Coorong Fish Condition Monitoring 2008/09–2009/10: Population and Recruitment Status of the Smallmouthed Hardyhead (*Atherinosoma microstoma*)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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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 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 smallmouthed hardyhead (*Atherinosoma microstoma*) in the North and South lagoons of the Coorong, in order to evaluate target F3: provide optimum conditions to improve recruitment success of smallmouthed hardyhead in the South Lagoon.

Quantitative fish surveys conducted during spring/summer in 2008/09 and 2009/10 indicated that management target F3 is being met in 2009/10, but not in 2008/09. In both years, smallmouthed hardyhead were found to persist and recruit successfully in the North Lagoon, with salinity ranging between 39-103 ppt, showing its strong ability to adapt to a hypersaline environment. Nevertheless, the extremely hypersaline conditions (up to 166 ppt) appeared to have restricted its southerly distribution. In 2008/09, almost no fish were collected in the South Lagoon, with salinity ranging between 116-166 ppt. In 2009/10, small volumes of spring inflows (~100 ML day^{1}) from the South East of South Australia considerably lowered the salinity in the southern part of the South Lagoon, leading to a noticeable biological response at a local scale, with large numbers of smallmouthed hardyhead recolonising the region. These fish probably came from Salt Creek, which is likely to serve as a recruitment refuge for smallmouthed hardyhead, being particularly important for the population recovery in the South Lagoon. In 2009/10, the overall abundance of smallmouthed hardyhead increased and a stronger cohort was produced than in 2008/09. Such responses provide insight into the population recovery when favorable conditions (i.e. salinity) are restored and show the resilience of the smallmouthed hardyhead population in the Coorong. However, freshwater inflows from the Murray barrages, and to a lesser extent small inputs from Salt Creek, are important to the survival of the smallmouthed hardyhead population in the Coorong. The first two years of condition monitoring

in the Coorong has established a baseline for this keystone species, by which future quantitative assessments could be made.

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 extraction 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 extent of the original Murray Estuary, establishing an abrupt physical and ecological barrier between the marine and freshwater systems. In recent years, the environmental condition has been exacerbated in the Coorong by the severe drought in the Basin, with very low or no flow releases through the barrages since 2002 (DFW 2010). Subsequently, the Murray Mouth was closed due to siltation, requiring dredging operation to maintain its opening since 2002 (DWLBC 2008). The Coorong was transformed into a marine/hypersaline environment, and the extreme hypersaline conditions in the South Lagoon was causing the severe, continuing degradation of critical habitats for nationally listed bird species, and compromising the Ramsar ecological character of the system (Roger 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 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 Condition Monitoring Plan (Maunsell Australia Pty Ltd. 2009), has been instigated since 2008/09 to assess whether these targets have been achieved. The current report presents the findings of the condition monitoring for smallmouthed hardyhead (*Atherinosoma microstoma*) (Target F3) in the North and South lagoons of the Coorong during the first two years (i.e. 2008/09 and 2009/10).

1.2. Objectives

The aim of the condition monitoring, linking to Target F3, was to assess the population status of smallmouthed hardyhead including the level of recruitment. Specific objectives were to:

1. Determine the relative abundance, distribution and size structure of smallmouthed hardyhead in the North and South lagoons of the Coorong.

2. Establish a recruitment index and assess recruitment success of this species.

3. Monitor key environmental parameters (primary salinity and macrophytes), and investigate their potential linkage to recruitment success.

2. METHODS

2.1. Field Sampling

Quantitative fish sampling was conducted at six sites along the North and South lagoons of the Coorong (Figure 2.1) during spring/summer in 2008/09 and 2009/10, targeting the main spawning and recruitment season of smallmouthed hardyhead. Field trips were carried out at approximately one-monthly intervals with four trips occurring in 2008/09 and five in 2009/10. Each site was sampled during the daylight hours using a standard seine net for assessment of relative abundance and a small seine net has also been adopted since February 2009 to more effectively assess recruitment of smallmouthed hardyhead (Table 2.1).

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. 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 gear type.

On each sampling occasion at each site for each gear type, all species were identified and the number counted, and a random subsample of up to 100 smallmouthed hardyheads was removed and individuals were measured for size (Total Length, mm). The relative abundance was defined as the number of fish per seine net shot, therefore the catch per unit effort (CPUE) was used interchangeably in this report. The CPUE of fish caught by the small seine net provided a recruitment index for smallmouthed hardyhead. At each site, salinity was tested using a TPS water quality meter, and the presence/absence of aquatic macrophytes recorded.

2.2. Data Analysis

In order to determine differences in the relative abundance of fish captured using standard and/or small seine nets between years and sites, a Mixed-model Analysis of Variance (ANOVA) was performed using the SAS package. Transformation using $Log_{10}(x)$ was performed to satisfy parametric assumptions of normality and homogeneity of variance. Due to a significant interaction between year and site effects, a pairwise comparison was conducted between sites for each year and a t-test was used to compare the difference between years for each site. All tests were considered significant at $p < 0.05$.

In addition, length frequency distributions of fish captured by standard and small seine nets 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).

Relative abundance data were plotted against environmental data to explore the potential relationships between key environmental conditions (i.e. salinity and macrophytes) and fish abundance as well as the level of recruitment. Regression analysis was conducted to determine the relationship between salinity and fish abundance and recruitment.

Table 2.1. Sampling effort for smallmouthed hardyhead by standard and small seine nets in the Coorong for 2008/09 and 2009/10.

Gear Type	**Site**	**2008/09**					**2009/10**					
		Nov	Dec	Jan	Feb	*Total*	Oct	Nov	Dec	Jan	Feb	*Total*
Standard seine	Mark Point	3	3	3	3	*12*	3	3	3	3	3	*15*
(net shots)	Noonameena	3	3	3	3	*12*	3	3	3	3	3	*15*
	Hells Gate	3	3	3	3	*12*	3	3	3	3	3	*15*
	Jack Point	3	3	3	3	*12*	3	3	3	3	3	*15*
	Salt Creek	3	3	3	3	*12*	3	3	3	3	3	*15*
	Salt Creek Inside				3	*3*	3	3	3	3	3	*15*
Overall						***63***						***90***
Small seine	Mark Point				3	*3*	3	3		3	3	*12*
(net shots)	Noonameena				3	*3*	3	3		3	3	*12*
	Hells Gate						3	3	3	3	3	*15*
	Jack Point						3	3	3	3	3	*15*
	Salt Creek						3	3	3	3	3	*15*
	Salt Creek Inside				3	*3*	3	3	3	3	3	*15*
Overall						***9***						***84***

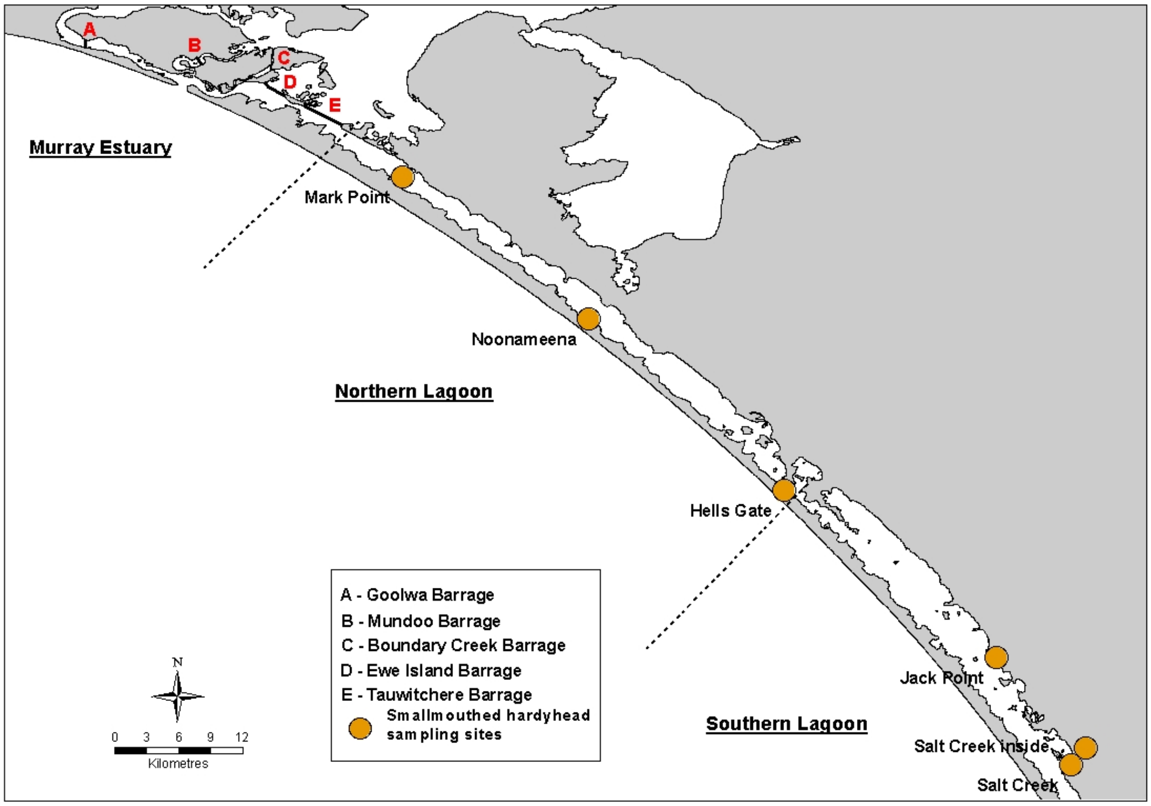

Figure 2.1. Sampling sites for smallmouthed hardyhead in the Coorong.

3. RESULTS

3.1. Catch Summary

A total of 43,206 fish representing 14 species were sampled in the North and South lagoons of the Coorong during the 2008/09 and 2009/10 seasons (Table 3.1). Smallmouthed hardyhead was by far the most dominant species, accounting for 99% of the catch. It was the only species present in the South Lagoon with the exception of two bluespot gobies (*Pseudogobius olorum*) collected in October 2009. Between 2008/09 and 2009/10, the number of species encountered increased from 7 to 13, respectively; there was also a substantial increase in the total number of fish,.

Table 3.1. Species and number of fish encountered during the 2008/09 and 2009/10 field trips by SARDI for the fish condition monitoring in the Coorong.

Common Name	Scientific Name	Classi-fication	Year / Region						
			2008/09		Subtotal	2009/10		Subtotal	Total
			North Lagoon	South Lagoon		North Lagoon	South Lagoon		
Congolli	*Pseudaphritis urvillii*	Diadromous				1		1	***1***
Tamar goby	*Afurcagobius tamarensis*	Estuarine	1		1	37		37	***38***
Yelloweye mullet	*Aldrichetta forsteri*	Estuarine	28		28	38		38	***66***
Longsnout flounder	*Ammotretis rostratus*	Estuarine				1		1	***1***
Smallmouthed hardyhead	Atherinosoma microstoma	Estuarine	4,324	728	5,052	22,948	14,954	37,902	***42,954***
River garfish	*Hyporhamphus regularis*	Estuarine	4		4	52		52	***56***
Bluespot goby	*Pseudogobius olorum*	Estuarine				7	2	9	***9***
Greenback flounder	*Rhombosolea tapirina*	Estuarine	15		15	14		14	***29***
Western Australian salmon	*Arripis truttaceus*	Marine	3		3	3		3	***6***
Prickly toadfish	*Contusus brevicaudus*	Marine				3		3	***3***
Australian anchovy	*Engraulis australis*	Marine				1		1	***1***
Sandy sprat	*Hyperlophus vittatus*	Marine				40		40	***40***
Blue sprat	*Spratelloides robustus*	Marine				1		1	***1***
Smooth toadfish	*Tetractenos glaber*	Marine	1		1				***1***
Overall			**4,376**	**728**	**5,104**	**23,146**	**14,956**	**38,102**	***43,206***
Species number			**7**	**1**	**7**	**13**	**2**	**13**	***14***

3.2. Abundance and Distribution

The relative abundance of smallmouthed hardyhead (or CPUE by the standard seine net) at various sites in the North and South lagoons during 2008/09 and 2009/10 are presented in Table 3.2 and Figure 3.1. Statistical analysis indicated a highly significant interaction between the year and site effects (Table 3.3). Pairwise results showed significant difference between Noonameena and three other sites in 2008/09, whilst in 2009/10 most sites presented significant difference, with the exception of Hells Gate x Jack Point and Mark Point x Salt Creek (Table 3.4).

There was a significant increase of smallmouthed hardyhead abundance in 2009/10, compared to 2008/09, at Mark Point, Noonameena and Salt Creek (Table 3.5 and Figure 3.1); whilst numbers remained similarly low (<15 fish per seine) in both years at Hells Gate and Jack Point. No statistical comparison was done between the years for fish caught from inside Salt Creek given there was only one sampling event (February) in 2008/09.

Table 3.2. Average catch per unit of effort (CPUE) of smallmouthed hardyhead by standard seine net at various sampling sites in the Coorong during 2008/09 and 2009/10.

Site	2008/09			2009/10		
	CPUE	± SE	n	CPUE	± SE	n
Mark Point	**2**	2	12	**143**	42	15
Noonameena	**248**	38	12	**975**	215	15
Hells Gate	**2**	1	12	**13**	10	15
Jack Point	**0**	0	12	**0.3**	0.3	15
Salt Creek	**0.4**	0.4	12	**71**	24	15
Salt Creek Inside	**182**	61	3	**247**	31	15
Total	***57***	*15*	*63*	***241***	*51*	*90*

Table 3.3. ANOVA results for comparison of the relative abundances of smallmouthed hardyhead, (log_{10} transformed data) collected by standard seine net, between years and among various sampling sites in the Coorong. Sampling events (months) are nested within years. Significant differences are highlighted in red.

Effect	Num DF	Den DF	F Value	Pr > F
Year	1	90	79.59	<.0001
Site	5	12	203.20	<.0001
Year*Site	5	90	13.68	<.0001
Month(Year)	7	90	2.63	0.0160
Month*Site(Year)	32	90	7.79	<.0001

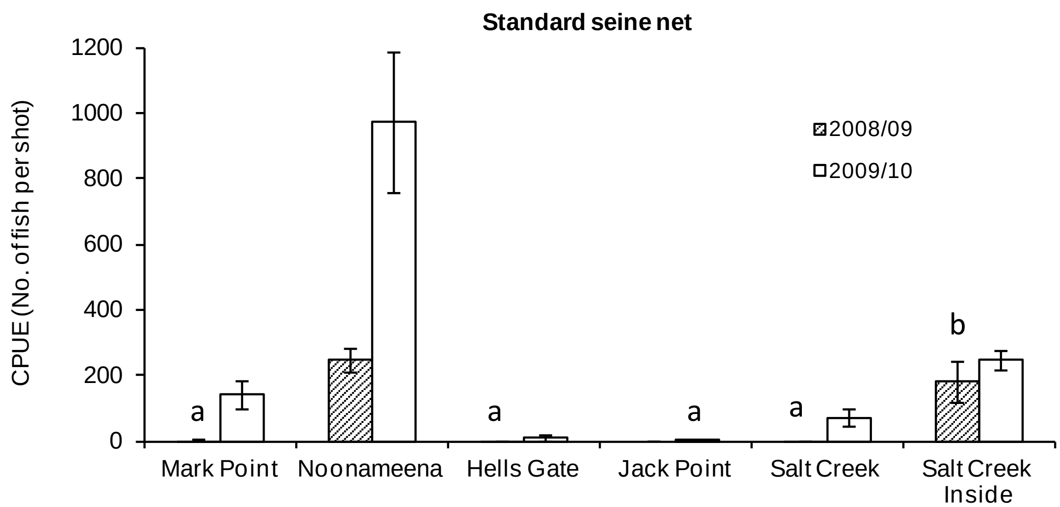

Figure 3.1. Catch per unit of effort (CPUE) (number of fish per seine) of smallmouthed hardyhead ± 1 S.E derived from standard seine net at various sampling sites in the Coorong during 2008/09 and 2009/10. Note [a] fish were in very low numbers; [b] in 2008/09, fish sampling was only conducted in February inside Salt Creek.

Table 3.4. Pairwise comparisons of the relative abundances of smallmouthed hardyhead (log_{10} transformed data) collected using standard seine net, between sites for each year. Significant differences are highlighted in red.

Year	Comparisons			DF	t Value	Pr > |t|	Tukey-Kramer Ajustment P
2008/09	Hells Gate	vs	Jack Point	90	1.59	0.1144	0.8807
2008/09	Hells Gate	vs	Mark Point	90	0.36	0.7229	1
2008/09	Hells Gate	vs	Noonameena	90	-14.46	<.0001	<.0001
2008/09	Hells Gate	vs	Salt Creek	90	1.15	0.2541	0.9863
2008/09	Jack Point	vs	Mark Point	90	-1.24	0.2187	0.9761
2008/09	Jack Point	vs	Noonameena	90	-16.05	<.0001	<.0001
2008/09	Jack Point	vs	Salt Creek	90	-0.45	0.6563	1
2008/09	Mark Point	vs	Noonameena	90	-14.81	<.0001	<.0001
2008/09	Mark Point	vs	Salt Creek	90	0.79	0.4304	0.9993
2008/09	Noonameena	vs	Salt Creek	90	15.61	<.0001	<.0001
		vs					
2009/10	Hells Gate	vs	Jack Point	90	1.96	0.0527	0.6739
2009/10	Hells Gate	vs	Mark Point	90	-7.92	<.0001	<.0001
2009/10	Hells Gate	vs	Noonameena	90	-19.43	<.0001	<.0001
2009/10	Hells Gate	vs	Salt Creek	90	-7.25	<.0001	<.0001
2009/10	Hells Gate	vs	Salt Creek Inside	90	-15.33	<.0001	<.0001
2009/10	Jack Point	vs	Mark Point	90	-9.89	<.0001	<.0001
2009/10	Jack Point	vs	Noonameena	90	-21.4	<.0001	<.0001
2009/10	Jack Point	vs	Salt Creek	90	-9.22	<.0001	<.0001
2009/10	Jack Point	vs	Salt Creek Inside	90	-17.29	<.0001	<.0001
2009/10	Mark Point	vs	Noonameena	90	-11.51	<.0001	<.0001
2009/10	Mark Point	vs	Salt Creek	90	0.67	0.5047	0.9998
2009/10	Mark Point	vs	Salt Creek Inside	90	-7.41	<.0001	<.0001
2009/10	Noonameena	vs	Salt Creek	90	12.18	<.0001	<.0001
2009/10	Noonameena	vs	Salt Creek Inside	90	4.1	<.0001	0.0041
2009/10	Salt Creek	vs	Salt Creek Inside	90	-8.08	<.0001	<.0001

Table 3.5. T-test results for comparison of the relative abundances of smallmouthed hardyhead, (log10 transformed data) collected using standard seine net, between years (2008/09 and 2009/10) for each site. Significant differences are highlighted in red.

Effect	Site	Num DF	Den DF	F Value	Pr > F
Year*Site	Mark Point	1	90	72.22	<.0001
Year*Site	Noonameena	1	90	13.96	0.0003
Year*Site	Hells Gate	1	90	0.43	0.5143
Year*Site	Jack Point	1	90	0.23	0.6296
Year*Site	Salt Creek	1	90	75.72	<.0001
Year*Site	Salt Creek Inside	0	.	.	.

3.3. Size Structure

The length frequency distributions of smallmouthed hardyhead collected from sites in the North and South lagoons throughout the sampling months are presented in Figures 3.2a,b and 3.3a,b. In 2008/09, the overall fish size ranged between 11 and 83 mm. The temporal pattern of length distributions was best shown at Noonameena; whilst length data was patchy for the rest of sites (Figure 3.2a,b). At Noonameena, no distinct monthly modal progression was found, with fish less than 30 mm collected throughout the sampling period, suggesting a protracted spawning season. There was a decline in the number of larger smallmouthed hardyhead in December and January. Samples collected in February at Mark Point showed a broad range of sizes were present and a distinct cohort of small fish (< 30 mm), indicating successful recruitment (Figure 3.2a). Sampling commencing in February 2009 at Salt Creek Inside also indicated good recruitment at this relatively 'fresh' site (salinity 39.8 ppt) whilst adjacent hypersaline sites in the South Lagoon were fishless.

In 2009/10, smallmouthed hardyhead were more broadly distributed across the region compared to the previous year, with size ranging between 7 and 86 mm. Total length range differed at most sites, except for Hells Gate and Jack Point (Figure 3.3a,b), where salinity levels continued to be high in 2009/10 (101-166 ppt). New recruits were present at most of the sites throughout the season except for Hells Gate and Jack Point, where no fish were collected in January and February 2010. It was remarkable that abundant fish of all sizes were collected at Salt Creek, near the southern end of the South Lagoon during 2009/10, whilst in contrast, only few fish were present at this site in 2008/09.

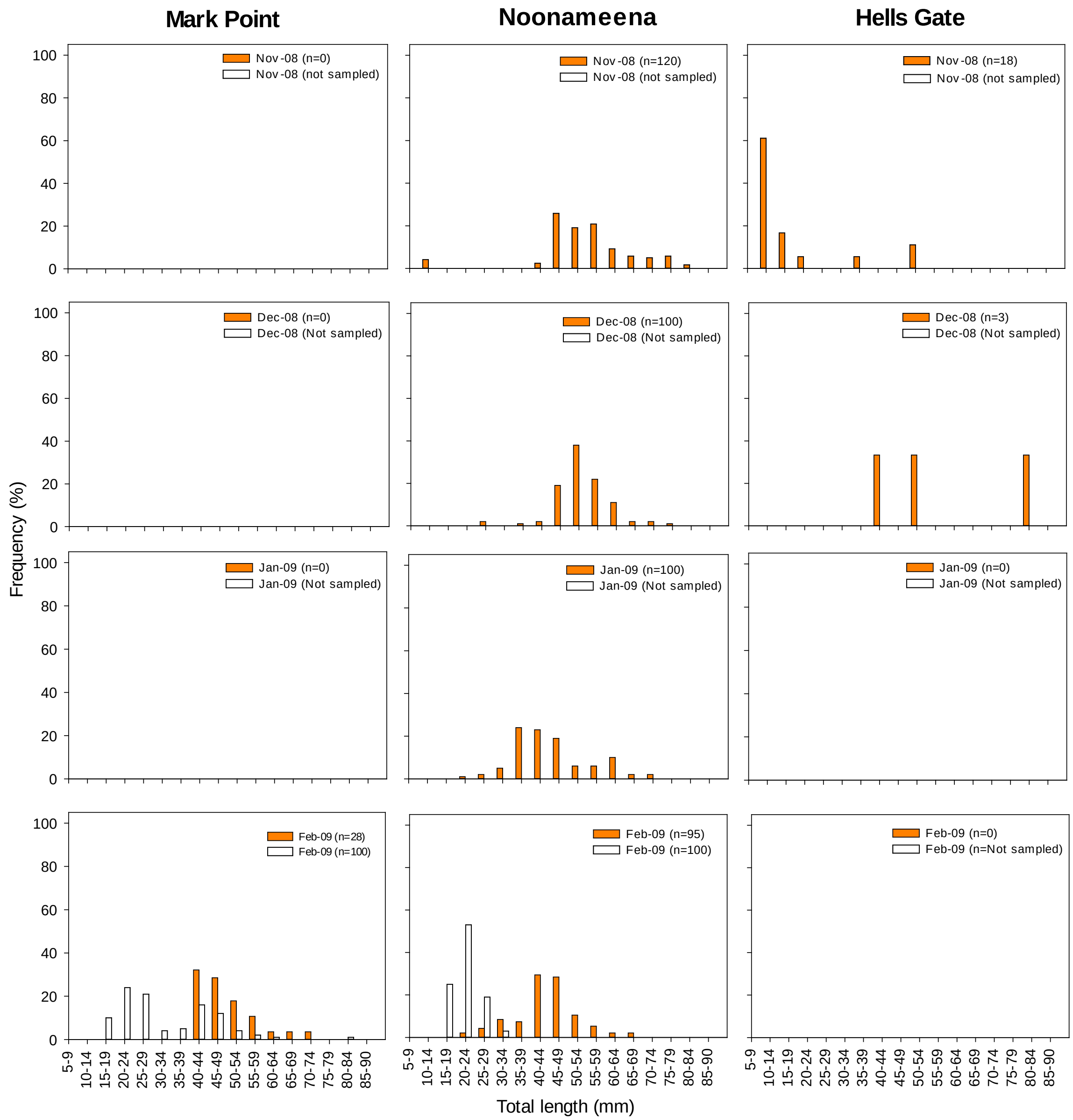

Figure 3.2a. Size frequency distributions of smallmouthed hardyhead sampled by standard seine (orange symbol) and small seine (white symbol) nets from selected sites in the North Lagoon of the Coorong between November 2008 and February 2009.

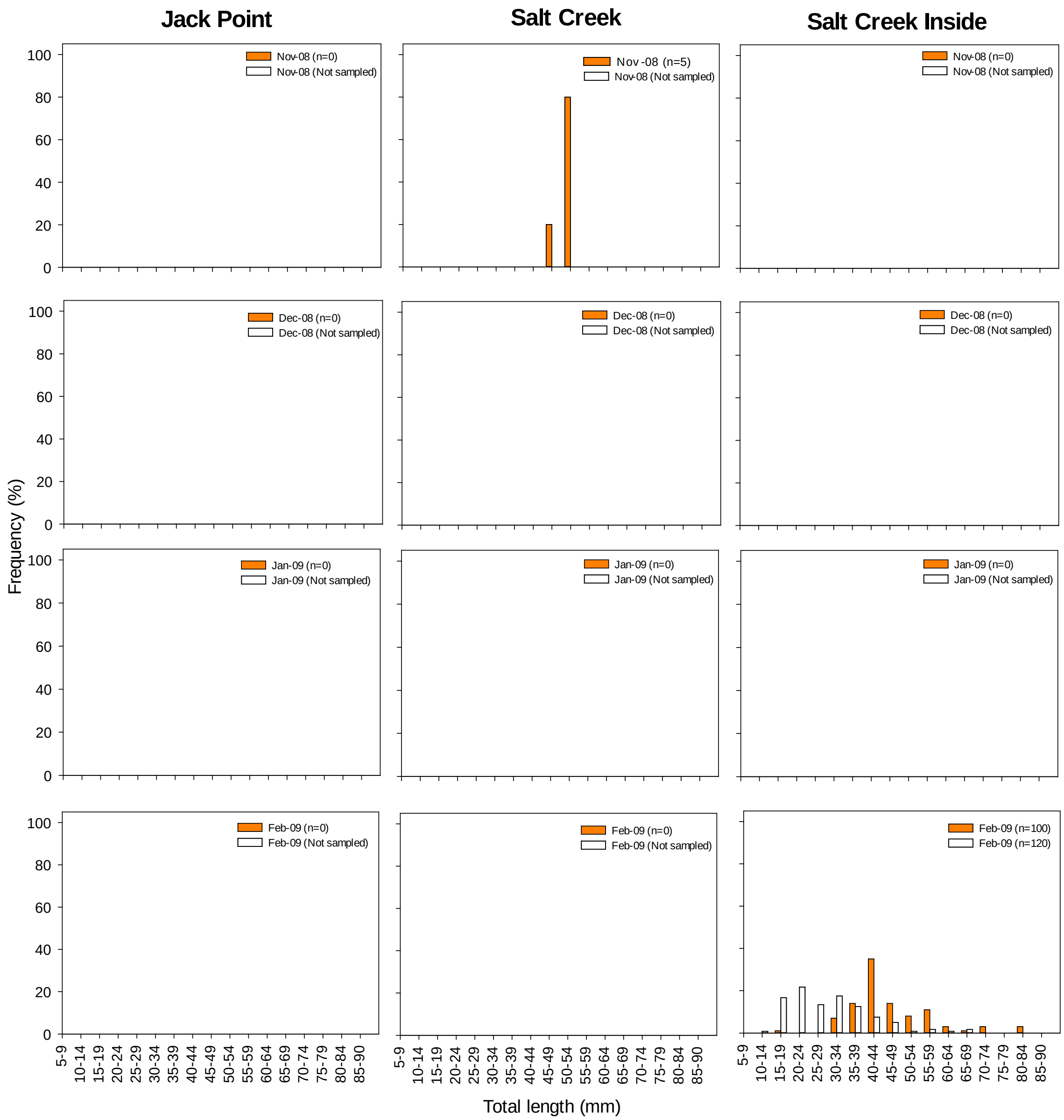

Figure 3.2b. Size frequency distributions of smallmouthed hardyhead sampled by standard seine (orange symbol) and small seine (white symbol) nets from selected sites in the South Lagoon of the Coorong between November 2008 and February 2009.

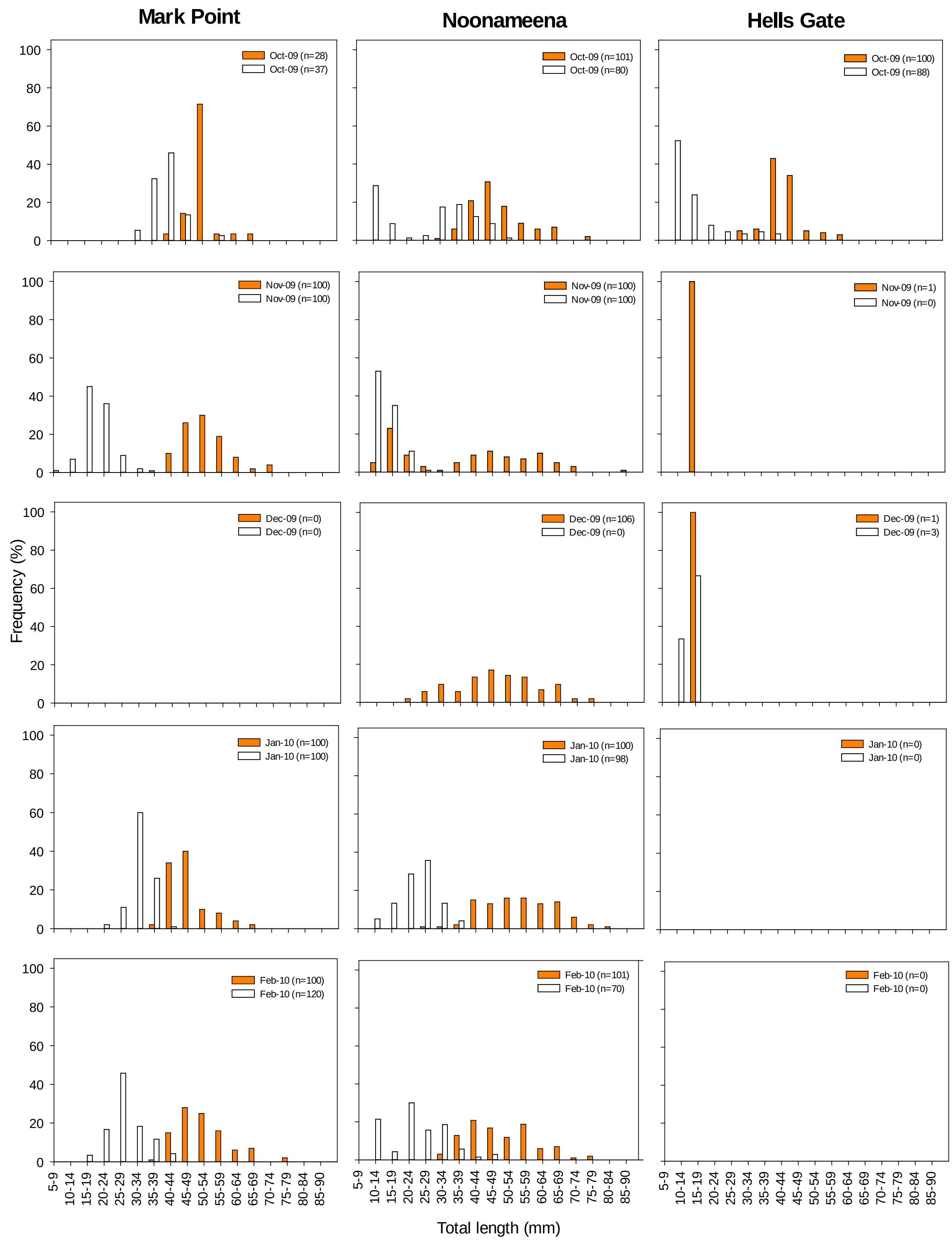

Figure 3.3a. Size frequency distributions of smallmouthed hardyhead sampled by standard seine (orange symbol) and small seine (white symbol) nets from selected sites in the North Lagoon of the Coorong between October 2009 and February 2010.

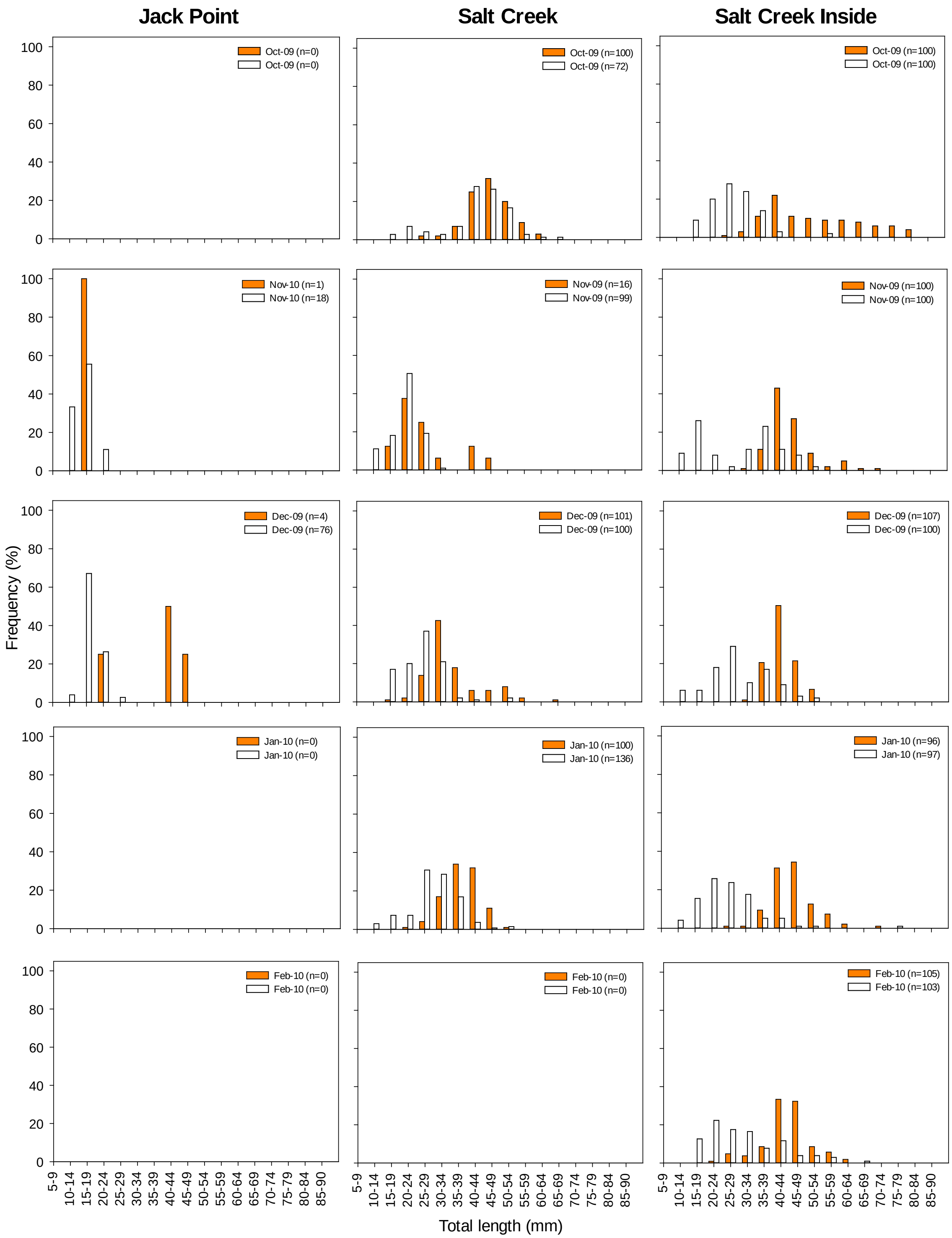

Figure 3.3b. Size frequency distributions of smallmouthed hardyhead sampled by standard seine (orange symbol) and small seine (white symbol) nets from selected sites in the South Lagoon of the Coorong between October 2009 and February 2010.

3.4. Recruitment

The recruitment index for smallmouthed hardyhead was obtained by using CPUE of fish caught in the small seine net (Table 3.6 and Figure 3.4). The average CPUE of new recruits in 2009/10 provided good baseline data. The CPUE for February 2009/10 were also presented to compare with the results from the previous year, showing an increase in the level of recruitment at Mark Point and Salt Creek Inside but a decrease at Noonameena (Table 3.6 and Figure 3.4). Overall, there was stronger recruitment in 2009/10 than in 2008/09.

Table 3.6. Relative abundances of new recruits of smallmouthed hardyhead, as indicated by fish caught using a small seine net (CPUE, number of fish per seine), at selected sites in the Coorong during 2008/09 and 2009/10. * The 2008/09 sampling was only conducted in February.

Site	**2008/09** (February)			**2009/10** (February)			**2009/10** (October-February)		
	CPUE	± SE	n	CPUE	± SE	n	CPUE	± SE	n
Mark Point*	**114**	44	3	**403**	115	3	**301**	61	12
Noonameena*	**175**	41	3	**91**	10	3	**186**	23	12
Hells Gate				**0**	0	3	**11**	7	15
Jack Point				**0**	0	3	**7**	3	15
Salt Creek				**0**	0	3	**196**	105	15
Salt Creek Inside*	**59**	18	3	**203**	52	3	**476**	66	15
Average (three sites)*	***116***	*25*	*9*	***233***	*58*	*9*	***333***	*37*	*39*
Average (all sites)				***116***	*40*	*18*	***193***	*30*	*84*

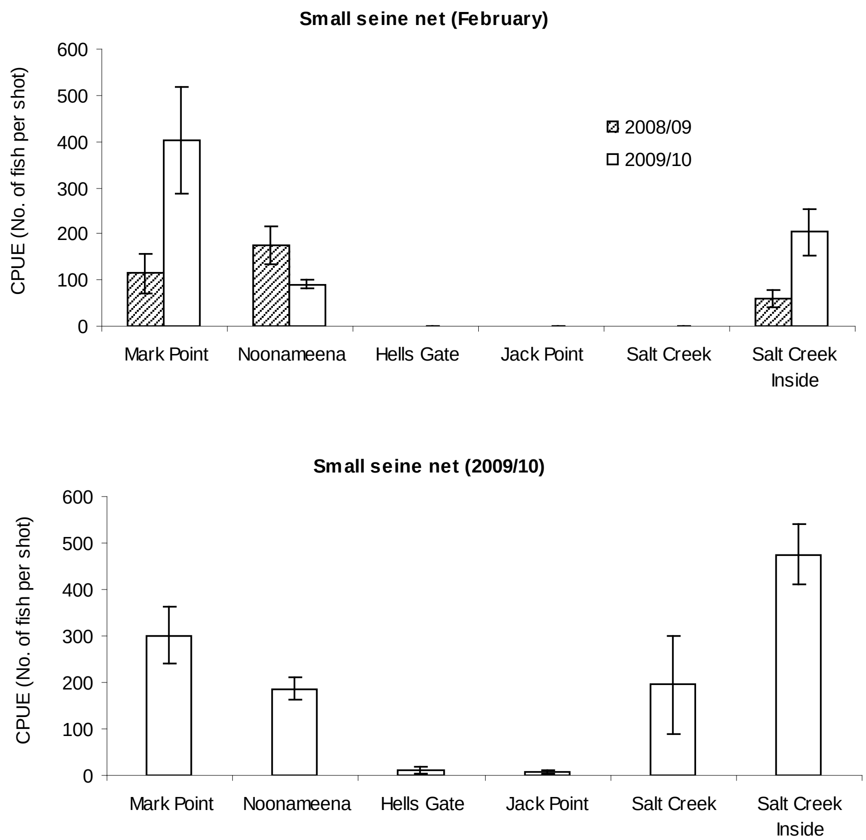

Figure 3.4. Relative abundances of new recruits of smallmouthed hardyhead ± 1 S.E., as indicated by fish caught using a small seine net (CPUE, number of fish per seine), at selected sites in the Coorong during 2008/09 and 2009/10.

3.5. Linkages to Environmental Conditions

3.5.1. Salinity

There was a general trend of increasing salinity from spring to summer except for the site within Salt Creek (i.e. Salt Creek Inside) which maintained a brackish condition throughout the sampling period (9-22 ppt). Salinities were similar between two years at the North Lagoon sites (i.e. Mark Point, Noonameena and Hells Gate). There was a considerable decline in salinity at the South Lagoon sites in 2009/10 (Figure 3.5), particularly at Salt Creek site in October and November 2009 probably due to the small flows of the creek into the lagoon during this period.

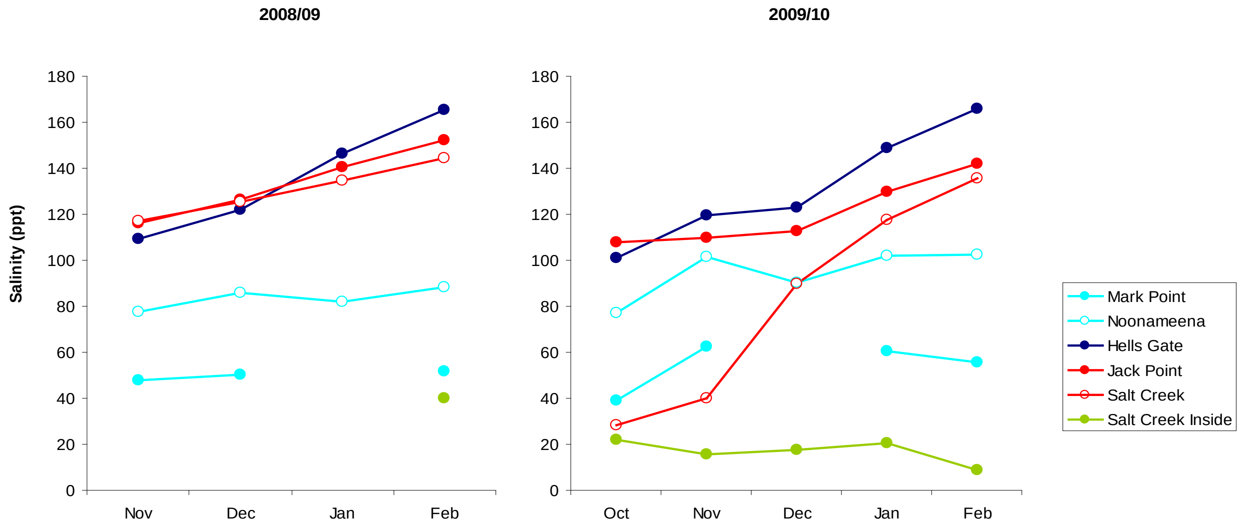

Figure 3.5. Monthly trends of salinity at sampling sites in the Coorong during 2008/09 and 2009/10.

There was a bell shaped distribution of relative abundance (or CPUE) of smallmouthed hardyhead across salinity levels in the Coorong during the sampling period in 2008/09 and 2009/10 (Figure 3.6). The greatest CPUE occurred between 80-100 ppt, nevertheless, fish were usually absent at salinities above 105 ppt.

There were negative relationships between salinity and smallmouthed hardyhead recruitment, except in 2008/09 which is likely due to the few sampling occasions. Regression analysis using the data during the peak recruitment period (from November to February) resulted in a significant ($p<0.001$) negative linear relationship between salinity and CPUE of new recruits, with a R^2 of 0.7108 (Figure 3.7).

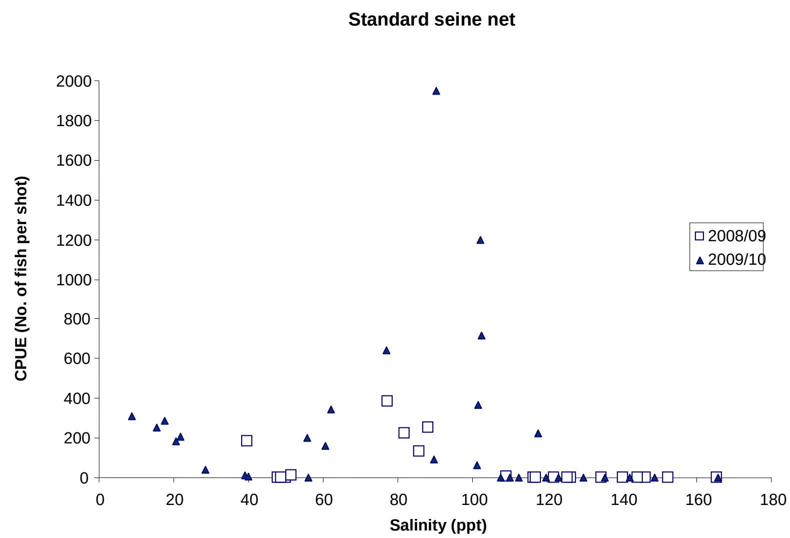

Figure 3.6. **CPUE of smallmouthed hardyhead collected using standard seine net plotted against salinity in the Coorong during 2008/09 and 2009/10.**

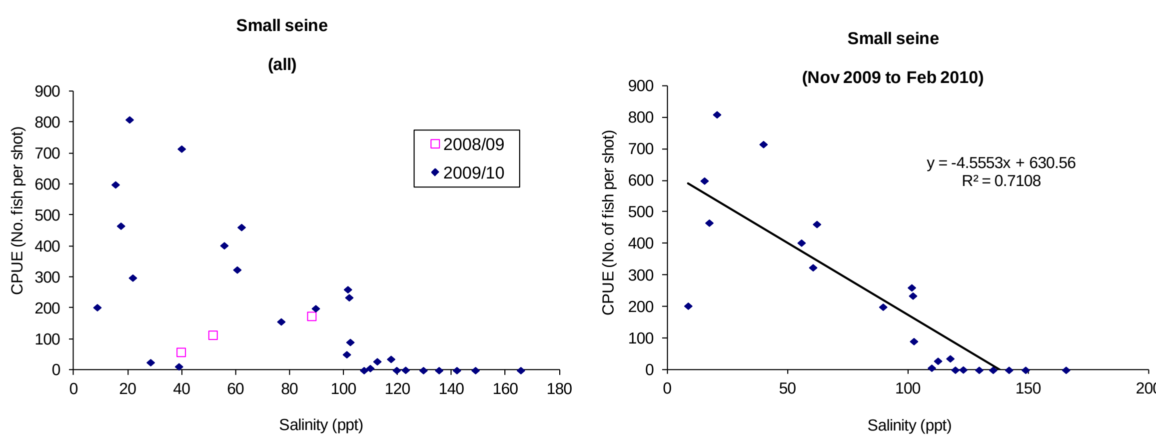

Figure 3.7. **Relationships between salinity and the CPUE of smallmouthed hardyhead new recruits collected using small seine net in the Coorong during 2008/09 and 2009/10.**

3.5.2. Macrophytes

Out of six sampling sites, the aquatic macrophytes *Ruppia spp*, were present only at Noonameena and Salt Creek Inside (Figure 3.8). All netting operations at Noonameena in 2008/09 and at Salt Creek Inside during both years occurred in areas with macrophytes. In 2009/10, the presence of macrophytes was recorded in 80% of seine netting and 75% of small netting operations at Noonameena.

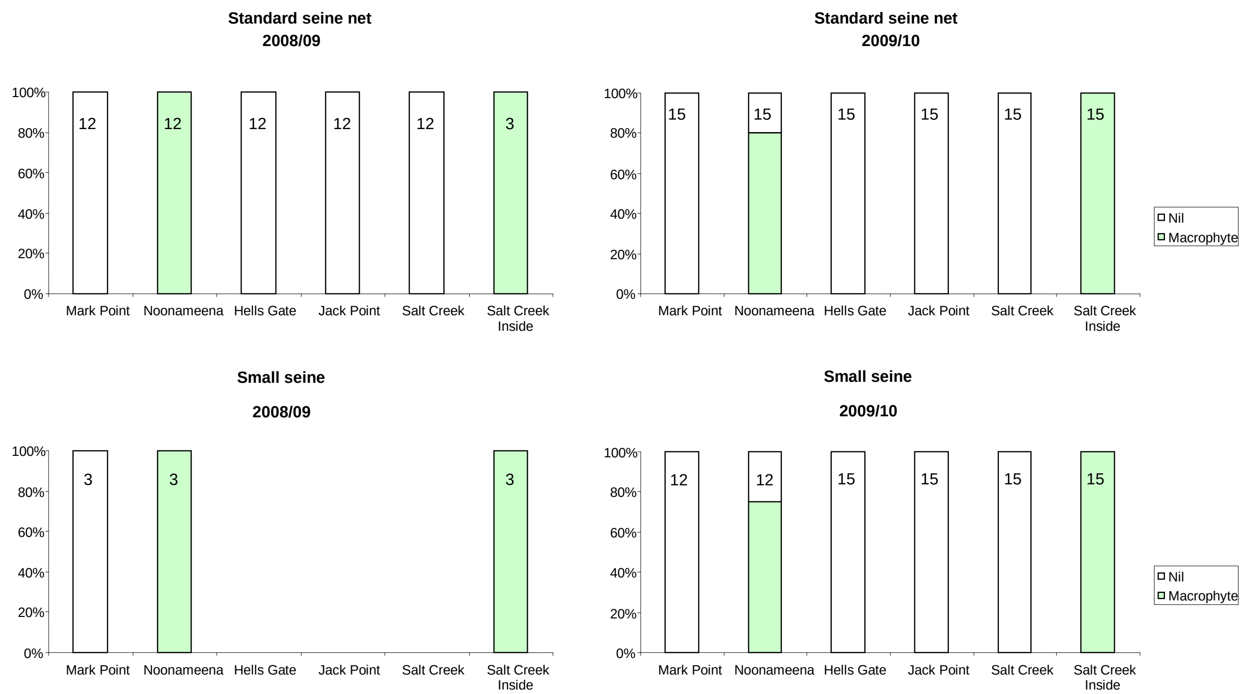

Figure 3.8. Percentage of sampling operations in an area with or without macrophytes during the 2008/09 and 2009/10 seasons. Numbers indicate total sampling operations at each site.

The overall abundance of smallmouthed hardyhead was much higher in areas with macrophytes; in both years (Figure 3.9). The abundance of new recruits in 2009/10 was also significantly greater in areas with macrophytes than without; whilst no difference was exhibited in 2008/09. Nevertheless, the sample size was very low for small seine netting in 2008/09 (only occurred in February 2009 at selected sites) thus the results should be treated with caution.

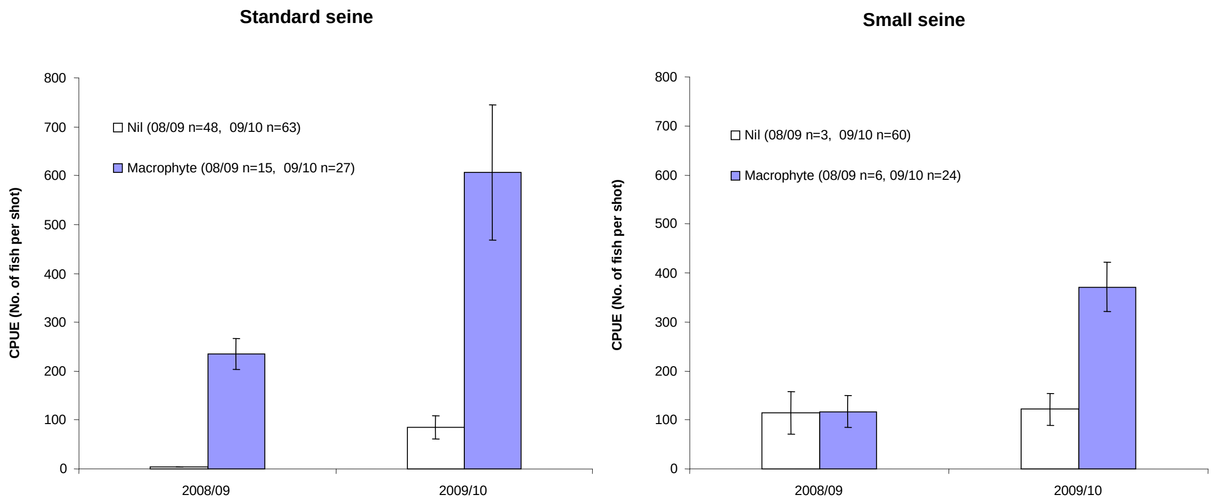

Figure 3.9. Comparisons of the relative abundances of smallmouthed hardyhead (CPUE by standard seine net and small seine net) between areas with and without macrophytes for 2008/09 and 2009/10.

4. DISCUSSION

4.1. Catch Summary

Between 2007 and 2010, there has been no freshwater release from the barrages to the Coorong. The North and South lagoons were generally in hypersaline conditions during 2008/09 and 2009/10. Species richness in 2008/09 was even less than that of the previous drought years (i.e. 2006-2008 n=13) when the ecological condition of the fish community was considered at a historical low point (Noell *et al.* 2009). In 2008/09 the species richness declined to a very low level (n=7) in the region, probably due to the hypersalination which would have increased osmoregulatory stress and/or diminished food resources, thus forcing certain fish taxa out of the area (Whitfield 1999). In 2009/10 the species richness recovered to 14, a similar level to that in 2006-2008, probably due to the freshening at the southern end of the South Lagoon (Figure 3.5) related to a small amount of freshwater inflow from Salt Creek (DFW 2010, Figure 3.10). The average daily discharge was 118 ML day^{-1} between mid October and end of December 2009 whilst there were no spring inflows in 2008/09. The increase in species richness must however be considered with caution as the total number of fish also increased.

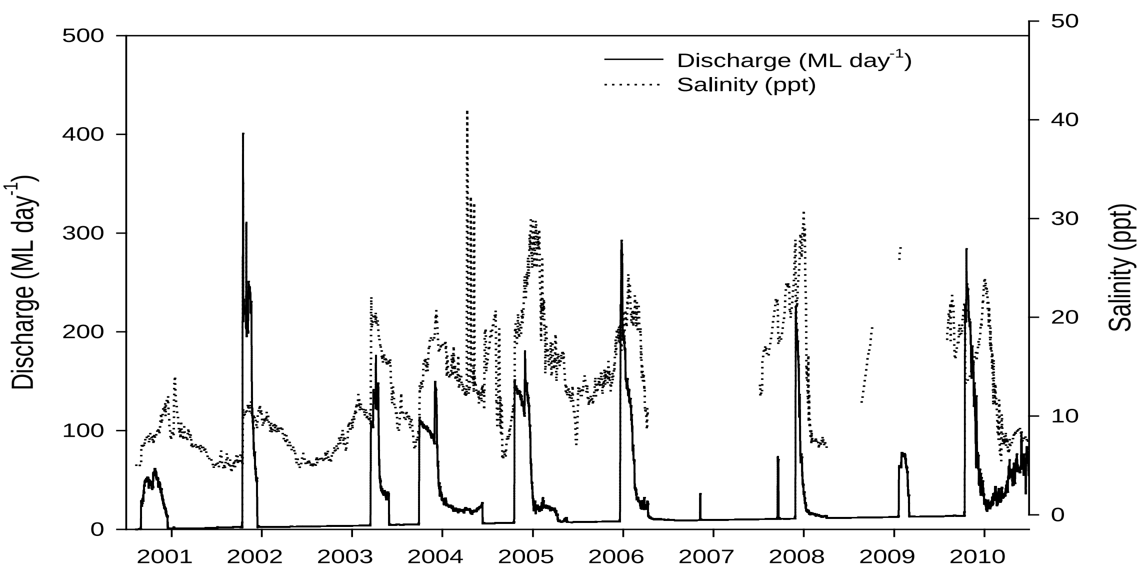

Figure 3.10. Daily flow discharge through the mouth of the Salt Creek with salinity levels (DFW 2010, Surface Water Archive, Station A2390568).

During the current investigation, smallmouthed hardyhead continued to be the dominant taxa in the Coorong, as in 2006-2008 (Noell *et al.* 2009). Small atherinids are particularly important species in fish assemblages of many temperate Australian estuaries (e.g. Potter *et al.* 1993; Potter & Hyndes 1994; Valesini *et al.* 1997; Griffiths & West 1999; Young & Potter 2002; Hoeksema & Potter 2006). Smallmouthed hardyhead commonly occur in shallow lagoons and brackish water lakes from the Tuggerah Lakes in NSW to the Coorong (Ivanstoff 1980). It is the most widely distributed fish species in the Coorong and plays a significant ecological role as a major food item for various piscivorous fish and water birds (Paton 1982; Rogers and Paton 2009; Deegan *et al.* 2010).

4.2. Smallmouthed Hardyhead

4.2.1. Abundance and distribution

Smallmouthed hardyhead is an euryhaline species with laboratory salinity tolerance of lower-upper LD_{50} ranging between 3.3-108 ppt (Lui 1969), and an even greater tolerance range in natural conditions (e.g. smallmouthed hardyhead were present in small numbers up to 133.5 ppt in the Coorong, Noell *et al.* 2009). Despite of its salinity tolerance, the extreme hypersaline conditions (>100 ppt) in recent years appears to have restricted the southerly distribution of this species in the Coorong. During 2008/09, fish were only collected in significant numbers at Noonameena, where salinities ranged between 77-88 ppt. There was hardly any fish sampled at Hells Gate, Jack Point and Salt Creek, where salinities were between 109-166 ppt throughout the sampling season (November to February). The pattern of distribution and abundance of smallmouthed hardyhead was similar to that found 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 throughout the protracted drought in the MDB. Conversely, during years with high freshwater inflows from the River Murray, salinities can range from fresh to brackish (5-30 ppt) in the North Lagoon and reduce to moderately hypersaline (55-70 ppt) in the South Lagoon (Geddes 1987).

During 2009/10, there was a significant increase in fish abundance at several sites in the North and South lagoons, compared to 2008/09. The catch rate was highest at Noonameena even though there was a slight increase in salinity to 77-103 ppt. Such hypersaline conditions may provide advantages to smallmouthed hardyhead by excluding potential predators and competitors 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 smallmouthed 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 in the South Lagoon (e.g. Salt Creek Site) was most likely attributed to the increased inflow from the Upper South East through Salt Creek (Figure 3.10), freshening the southern end of the Coorong thus restoring suitable habitats for smallmouthed hardyhead (Figure 3.5). In addition, the flow discharges may have facilitated the dispersion of the abundant fish from the Creek to the South Lagoon. Fish abundance in the brackish creek (i.e. Salt Creek Inside with salinities ranging 9-22 ppt) was only just below that at Noonameena during the 2009/10 season.

4.2.2. Size structure and recruitment

The spatial and temporal patterns of length-frequency distributions of smallmouthed hardyhead provide suitable indication of recruitment dynamics. It appears that early-spawned fish from a September-December spawning season (Molsher *et al.* 1994) start to appear in small seine net samples in October and in standard seine net samples in November. The presence of small juveniles throughout the spring/summer sampling season reflects a protracted spawning period of this species. The decline in the number of larger fish (e.g. at Noonameena in December/January 2008/09) was likely related to post-breeding mortality, due to the short life cycle of this species (mostly up to 1 year) (Molsher *et al.* 1994). In the current study, the maximum total lengths recorded were 83 mm in 2008/09 and 86 mm in 2009/10; these were similar to that found by Molsher *et al.* (1994) in the Coorong (i.e. 85 mm). The length data indicated that recruitment occured in both 2008/09 and 2009/10, although the cohort of the later year was stronger.

In 2008/09, size frequencies suggest that fish recruitment was spatially restricted to the northern part of the North Lagoon and within the freshwater creek (i.e. Salt Creek Inside with a salinity level of 40 ppt). The constant high salinities (>109 ppt) during the reproductive season was likely to be a limiting factor for 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 determined tolerances (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 within a lower salinity range (32-74 ppt), it was suggested that salinity may affect their population ecology by limiting their food resources (Molsher *et al.* 1994).

In 2009/10, inflows from the South East of South Australia significantly reduced the salinity in the southern end of the South Lagoon (i.e. Salt Creek). Restoration of suitable physical-chemical environment and habitats probably led to the enhanced recruitment of smallmouthed hardyhead at a local scale. The "freshening" effect may have extended northward to mid of the South Lagoon (i.e. Jack Point), where a small salinity decline was observed and new recruits were collected in November and December 2009. However, such effects appear to be short-lived. With the decline of flow input from the Upper South East of South Australia in the summer (Figure 3.10) and increase in evaporation rate, there was a steep rise in salinity at the southern end of the South Lagoon, from 29 ppt in October 2009 to 135 ppt in February 2010 (Figure 3.5). The smallmouthed hardyhead population seemed to have contracted southward toward Salt Creek, and essentially disappeared from the South Lagoon by February 2010.

The small seine net used in the current study was an effective gear type for quantitative assessment of new recruit abundance and the CPUE provided a suitable recruit index for smallmouthed hardyhead. The baseline data established in 2009/10 indicates that the fresh-brackish creek (i.e. Salt Creek Inside) is a strong hold for smallmouthed hardyhead recruitment. This system potentially provides a source population for the South Lagoon when environmental conditions become favorable. In contrast, recruitment success in the North Lagoon is no doubt important, and appears to play a key role in sustaining the core smallmouthed hardyhead population in the Coorong.

4.2.3. Linkages to environmental conditions

Salinity is one of the key driving factors in the ecological health of the Coorong (Geddes and Butler 1984; Geddes 1987, 2003, 2005; Brookes *et al.* 2009). Recent studies have demonstrated its significant effects in fish assemblage composition, abundance and distribution (Noell *et al.* 2009) as well as the food web structure in the Coorong (Deegan *et al.* 2010). A general decline in fish species diversity along the salinity gradient was observed in the current monitoring study. This was probably a response to the greater osmoregulatory stress and diminishing food resources with increasing salinity. This situation provided an opportunity for highly salt-tolerant species to extend their ecological niche (Colburn 1988), including smallmouthed hardyhead. During the current monitoring study, the highest salinity where smallmouthed hardyhead were collected was 123 ppt, which was lower than the recent record of 133.5 ppt by Noell *et al.* (2009). Despite smallmouthed hardyhead being among the most salt-tolerant fish species in the world (Molsher *et al.* 1994), its distribution range in the Coorong has clearly been limited by the extreme hypersaline conditions in recent years. For example, almost no fish were sampled in the southern part of the North Lagoon and in the South Lagoon during 2008/09. At this stage, the ecosystem was under severe stress with continuing degradation, which lead to the proposed 'South Lagoon Pumping Scheme', as an urgent management response to mitigate the extensive adverse impacts of current hypersalinity in the region (DENR 2010).

Although salinity is a limiting factor that restricts fish distribution, no simple equation (e.g. linear relationship) could be developed between salinity and smallmouthed hardyhead abundance. The relationship may have been confounded by the complex inter-species interaction (i.e. competition, predation). The bell shape relationship is likely attributed to the euryhaline nature of smallmouthed hardyheads, allowing them to explore suitable niche in hypersaline areas where potential predation and competition decreases. This at least partially explains the dominance of smallmouthed hardyhead in the North Lagoon, particularly near Noonameena where salinities ranged between 77-103 ppt in the last two years.

On the other hand, similar to Noell *et al.* (2009) findings, our study indicated that salinity was a limiting factor for the recruitment of smallmouthed hardyhead. A previous study suggested that seasonal reduction of salinity by freshwater influence might act as a partial cue to spawning in this species (Molsher *et al.* 1994). In addition, freshwater inflows are an important source of nutrients and organic matter to the Coorong and benefit the food webs (Brookes *et al.* 2009). This may affect fish recruitment, for example if breeding seasons coincide with seasonal peaks in food availability. In the Coorong, smallmouthed hardyhead feed mainly on zooplankton, which are most abundant during winter and spring, when salinities are relatively low (Geddes 1987). Freshwater releases from the Murray barrages lead to increases in zooplankton abundance in the Murray Estuary and Coorong (Geddes 2005), which would enhance the survival and growth of larvae and young fish, therefore benefiting recruitment (Whitfield 1994; Gillanders and Kingsford 2002).

Aquatic macrophytes are fundamentally important to the ecology of the Coorong. They form complex habitats and productivity base for invertebrates, fish and water birds (Geddes 2005). The current study found significantly greater abundances of adults and new recruits of smallmouthed hardyhead in areas associated with macrophytes. During fish sampling, *Ruppia polycarpa* was observed as an extremely dense submergent aquatic vegetation within the freshwater creek (i.e. Salt Creek Inside) in both years, and macrophyte beds (i.e. *Ruppia tuberosa*) were also present at Noonameena on most occasions. Macrophytes not only provide physical structure (i.e. shelter) for small fish (e.g. smallmouthed hardyhead) but also benefit food webs by enhancing the diversity and abundance of food resources (Deegan *et al.* 2010). The positive effect of aquatic plants on smallmouthed hardyhead recruitment may also be through their direct influence on reproduction. An earlier study in the Coorong suggested that their reproductive capacity (i.e. batch fecundity and gonadosomatic indices) might have been compromised when the growth and performance of *Ruppia tuberosa* was reduced (Molsher *et al.* 1994). In addition, smallmouthed hardyhead produce large adhesive eggs (1.6-2.5 mm in diameter, Appendix

I), which could possibly attach to macrophytes and use them as supporting structures, thus improving survival and hatch rates.

In recent years three aquatic macrophyte species, *Ruppia megacarpa*, *Lepilaena cylindricarpa* and *Zostera muelleri*, which formerly proliferated in the Murray Estuary and North Lagoon of the Coorong (Geddes 1987), have been lost from the system (Nicol 2007). This was probably due to the protracted periods of increased salinity caused by reduced freshwater inflows from the Murray barrages. *Ruppia tuberosa*, a more salt-tolerant species that previously dominated the South Lagoon, has disappeared from it and has started to colonise part of the North Lagoon (Roger and Paton 2009). These changes would have a profound impact on the ecosystem and its constituent biota, including fish populations. Restoration of freshwater inflows is crucial for the recovery of ecological health of the Coorong. Even for the most salt-tolerant species, such as smallmouthed hardyhead, freshwater input plays an important role in its population ecology, particularly through maintaining suitable salinities and habitat quality (i.e. macrophytes and food resources) and potentially as a partial trigger of spawning. The current study also indicates that small volumes of discharge (fresh or brackish water) from Salt Creek (e.g. ~100 ML day^{-1}) could result in a significant biological response, promoting species diversity and enhancing abundance and recruitment of smallmouthed hardyhead in the southern part of the South Lagoon. In fact, the fresh/brackish water body within Salt Creek probably serves as a recruitment refuge for smallmouthed hardyhead, importantly when the South Lagoon becomes extremely hypersaline. This provides a source of population, in addition to that from the northern Coorong, to recolonise the southern Coorong once favourable conditions return. Ensuring the long-term sustainability of smallmouthed hardyhead, a keystone species, has significant implications for maintaining the ecological integrity of the Coorong.

5. CONCLUSIONS

Condition monitoring of the smallmouthed hardyhead population in the North and South lagoons of the Coorong for the first two years (i.e. 2008/09 and 2009/10) indicates 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 in 2009/10, but not in 2008/09. Although these surveys were undertaken after an extended drought period (2001/02-2009/10) with a lack of barrage freshwater releases and considerable increases in salinity throughout the Coorong, smallmouthed hardyhead were found to persist and recruit successfully in the North Lagoon in both years, with salinities levels ranging between 39-103 ppt. Nevertheless, the extremely hypersaline conditions (salinity up to 166 ppt) appeared to have restricted its southerly distribution. In 2008/09, almost no fish were collected in the South Lagoon, even though considerable numbers of smallmouthed hardyhead existed in the adjacent Creek connecting to the southern end of the Coorong. In 2009/10, small volumes of inflows (~100 ML day^{-1}) from Salt Creek during spring (October-December) considerably lowered the salinity in the southern part of the South Lagoon, and a significant biological response occurred at a local scale, with large numbers of smallmouthed hardyhead recolonising the region likely from the source population within the Creek. With reduced salinity and profuse aquatic macrophytes, Salt Creek Inside probably serves as a recruitment refuge for smallmouthed hardyhead, being particularly significant for the recovery of the South Lagoon population. The overall abundance of smallmouthed hardyhead increased in 2009/10 and the new cohort produced was stronger than in 2008/09. Such responses provide insight into the population recovery when favorable conditions (i.e. salinity) are restored and show the resilience of smallmouthed hardyhead population in the Coorong. However, there is no doubt that extended droughts or low flow periods can increase stress on populations of aquatic species and lead to decreased ability to recover post drought (Bond *et al.* 2008). In this regard, freshwater inflows from the Murray barrages, and to a lesser extent small inputs from Salt Creek, are paramount in conferring resilience to smallmouthed hardyhead population and ensuring their long-term sustainability in the Coorong.

The first two years of condition monitoring in the Coorong have provided valuable information on the ecology of smallmouthed hardyhead and established a baseline by which future quantitative assessment can be made. It is important to continue to monitor the population status and biological performance of this keystone species, and the current flow event provides a unique opportunity to investigate its recovery and the responses of estuarine-lagoonal fish assemblages after a long period of drought.

Additional ecological investigations should be undertaken to improve our understanding of the environmental requirements (i.e. salinity and flow regimes, habitats and food resources) to improve recruitment success and population resilience of smallmouthed hardyhead and other key species in the Coorong. Information developed will contribute to the knowledge base for the adaptive management to ensure the ecological sustainability of the CLLMM region.

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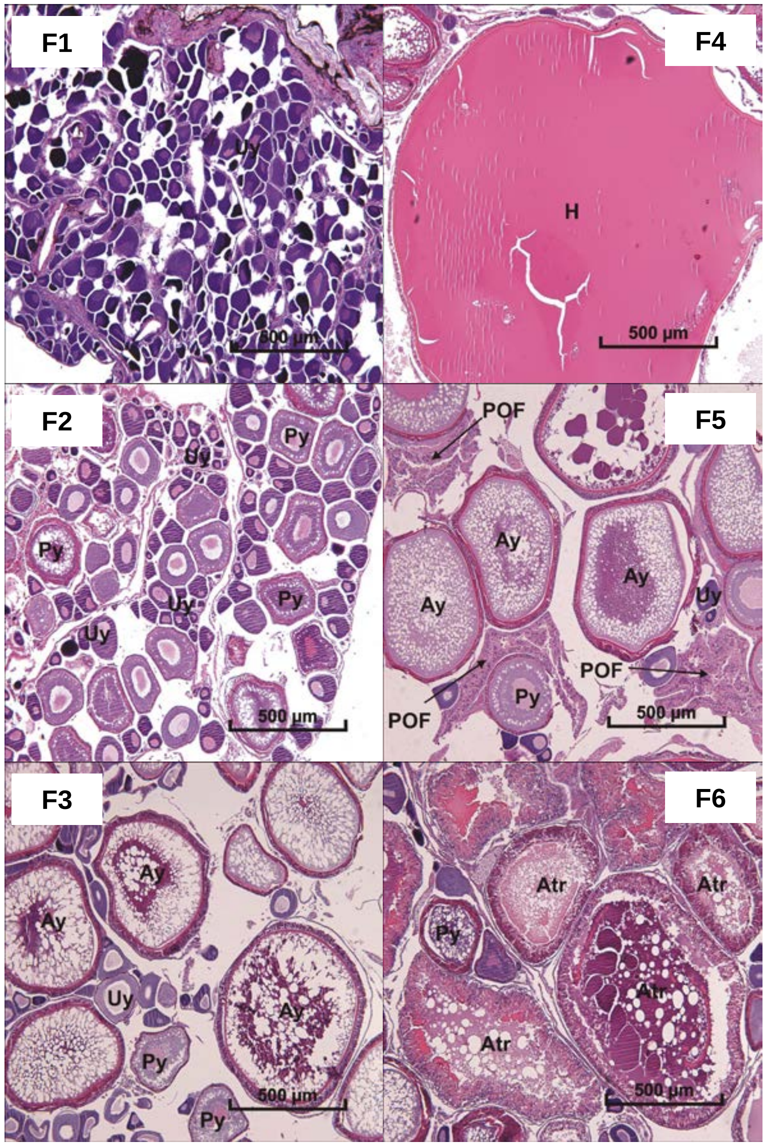
APPENDIX



Appendix 1. Female gonad histology for different developmental stages (F1-F6) of smallmouthed hardyhead from the Coorong. Oocyte descriptions: Uy – unyolked, Py- partially yorked, Ay – advanced yorked, H – hydrated, POF – post ovulated follicle, Atr – artresia.