes and/or migratory nuclei). This result was consistent with macroscopic staging of ovaries. However, no microscopic analysis was conducted for samples collected from May to June 2009. There were no fish with substantial levels of atresia (>50%) in July (Figure 3.24), whilst 3% of samples exhibited such characteristics in August, suggesting a small proportion of females did not spawn successfully and regressed.

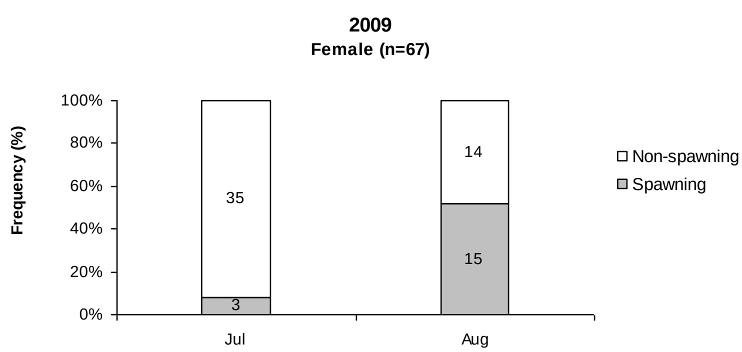


Figure 3.23. Percentage female greenback flounder in spawning condition as identified by histological analysis of ovaries in samples from the Murray Estuary and Coorong during the winter of 2009. (Numbers are sample sizes).

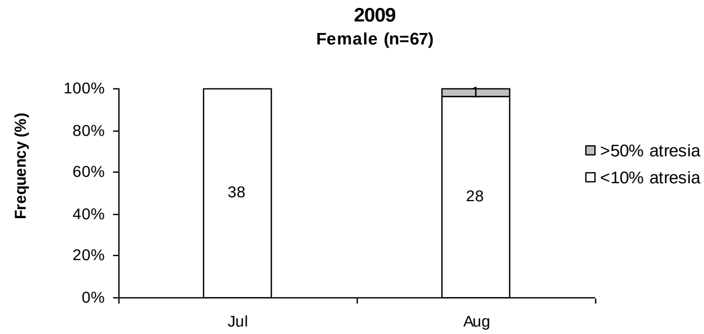


Figure 3.24. Percentage of greenback flounder with different levels of atresia in ovaries identified by histological analysis. Samples were from the Murray Estuary and Coorong during the winter of 2009. (Numbers are sample sizes).

3.2.5. Recruitment

A total of 550 greenback flounder were collected between November and January from the Murray Estuary and Coorong, of which 258 fish were sampled during 2008/09 and 292 fish during 2009/10 (Table 3.3). Most of the fish (98.5%) were sampled in the vicinity of the Murray Mouth (i.e. Godfrey's Landing and Sugars Beach), whilst the remaining 1.5 % were from the northern area of the North Lagoon (i.e. Mark Point). All fish sampled were less than 170 mm TL (Figure 3.25). Examination of daily rings in otoliths confirmed that all fish were YOY (i.e. new recruits of the season).

Table 3.3. The number of greenback flounder juveniles sampled in the Murray Estuary and Coorong using seine net during 2008/09 and 2009/10.

Total number	2008/09				2009/10				
				Subtotal				Subtotal	Total
	November	December	January		November	December	January		
Sampling sites:									
Sugars Beach	37	32	28	97	139	41	69	249	346
Godfrey's Landing	59	36	62	157	5	11	23	39	196
Mark Point	2	0	2	4	2	1	1	4	8
Overall	*98*	*68*	*92*	*258*	*146*	*53*	*93*	*292*	*550*

Length frequency distributions

Length frequency distributions of juvenile fish from three sites combined are presented in Figure 3.21. In 2008/09, fish collected ranged from 20 to 159 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 TL) emerging again in January 2009, suggesting recent spawning events. However, no fish greater than 90 mm were sampled.

In 2009/10, fish ranged from 30 to 170 mm TL. Similar 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 TL in November 2009 (Figure 3.21). These size classes can be tracked in the following two months. In January 2010, there was no evidence of continued recruitment of small fish (20-29 mm TL); size distribution was represented by more larger-fish than in previous year.

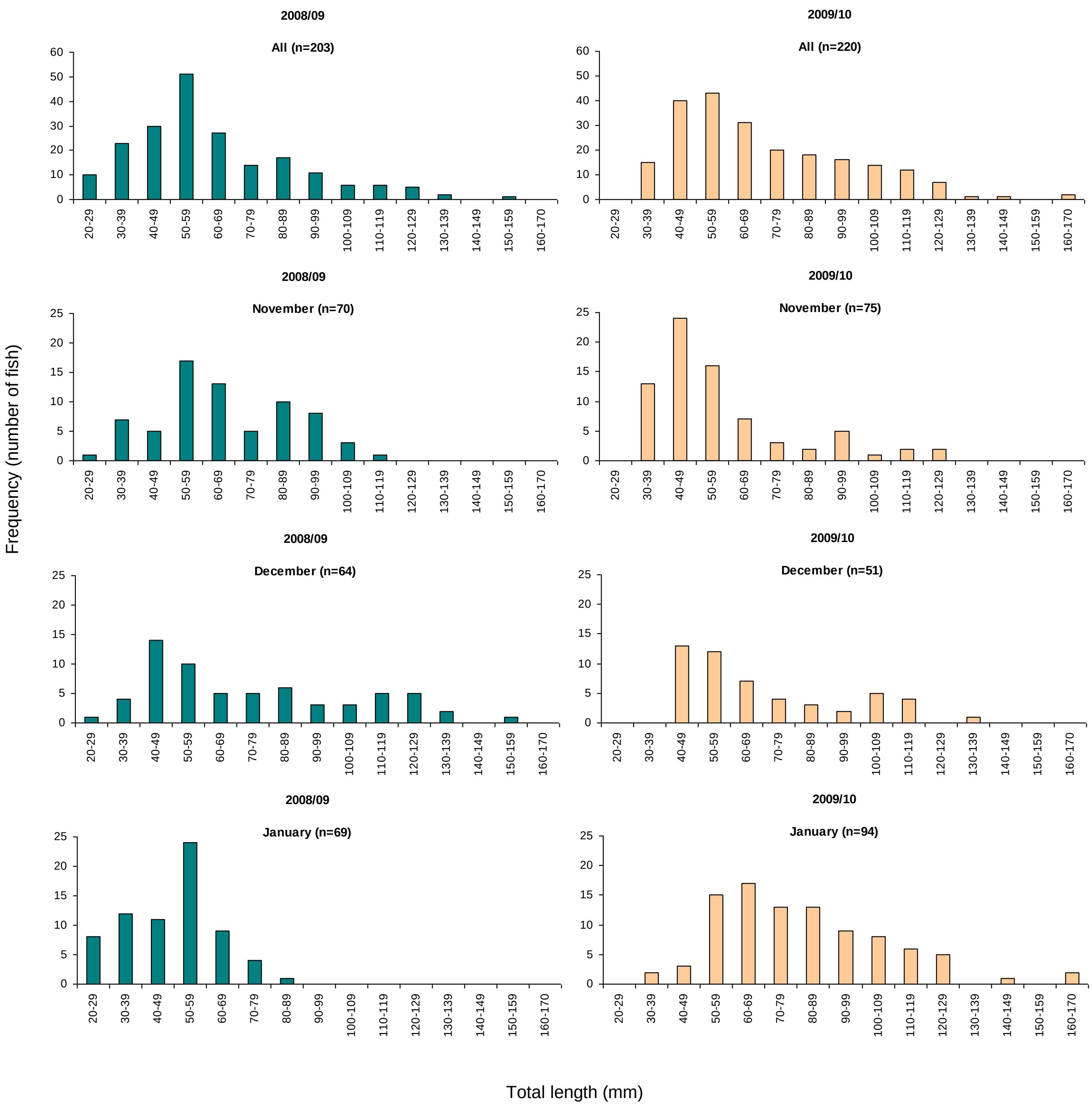


Figure 3.25. Length frequency distributions of greenback flounder sampled using seine net from the Murray Estuary and Coorong during 2008/09 and 2009/10 (note scale difference on y-axis).

Recruitment index

Catch per unit effort (CPUE) of the juvenile flounder by seine net represents relative abundance of new recruits thus provides a recruitment index for this species in the Coorong. CPUE varied between sites and across months (Table 3.4). CPUE was significantly higher in 2008/09 than in 2009/10 at Godfrey's Landing (p=0.004) whilst there was no difference between years at Sugars Beach (p=0.151) and Mark Point (p=1) (Figure 3.26).

Table 3.4. The Catch per unit of effort (CPUE) of greenback flounder juveniles by seine net in the Murray Estuary and Coorong during 2008/09 and 2009/10.

CPUE (fish per seine net shot)	**2008/09** November		December		January		average		**2009/10** November		December		January		average	
	Mean	*± SE*	Mean	*± SE*	Mean	*± SE*	Mean	*± SE*	Mean	*± SE*	Mean	*± SE*	Mean	*± SE*	Mean	*± SE*
Sampling sites:																
Sugars Beach	12.3	*3.3*	10.7	*7.7*	9.3	*6.4*	10.8	*5.3*	46.3	*20.6*	13.7	*6.2*	23.0	*13.7*	27.7	*15.3*
Godfrey's Landing	19.7	*2.9*	12.0	*5.8*	20.7	*7.5*	17.4	*5.5*	1.7	*1.2*	3.7	*1.9*	7.7	*0.3*	4.3	*1.9*
Mark Point	0.7	*0.3*	0.0	*0.0*	0.7	*0.7*	0.4	*0.4*	0.7	*0.3*	0.3	*0.3*	0.3	*0.3*	0.4	*0.3*
Average across sites	10.9	*5.3*	7.6	*5.8*	10.2	*7.1*	9.6	*5.9*	16.2	*16.6*	5.9	*4.8*	10.3	*8.9*	10.8	*11.1*

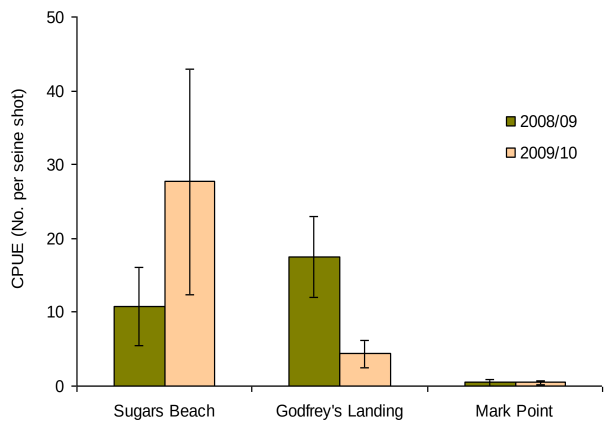


Figure 3.26. Catch per unit effort (CPUE) of juvenile greenback flounder caught by seine net at regular sampling sites in the Coorong between November and January during 2008/09 and 2009/10. Standard error bars are presented.

4. DISCUSSION

Over the last decade, extensive drought in 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 1000 GL y^{-1} since 2000/01. Between 2007/08 and 2009/10, there were no barrage releases. Consequently the salinity increased considerably throughout the Murray Mouth and Coorong, which 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; Ferguson *et al.* 2010; Zampatti *et al.* 2010).

4.1. Black Bream

4.1.1. Abundance and distribution

The relative abundance of black bream, as indicated by fishery catches, has declined substantially in the Murray Estuary and Coorong. The annual catch of this species dropped steeply from the mid to late 1980's, with a 92% reduction from the peak (46.7 t) in 1984/85 to 3.7 t in 1990/91. In the last 20 years (1990/91 to 2009/10), catches remained less than 20% of the peak value except for 2002/03. The annual catches were historically low in 2008/09 (1.8 t) and 2009/10 (1.1 t), reflecting that the population abundance had substantially declined. Combination of low catches and high CPUE suggest that CPUE has ceased to become a meaningful estimate of relative abundance during the drought due to aggregation of black bream into smaller area of habitat. Therefore, interpretation of the fishery catch and CPUE 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 distribution of black bream along the Coorong. In the last 20 years, there has been a contraction of the fishing ground from the North Lagoon to the Murray estuary, and since 2005/06 almost all black bream have been harvested within the estuary sub-region. Notably, the decline 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 reduced habitat due to poor environmental conditions resulting from the decadal drought (2002 to 2011). The positive relationship between the annual flow 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.

4.1.2. 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 (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 two years and were shown as 5 and 11 year olds in 2009/10, respectively. These two strong cohorts originated from 2003/04 when there was an experimental barrage release 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 three years and two strong cohorts persisted in samples over multiple years (at least 8 years for 1997/98 cohort and 3 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). Given that black bream can live for more than 20 years and that it is unlikely that they leave the Coorong , the most likely explanation for the highly truncated age structures is that fishing has impacted on this species (Sarre 2000; Ferguson and Ye 2008; Ferguson *et al.* 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.

Nevertheless, few individuals (4%) greater than 11 years old were present in age structures from 2008/09 and 2009/10. Such truncation of age structures had previously been reported for this population in 2002, 2003, 2004, and 2007 (Ferguson and Ye 2008). The most likely explanation for this truncation in age structure, is the impacts of fishing which removes older, larger individuals (Hilborn and Walters 1992; Planque *et al.* 2010; Walsh *et al.* 2010). 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 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 and climate change predictions indicate further flow reduction (Hughes 2003).

4.1.3. Spawning and recruitment

From the current study, sex ratios of black bream were generally weighted toward females (ratio). In recent years (2003, 2004, 2007, 2008), sex ratios of commercial catches from the Coorong varied greatly between samples (Ferguson and Ye 2008; Cheshire *et al.* 2011), suggesting spatial, or temporal separation of the sexes in black bream. Formation of single sex schools during spawning has been reported for this species in Victoria (Hobday and Moran 1983). These aggregations are highly vulnerable to fishing especially when the area of favourable estuarine habitat in the Coorong is reduced under low flow conditions. This is supported by highly seasonal catches of black bream which occur in the spring-summer spawning period.

The investigation of aspects of reproductive biology indicated that spawning occurred during both 2008/09 and 2009/10. The trends in GSI and macroscopic and histological analyses of gonads suggests that fish spawn during spring/summer in the Coorong. Several other studies have also recorded spawning activity for black bream during this time (e.g. Harbison 1974; Hall 1984; Coutin *et al.* 1997; Norriss *et al.* 2002; Cheshire *et al.* 2011). Histological examination of ovaries showed a higher level of atresia in 2009/10 than in the prior year, which might have resulted from stress caused by deteriorating environment conditions as the extended drought progressed for a further year. Failure to spawn as indicated by regression of ovary development and resorption of ova during periods of unfavorable environmental conditions has been reported for other species (e.g. Lake 1967).

The monthly length frequency distributions of juveniles infer the temporal patterns of recruitment during the current spawning season. Emergence of the dominant size groups (20-29 and 30-39 mm TL) in March suggests that spawning occurred at least till mid-summer (Norriss *et al.* 2002); with the presence of larger-sized YOY further suggesting spawning events earlier in the season (spring). Results from the reproductive study support this. Additionally the growth of the new recruits over time was identified through the monthly modal progression in length distributions.

The presence of YOY in the Murray Estuary (mostly below the Goolwa Barrage) and length frequency distributions of juveniles demonstrated some recruitment success of this species in both years. However, the level of recruitment was much lower in 2009/10 than in 2008/09, 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 have been made for the Coorong during the last three years (The Living Murray fish condition monitoring occurred in the later two years), 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.

4.2. Greenback Flounder

4.2.1. 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 to no more than 13% of this value. The annual catches were historically low in 2008/09 (0.5 t) and 2009/10 (1.0 t), suggesting a very low population abundance. 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 therefore needs to be interpreted with caution.

Spatially resolved fishery catches indicated extensive distribution and abundance of greenback flounder in the North Lagoon of the Coorong between 1984/85 to 2000/01. Since 2001/02, there has been a significant reduction in freshwater inflows and a general increase in salinity levels in the Coorong, followed by the contraction of estuarine habitats. By 2008/09 and 2009/10, almost all fishery catch (99%) came from the Murray estuary. The sudden rise in CPUE in the last two years even when the biomass declined was likely attributed to the increased catchability due to habitat reduction as well as the small number of fishing days. The importance of flows in maintaining the environmental conditions and habitat for greenback flounder is also supported by the positive relationship between barrage discharge and the proportional catch from the southern part of the Coorong.

4.2.2. 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 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. Age structures of females were dominated by 2 year olds in 2007/08 and 1 and 2 year olds in 2008/09. 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 lagoons (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).

4.2.3. Spawning and recruitment

All fish samples collected from the fishery for the reproductive study during 2009 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 commercial netting.

Sampling between May and August of 2009 indicated that spawning occurred from June through to August. The female GSI's were comparable to the peak value in previous studies (Crawford 1984a; Cheshire *et al.* 2011). The temporal pattern in GSI was consistent with the pattern of ovarian development. In Tasmania, greenback flounder have a protracted spawning season, spanning from late autumn to spring (Kurth 1957; Crawford 1984a). However, the abundance of larvae are reported to be the greatest between June and August (Crawford 1984b; Jenkins 1986), suggesting that peak spawning occurs in winter.

The complex structure in the length frequency distributions of juveniles further suggested that multiple spawning events may have occurred over an extended period. This suggests that spawning season may have extended from winter into late spring in the Coorong, as indicated for the Tasmanian populations (Kurth 1957; Crawford 1984a). A protracted spawning season with recruitment occurring over several months may enhance the opportunity for larvae and juveniles to find favorable environmental conditions, thus alleviating crowding in nursery area (Crawford 1984a). However, in 2009/10, the length distribution was dominated by larger fish with no further recruits in January, suggesting a shorter spawning season than in 2008/09. Additionally, the modal progression for several length classes also demonstrated that growth occurred over the sampling period (November to January) in both years. In 2008/09, a small size group (20-39 mm) continued to appear in January.

The length frequency distributions of juveniles and the presence of YOY indicated that recruitment of greenback flounder occurred in the Coorong in 2008/09 and 2009/10. However, the level of recruitment was lower in 2009/10 than the previous year, possibly due to worsened environmental conditions caused by continuing drought. Greenback flounder are likely to be affected by freshwater flows to estuaries (Robins and Ye 2007). As this species spawns during winter 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 level 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). 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). From 2007/08 to 2009/10, there were no barrage releases, and the salinity level in the North and South lagoons increased to 52 to 164 ppt respectively (Appendix III, and Noell *et al.* 2009), excluding a large area of the Coorong as a favorable spawning ground thus impacting on recruitment success of greenback flounder.

5. CONCLUSIONS

Condition monitoring of the populations of black bream and greenback flounder in the Murray Estuary and Coorong for the first two years (i.e. 2008/09 and 2009/10) indicated 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 not met in 2008/09 or 2009/10. This was reflected, for both species, by (i) a significant decline in population abundance, particularly over the last ten years, (ii) historically low level of abundance in the last two years, (iii) considerable contraction of distributional range to a reduced habitat in the Murray Estuary, (iv) truncated population age structures which indicate longevity overfishing, and (v) a decline in juvenile recruitment from 2008/09 to 2009/10.

The extended drought (2001/02-2009/10) in the MDB, combined with extensive river regulation and water abstraction, led to the subsequent lack of freshwater releases and considerable increases in salinity throughout the Coorong. Such conditions and the absence of a favorable salinity gradient have likely had a severe impact on the estuarine fish assemblages including TLM target species. Freshwater inflows are important for the recovery of depleted populations of black bream and greenback flounder given their critical role in facilitating successful spawning and recruitment and maintaining estuarine fish habitat in 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. 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, including flow regimes, that influence the recruitment success of key estuarine species and fish habitat.

The first two years of condition monitoring in the Coorong have provided valuable information on the population ecology of black bream and greenback flounder and have 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. Classification of development of ovaries and testes for macroscopic staging (after Fowler *et al.* 1999) (Cheshire *et al.* 2011).

Gonad Stage	Macroscopic characteristics
F1- Immature	Ovaries small and undeveloped, clear or translucent showing little or no colouration
F2- Developing	Ovaries small but larger than F1 and become more orange/yellow/white (varies between species) no individual oocytes discernable.
F3- Developed	Ovaries larger and turgid, yellow/orange in colour, individual oocytes discernible
F4- Hydrated	Large ovaries, taking up a large space in gut cavity, with hydrated oocytes easily discernable.
F5- Regressing /Spent	Ovaries are large, similar in size and colour to F2 stage, however more flaccid with a granular appearance.
M1- Immature	Undeveloped testes usually dark in colour.
M2- Developing	Developing testes whereby they are larger and become grey - white in colour but no milt present.
M3- Developed	Developed testes that are large and white in colour and milt is present

Appendix II. Average values of water temperature (°C) at key sampling sites throughout the period of fish condition monitoring in the Coorong during 2008/09 and 2009/10.

Temperature (°C)	Region / Site	Murray Estuary						North Lagoon		
Year	Month	Boundary Creek	Godfrey's Landing	Goolwa Barrage Hindmarsh Island side	Goolwa Barrage Sir Richard Peninsula side	Sugars Beach	*Average*	Mark Point	Noona-meena	*Average*
2008/09	Nov		19			19	*19*	24	23	*23*
	Dec		20			22	*21*	21	21	*21*
	Jan		23			30	*27*	24	23	*24*
	Feb	21			21		*21*	21	18	*19*
	Mar	22		21	20		*21*			
	Apr	14		16	16		*15*			
	Jun	12		12	12		*12*	12		*12*
Average		*17*	*21*	*16*	*17*	*24*	*19*	*20*	*21*	*21*
2009/10	Oct							15	15	*15*
	Nov		24			26	*25*	25	21	*23*
	Dec		21			19	*20*	22	21	*22*
	Jan		22			22	*22*	23	22	*22*
	Feb	24		25	24		*24*	22	20	*21*
	Mar	24		22	23		*23*			
	Apr	19		20	19		*20*			
Average		*22*	*23*	*23*	*22*	*22*	*22*	*21*	*20*	*21*
Overall average		19	22	19	19	23	*21*	21	20	*21*

Appendix III. Average values of salinity (ppt) at key sampling sites throughout the period of fish condition monitoring in the Coorong during 2008/09 and 2009/10.

Salinity (ppt)	Region / Site	Murray Estuary						North Lagoon		
Year	Month	Boundary Creek	Godfrey's Landing	Goolwa Barrage Hindmarsh Island side	Goolwa Barrage Sir Richard Peninsula side	Sugars Beach	*Average*	Mark Point	Noona-meena	*Average*
2008/09	Nov		38			38	*38*	48	77	*63*
	Dec		39			38	*38*	50	86	*74*
	Jan		39			39	*39*	49	82	*71*
	Feb	46			41		*44*	52	88	*70*
	Mar	42		40	40		*41*			
	Apr	39		38	38		*38*			
	Jun	37		38	38		*37*	42		*42*
Average		*41*	*38*	*38*	*39*	*38*	*39*	*49*	*84*	*68*
2009/10	Oct							39	77	*58*
	Nov		39			39	*39*	62	102	*82*
	Dec		39			38	*38*	56	90	*73*
	Jan		42			39	*41*	61	102	*81*
	Feb	47		32	38		*39*	56	103	*79*
	Mar	44		39	38		*40*			
	Apr	41		39	39		*40*			
Average		*44*	*40*	*37*	*38*	*39*	*39*	*55*	*95*	*75*
Overall average		42	40	38	39	38	39	52	90	72

Appendix IV. Average values of dissolved oxygen (mg/L) at key sampling sites throughout the period of fish condition monitoring in the Coorong during 2008/09 and 2009/10.

Dissolved Oxygen (mg/L)	Region	Site								
		Murray Estuary						*North Lagoon*		
Year	Month	Boundary Creek	Godfrey's Landing	Goolwa Barrage Hindmarsh Island side	Goolwa Barrage Sir Richard Peninsula side	Sugars Beach	*Average*	Mark Point	Noona-meena	*Average*
2008/09	Nov		10.7			11.2	*10.9*	10.4	9.8	*10.1*
	Dec		10.9			9.3	*10.1*	10.0	10.0	*10.0*
	Jan		8.4			8.8	*8.6*	8.4	7.4	*7.7*
	Feb	8.4			9.6		*9.0*	8.8	8.4	*8.6*
	Mar	7.0		6.9	8.9		*7.6*			
	Apr	9.0		13.2	13.2		*11.8*			
	Jun	10.1		12.2	12.2		*11.5*	11.5		*11.5*
Average		*8.6*	*10.0*	*10.8*	*11.0*	*9.8*	*10.0*	*9.7*	*8.7*	*9.2*
2009/10	Oct							12.5	11.3	*11.9*
	Nov		10.6			10.4	*10.5*	8.5	9.3	*8.9*
	Dec		10.1			9.6	*9.8*	10.4	9.3	*9.8*
	Jan		8.4			8.1	*8.2*	9.0	8.1	*8.5*
	Feb	7.5		9.1	8.1		*8.2*	9.1	9.0	*9.0*
	Mar	6.9		5.0	5.3		*5.7*			
	Apr	8.2		5.8	5.8		*6.6*			
Average		*7.5*	*9.6*	*6.6*	*6.4*	*9.3*	*8.3*	*9.8*	*9.4*	*9.6*
Overall average		8.1	9.7	8.7	9.0	9.5	*9.1*	9.8	9.1	*9.4*

Appendix V. Average values of pH at key sampling sites throughout the period of fish condition monitoring in the Coorong during 2008/09 and 2009/10.

pH	Region	Site								
		Murray Estuary						*North Lagoon*		
Year	Month	Boundary Creek	Godfrey's Landing	Goolwa Barrage Hindmarsh Island side	Goolwa Barrage Sir Richard Peninsula side	Sugars Beach	*Average*	Mark Point	Noona-meena	*Average*
2008/09	Nov		7.8			7.9	*7.9*	8.2	8.3	*8.2*
	Dec		8.3			8.3	*8.3*	8.3	8.2	*8.3*
	Jan		8.1			8.1	*8.1*	8.3	8.2	*8.2*
	Feb	8.3			8.4		*8.4*	8.4	8.4	*8.4*
	Mar									
	Apr	8.2		8.4	8.4		*8.3*			
	Jun	8.4		8.5	8.6		*8.5*	8.4		*8.4*
Average		*8.3*	*8.1*	*8.5*	*8.5*	*8.1*	*8.3*	*8.3*	*8.3*	*8.3*
2009/10	Oct							8.5	8.7	*8.6*
	Nov		8.5			8.7	*8.6*	8.8	8.2	*8.5*
	Dec		8.5			8.4	*8.4*	8.7	8.2	*8.4*
	Jan		8.5			8.3	*8.4*	8.7	8.3	*8.5*
	Feb	8.2		8.3	8.2		*8.2*	8.4	8.2	*8.3*
	Mar	8.1		8.1	8.2		*8.1*			
	Apr	8.3		8.2	8.1		*8.2*			
Average		*8.2*	*8.5*	*8.2*	*8.2*	*8.5*	*8.3*	*8.6*	*8.3*	*8.5*
Overall average		8.2	8.3	8.3	8.3	8.3	*8.3*	8.5	8.3	*8.4*

Appendix VI. Average values of Secchi disc depth (mm) at key sampling sites throughout the period of fish condition monitoring in the Coorong during 2008/09 and 2009/10.

Secchi disc depth		Region	Site							
(mm)		***Murray***	***Estuary***					***North***	***Lagoon***	
Year	Month	Boundary Creek	Godfrey's Landing	Goolwa Barrage Hindmarsh Island side	Goolwa Barrage Sir Richard Peninsula side	Sugars Beach	*Average*	Mark Point	Noona-meena	*Average*
2008/09	Nov		2001			2001	*2001*	1500	610	*1055*
	Dec		1370			500	*935*	1960	350	*887*
	Jan		1360			2001	*1681*	2001	550	*1034*
	Feb	1300			1120		*1210*	1400	400	*900*
	Mar	900		1150	2001		*1350*			
	Apr			2001	2001		*2001*			
	Jun	2001		2001	2001		*2001*	2001		*2001*
Average		*1400*	*1577*	*1717*	*1781*	*1501*	*1607*	*1710*	*459*	*1036*
2009/10	Oct							1440	1000	*1220*
	Nov									
	Dec							700	290	*495*
	Jan		1900			1100	*1500*	1160	330	*745*
	Feb			2000	1440		*1720*	850	340	*595*
	Mar			2000	2000		*2000*			
	Apr	2000		2000	2000		*2000*			
Average		*2000*	*1900*	*2000*	*1813*	*1100*	*1767*	*1086*	*519*	*802*
Overall average		1550	1706	1859	1795	1340	*1672*	1374	489	*915*