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Coorong fish intervention monitoring during barrage releases in 2010/11

Dr Qifeng Ye, Luciana Bucater and David Short

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EXECUTIVE SUMMARY

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region is recognised as a wetland of international importance under the Ramsar Convention, and is also considered an 'icon site' under the Murray-Darling Basin (MDB) Authority's Living Murray program. Over the last decade, the Coorong ecosystem has become increasingly degraded due to protracted drought in the MDB, subsequent lack of freshwater inflows, considerable increases in salinity and lack of connectivity between freshwater and estuarine/marine habitats. Many native fish species that reside in the Coorong Estuary and depend upon its habitat as a breeding, nursery and feeding grounds have been negatively impacted. Increased flows in the River Murray in 2010/11, however, have resulted in the first barrage releases into the Coorong since 2007, providing a unique opportunity to investigate ecological responses and short-term recovery after a long period of drought. Intervention monitoring was conducted in the Murray Estuary, Northern Lagoon and Southern Lagoon to investigate changes in fish assemblage structure and distribution, abundance and recruitment of key species in comparison to baseline data collected during a drought year (2006/07).

Following the barrage releases in 2010/11, salinities fell significantly from previously ranging between marine and extremely hypersaline (up to 168‰) to the current levels of 1-5‰ in the Estuary, 8-76‰ in the Northern Lagoon, and 54-98‰ in the Southern Lagoon. Broadly decreased salinities, coupled with other freshwater induced environment changes, have elicited significant ecological responses in fish assemblages in the region. The fish assemblage composition changed significantly compared to that of the drought years, mainly attributed to an increase in the diversity and abundance of freshwater species, and increased abundances of small-bodied estuarine/opportunist species (smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (congolli) following enhanced recruitment. The freshening of the Coorong also resulted in a southward range expansion of some key species, such as black bream (adult), and potentially yelloweye mullet, congolli and greenback flounder. For the later three species, comparisons and definitive conclusions cannot be made because the most southerly site where they were present in the Northern Lagoon in 2010/11 was not sampled in 2006/07. Length frequency distributions indicated successful recruitment for most of the key species (i.e. smallmouthed hardyhead, Tamar goby, yellow-eye mullet, sandy sprat, congolli and greenback flounder), and many new recruits occurred in the Northern Lagoon, where they were formerly absent or less abundant. The dramatic increase in smallmouthed hardyhead abundance in the Southern Lagoon following salinity

reductions (to <100‰) is of particular ecological significance, given the important role of this keystone species in the trophic ecology of the region.

Freshwater inflows play an important role in structuring fish assemblages in the Murray Estuary and Coorong, maintaining estuarine habitats and facilitating the recruitment of estuarine and catadromous species. Current intervention monitoring for barrage releases indicated some signs of early ecological recovery, particularly in respect to the responses of small-bodied estuarine fish and catadromous congolli, following years of no/low freshwater inflows into the Coorong region. The results support the hypotheses regarding the recovery of estuarine fish assemblages, enhanced recruitment and a southward range expansion for some species. However, it is uncertain how/whether some commercially important large-bodied estuarine dependent species (e.g. black bream and mulloway) would benefit from the current and potentially future freshwater inflows to the Coorong. Further monitoring will be required in subsequent years to continue to investigate the response and recovery of estuarine fish assemblages and assess the recruitment response of key large-bodied estuarine species to flow events. Data collected in this and future studies will form an important basis for environmental water allocation and adaptive management to ensure the long-term ecological sustainability of 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, 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). The region is classified as an 'icon site' under the Murray-Darling Basin Authority's Living Murray 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) modified estuarine lagoon system with a strong north-south salinity gradient, generally ranging from brackish/marine in the Murray Mouth area to hypersaline in the North and Southern Lagoons (Geddes and Bulter 1984; Geddes 1987). Nonetheless, salinities are spatiotemporally variable and highly dependent on the freshwater inflows from the River Murray, with varied salinities supporting different ecological communities (Brookes *et al.* 2009). In addition, the southern end of the Southern 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 1930s 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, this situation has been exacerbated by 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 a dredging operation to maintain its opening since 2002 (DWLBC 2008). The Coorong was transformed into a marine/hypersaline environment, and extreme hypersaline conditions in the Southern Lagoon caused severe and continuing degradation of critical habitats for nationally listed bird species, and compromised 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 reside in the Coorong estuary and depended on its habitat for breeding, nursery and feeding grounds have been negatively impacted (Noell *et al.* 2009), and recruitment of catadromous fish failed due to lack of connectivity between freshwater and estuarine/sea (Zampatti *et al.* 2010).

In winter 2010, flows in the River Murray increased significantly. Larger than expected flows into Lake Alexandrina resulted in the first barrage releases into the Coorong since 2007. This provided a unique opportunity to investigate immediate ecological responses and whether/how the ecosystem recovers in the short term when freshwater is restored into the Coorong after a long period of drought.

1.2. Objectives

The objective of this project was to conduct intervention monitoring of fish assemblages in the Murray Estuary and Coorong following the barrage releases. Key questions and hypotheses included,

1. Was the current barrage release volume large enough to elicit a significant ecological response regarding the recovery of estuarine fish assemblages following years of no barrage releases into the Murray Estuary and Coorong? **(Recovery of estuarine fish assemblages)**
2. Was the barrage release enhancing the recruitment of selected fish species of significant ecological, conservation and/or commercial values (i.e. black bream, greenback flounder, smallmouthed hardyhead, Tamar goby, yellow-eye mullet, sandy sprat, congolli and mulloway)? **(Recruitment response)**
3. With salinity reductions occurring in the Northern Lagoon, would estuarine fish recolonise and recruit in this part of the Coorong? **(Spatial scale of the ecological benefit)**
    - We hypothesised that the freshening of the Murray Estuary and Coorong would result in an increase in species diversity and abundance and a greater southward distributional range of some species throughout the region.
    - With salinity reductions in the Northern Lagoon, recruitment of some estuarine species would be detected in this area.

2. METHODS

2.1. Field Sampling

Fish sampling was conducted at thirteen sites in the Murray Mouth and Coorong region during four sampling occasions in November 2010, December 2010, February 2011 and March 2011. Five sites were located near (within 15 km) the Murray Mouth, five in the Northern Lagoon, and three in the Southern Lagoon (Table 1 and Figure 1). Each site was sampled during the day with a seine net, (length = 61 m, wing length = 29 m (22 mm mesh), 3 m bund (8 mm mesh). *n* = 3 hauls), with four of these sites (two in the Estuary and two in the Northern Lagoon) also sampled overnight using sinking composite gill nets (9 m panels: 38, 50, 75, 115 and 155 mm stretched mesh. *n* = 3). Southern Lagoon sites were not sampled using gill net, due to the likely absence of large-bodied fish species. The seine net was deployed in a semi-circle, which sampled to a maximum depth of 2.0 m and swept an area of ~592 m^2. Gill nets were set in the afternoon or night (at 1500-2000 hours), and retrieved the next day 11-19 hours later. The gill nets had a drop of 2 m and were generally set in water depths less than 2 m and so often sampled the entire water column.

All fish collected using seine and gill nets were identified to species and the total number of individuals of each species recorded. For the key species (i.e. black bream, greenback flounder, smallmouthed hardyhead, Tamar goby, yellow-eye mullet, congolli, mulloway and sandy sprat) total length measurements were taken to the nearest 1 mm for up to 50 individuals per species per sampling gear type. Sub-samples of each key species were collected for future otolith microstructure analysis (ageing).

On each sampling occasion, a series of physio-chemical parameters (i.e. water temperature, salinity, dissolved oxygen and pH were measured at 30 cm beneath the water surface using a TPS water quality meter (model 90FL)) and a measure of transparency was obtained from a Secchi disk depth measurement.

Table 1. Fish sampling sites and methods for barrage release intervention monitoring in the Coorong during 2010/11.

Site	Latitude (°S)	Longitude(°E)	Distance from mouth (km)	Sampling gear
Murray Mouth (MM)				
Beacon 19 (M1)	35.534	138.832	6.5	Seine and gill nets
Boundary Ck Lower (M2)	35.564	138.923	3.5	Seine net only
Boundary Ck Structure (M3)	35.556	138.934	5.7	Seine and gill nets
Godfrey's Landing (M4)	35.568	138.932	4.4	Seine net only
Pelican Point (M5)	35.595	139.014	12.8	Seine net only
Northern Lagoon (NL)				
Mark Point (N1)	35.638	139.076	20.3	Seine and gill nets
Long Point (N2)	35.693	139.166	31.5	Seine net only
Noonameena (N3)	35.757	139.232	40.2	Seine and gill nets
Mt Anderson (N4)	35.811	139.293	48.1	Seine net only
Hells Gate (N5)	35.903	139.398	62.9	Seine net only
Southern Lagoon (SL)				
Villa dei Yumpa (S1)	35.914	139.463	70.2	Seine net only
Jack Point (S2)	36.042	139.576	85.8	Seine net only
Salt Creek (S3)	36.132	139.638	98.4	Seine net only

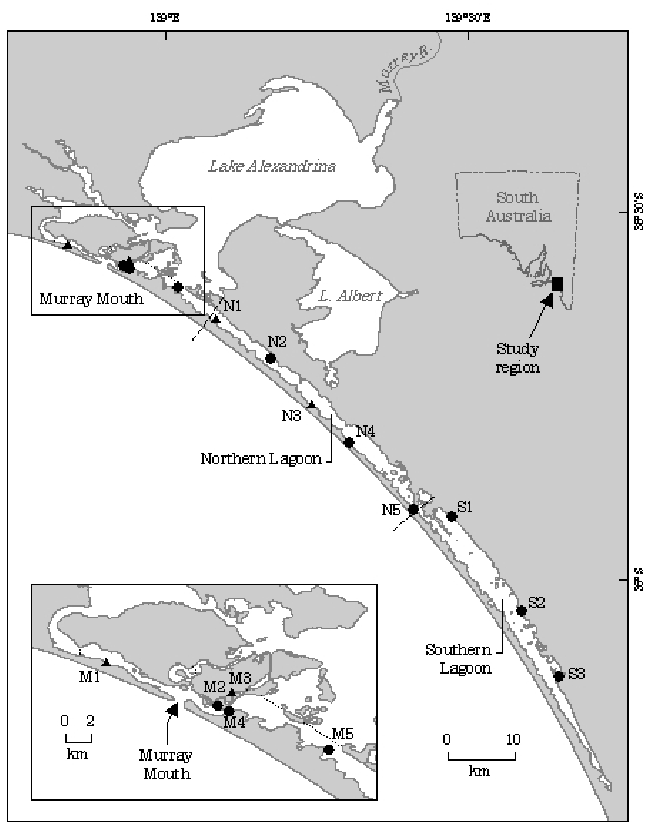

Figure 1. Fish sampling sites for barrage release intervention monitoring in the Coorong. ▲both seine and gill netting ● seine netting only. Dotted lines representing barrages and dashed lines approximated boundaries between subregions.

2.2. Life-cycle designations

Each species was categorised as marine straggler (S), marine estuarine opportunist (O), solely estuarine (E), estuarine and marine (E&M), catadromous (C) or freshwater (native (FN) and exotic (FE)), using similar criteria of Potter and Hyndes (1999) after Noell *et al.* (2009). Marine straggler refers to those species that only occasionally occur in estuaries, whereas marine estuarine opportunist species enter estuaries regularly, often in large numbers. Solely estuarine refers to those species that complete their life cycle in estuaries, whereas the 'estuarine and marine' species group is represented by discrete estuarine and marine populations. Catadromous species are those species that spend much of their life cycle in fresh water, but migrate downstream to spawn in estuaries or the sea, while freshwater species are those whose life cycle is typically restricted to fresh water. The various species were allocated to one of the above life-cycle categories on the basis of extensive studies on the biology of fish species in south-western Australian estuaries (see Potter and Hyndes 1999), along with knowledge of the biology of species that occur in the Coorong.

2.3. Multivariate Analysis

Fish assemblage data collected during the barrage releases in 2010/11 was compared with those collected during a drought period in 2006/07 (Noell *et al.* 2009). All multivariate analyses were performed using the PRIMER v6 package (Clarke and Warwick 2001). Note that, the current data (November 2010, December 2010, February 2011 and March 2011) was compared against samples collected during November 2006, December 2006 and March 2007.

For each gear type used, the relative abundances of fish (i.e. number of fish per seine or gill net) at each site on each sampling occasion were ordinated using non-metric multidimensional scaling (MDS). Prior to ordination, the relative abundance of fish in seine net and gill net samples were log and square-root transformed, respectively, to downweight excessive influence of high-abundance species, a dummy species was added to adjust for blank samples, and the Bray-Curtis similarity measure used to construct the association matrix. Permutational analysis of variance (PERMANOVA: Anderson 2001) was used to test whether the species abundance data differed between subregions and years; where significant interactions occurred, pairwise analyses were also performed.

Principal coordinates (PCO) analysis for the ordination of samples in multivariate space was performed with vector overlays to indicate species that are correlated (Spearman rank correlation, $\rho > 0.5$) with the ordination axes. For significantly different assemblages, one-way similarity percentages (SIMPER) analysis was used to determine which species contributed most to any dissimilarities between groups (Clarke and Warwick 2001).

Unlike species abundance data, no data transformation was necessary for any of the water quality variables, as indicated from a draftsman plot. Multivariate species data was used to model the relationship(s) between assemblage structure, as described by the Bray-Curtis resemblance matrix, and one or more water quality predictor variables using the DistLM (distance-based linear models) routine and the model-building criteria of forward R^2 (Akaike 1973; Burnham and Anderson 2002). Note that it was not necessary to normalise the environmental data prior to running DistLM, because normalisation is done automatically as part of the matrix algebra of regression in this routine (Anderson *et al.* 2008). Ordination of fitted values for the DistLM was achieved through distance-based redundancy analysis (dbRDA), with vector overlays to show individual water quality variables that are important in driving variation along dbRDA axes.

3. RESULTS

3.1. Barrage outflow

In winter 2010, flows in the River Murray has increased significantly and by August/September the water levels in the Lower Lakes and Coorong lagoon had risen substantially resulting in the first freshwater barrage releases into the Coorong since 2007. Barrage discharge steadily increased from September to December 2010, when it had a sharp increase, peaking in January 2011, at approximately 125 GL day^{-1}. The discharge declined in late January/early February and then rose again and remained stable at around 80 GL day^{-1} since late February Figure 2). At the time of the reporting there was no data available for water inflow to the Coorong, therefore number of logs/gates was used, which is correlated to the inflow.

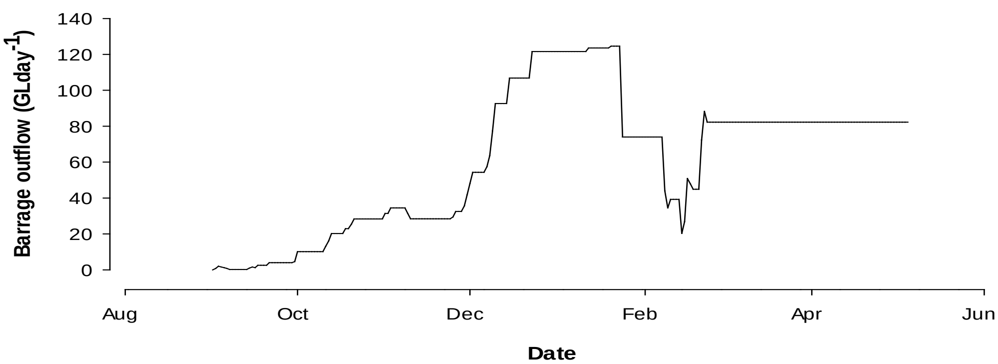

Figure 2. Barrage outflow estimated using number of logs/gates opened in 2010/11. Data sourced from SA water.

3.2. Water Quality

Water quality parameters, i.e. temperature, salinity, dissolved oxygen (DO), pH and turbidity (Secchi disk depth) recorded during the intervention monitoring (November and December 2010 and February and March 2011) were presented and compared with previous records in 2006-2008 (Noell *et al.* 2009) during no/minimum flow periods in the Coorong (Figure 3). There was a remarkable reduction in salinities at all sampling sites during the barrage releases, while the north to south increasing salinity gradient remained in the Coorong. With the River Murray inflows in 2010/11, an increase of turbidity and DO were observed in the Estuary subregion compared to those in previous drought years. There was also an increase in pH across the Coorong region.

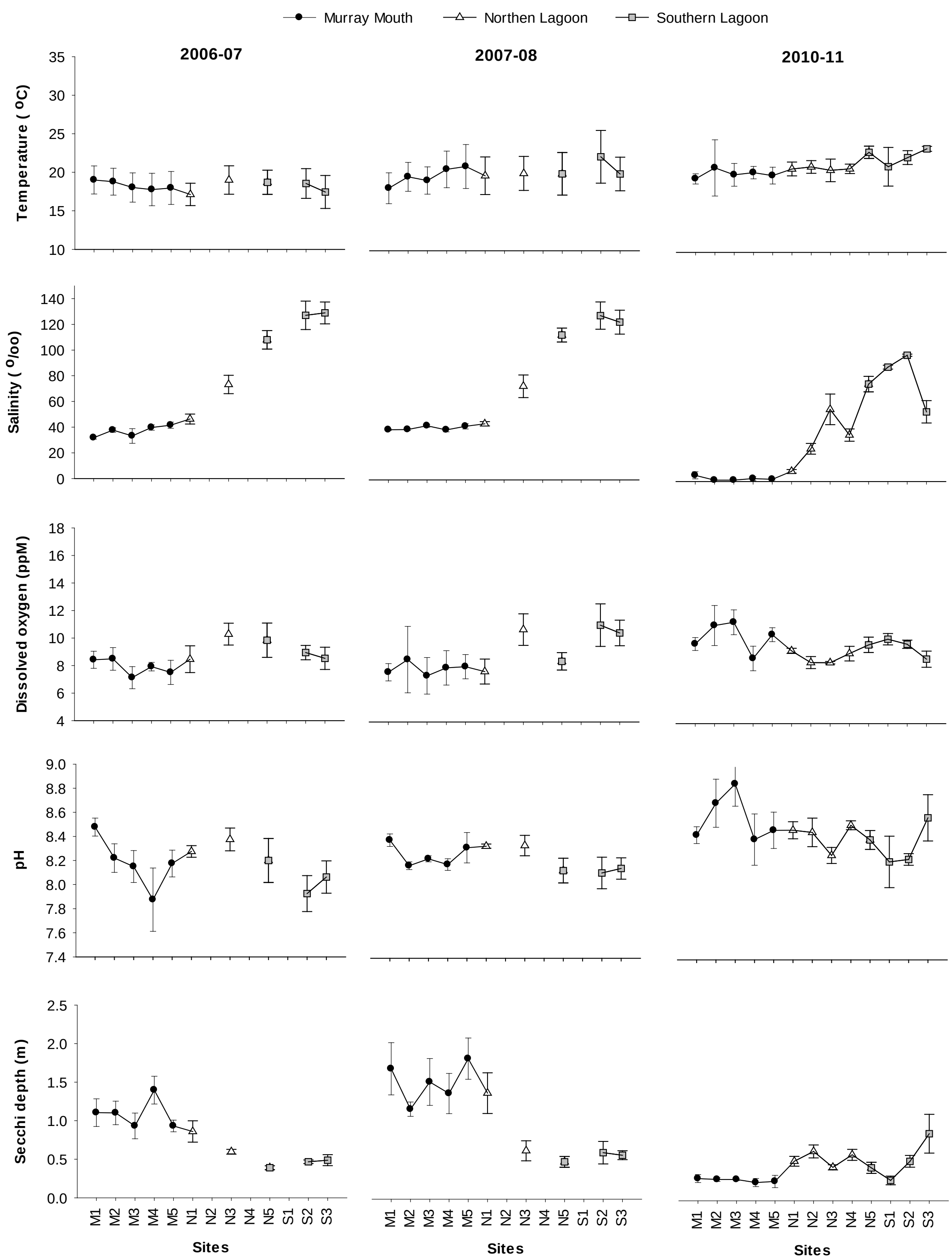

Figure 3. Mean values ± 1 S.E. for water temperature, salinity, dissolved oxygen, pH and Secchi depth for each sampling site (sampling occasions pooled) within the Murray Mouth and Coorong region during 2006/07, 2007/08 and November/December 2010 and February/March 2011 (2006/07 and 2007/08 data sourced from Noell *et al.* 2009).

3.3. Catch summary, species richness and abundance

A total of 80,448 fish representing twenty-four species were sampled using seine net in the Murray Estuary and Coorong during the intervention monitoring (Table 2). These species ranged from freshwater (native and exotic), catadroumous, solely estuarine, estuarine and marine to marine estuarine opportunist. The most abundant fish species collected were smallmouthed hardyhead, sandy sprat, bony herring, redfin perch and Australian smelt, numerically accounting for almost 95% of the catch. Species richness was slightly higher in the Estuary (23) than that in the Northern Lagoon (21), whilst only a single species was caught in the Southern Lagoon (i.e. smallmouthed hardyhead). Total fish abundance, on the other hand, was higher in the Northern Lagoon (45% of the total catch) than in the Estuary (36%) and Southern Lagoon (19%) (Table 2 and Figure 4). There was an increase in species richness and abundance at most of the sites in the current year compared to those in the drought year.

Table 2. Species and number of fish sampled using the standard seine net during the November and December 2010 and February and March 2011 field trips for the barrage release intervention monitoring in the Coorong. MM=Murray Mouth, NL = Northern Lagoon and SL = Southern Lagoon.

			Region			
Common Name	**Scientific Name**	**Classification**	**MM**	**NL**	**SL**	**Total**
Common galaxias	*Galaxias maculatus*	C	48	1		49
Congolli	*Pseudaphritis urvilli*	C	101	45		146
Tamar goby	*Afurcagobius tamarensis*	E	941	26		967
Smallmouthed hardyhead	*Atherinosoma microstoma*	E	1,488	33,819	15,636	50,943
River garfish	*Hyporhamphus regularis*	E	90	37		127
Bluespot goby	*Pseudogobius olorum*	E	12	2		14
Scary's Tasman goby	*Tasmanogobius lasti*	E	68	60		128
Bridled goby	*Arenigobius bifrenatus*	E&M	307			307
Prickly toadfish	*Contusus brevicaudus*	E&M	1	3		4
Goldspot mullet	*Liza argentea*	E&M	4			4
Greenback flounder	*Rhombosolea tapirina*	E&M	242	59		301
Goldfish	*Carassius auratus*	FE	1			1
Carp	*Cyprinus carpio*	FE	262	3		265
Redfin perch	*Perca fluviatilis*	FE	2,900	253		3,153
Golden perch	*Macquaria ambigua*	FN	19	2		21
Bony herring	*Nematolosa erebi*	FN	4,267	818		5,085
Flat-headed gudgeon	*Philypnodon grandiceps*	FN	844	16		860
Australian smelt	*Retropinna semoni*	FN	1,148	330		1,478
Yelloweye mullet	*Aldrichetta forsteri*	O	484	185		669
Longsnout flounder	*Ammotretis rostratus*	O	78	5		83
Southern longfin goby	*Favonigobius lateralis*	O	81	2		83
Soldier	*Gymnapistes marmoratus*	O	1	6		7
Sandy sprat	*Hyperlophus vittatus*	O	15,506	246		15,752
Sea mullet	*Mugil cephalus*	O		1		1
Total			**28,893**	**35,919**	**15,636**	**80,448**
% catch			**36**	**45**	**19**	

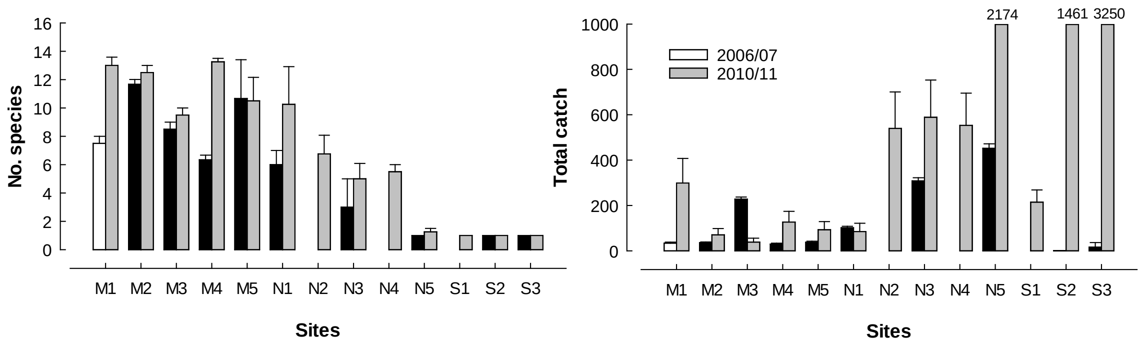

Figure 4. Mean number of species (left) and density of fish ± 1 S.E.(right) derived from seine net samples collected in the Estuary and Northern Lagoon of the Coorong in 2006/07 and 2010/11.

A total of 5,414 fish representing fourteen medium-large bodied species were sampled using gill nets in the Murray Estuary and Northern Lagoon (Table 3). These species ranged from freshwater (native and exotic), catadromous, solely estuarine, estuarine and marine to marine estuarine opportunist. The most abundant species sampled, in descending order, were bony herring, yelloweye mullet and Western Australian salmon, which collectively accounted for 98% of the catch (by number). Species number was greater in the Estuary (13) than in the Northern Lagoon (8), whilst total fish abundance was greatest in the Northern Lagoon, with >90% of the three most abundant species sampled in this subregion (Table 3 and Figure 5). Across all sites, the species number appeared higher in this study compared to 2006/07 (Figure 5). In addition, total fish abundance was substantially higher particularly at the two sites in the Northern Lagoon.

Table 3. Species and number of fish sampled using gill nets during the November and December 2010 and February and March 2011 field trips for the barrage release intervention monitoring in the Coorong. MM=Murray Mouth and NL = Northern Lagoon

			Region		
Common Name	**Scientific Name**	**Classification**	**MM**	**NL**	**Total**
Congolli	*Pseudaphritis urvilli*	C	2		2
Black bream	*Acanthopagrus butcheri*	E	5	3	8
Greenback flounder	*Rhombosolea tapirina*	E&M	1		1
Goldfish	*Carassius auratus*	FE	1		1
Carp	*Cyprinus carpio*	FE	21	22	43
Redfin perch	*Perca fluviatilis*	FE	12	9	21
Golden perch	*Macquaria ambigua*	FN	1		1
Bony herring	*Nematolosa erebi*	FN	336	4,109	4,445
Yelloweye mullet	*Aldrichetta forsteri*	O	24	627	651
Mulloway	*Argyrosomus japonicus*	O	16	11	27
Australian herring	*Arripis georgianus*	O		2	2
Western Australian salmon	*Arripis truttaceus*	O	2	207	209
Sea mullet	*Mugil cephalus*	O	2		2
Yellowfin whiting	*Sillago schomburgkii*	O	1		1
Total			**424**	**4,990**	**5,414**
% catch			**8**	**92**	

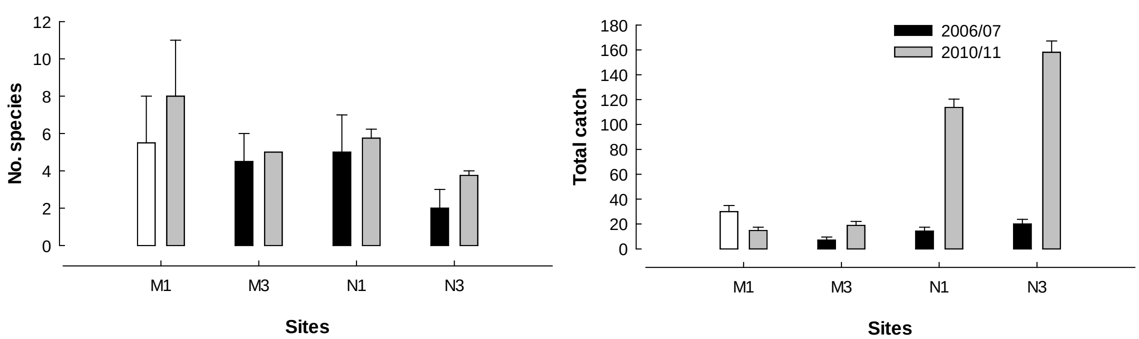

Figure 5. Mean number of species (left) and density of fish ± 1 S.E. (right) derived from gill net samples collected in the Estuary and Northern Lagoon of the Coorong in 2006/07 and 2010/11.

3.4. Spatiotemporal variation in fish assemblage structure and link to environmental variables

3.4.1. Seine net samples

PERMANOVA detected a significant interaction (*P*=0.001) when comparing fish assemblage structure between 2006/07 and 2010/11 across three subregions (i.e. Estuary, Northern Lagoon and Southern Lagoon) (Table 4). Pairwise comparisons revealed that, in all the three subregions, fish assemblage structure in 2010/11 differed significantly from those in 2006/07 (Table 5). Similarly, there was significant spatial difference between subregions, in both drought and flow years (Table 6). The MDS plot also showed distinct separation between years particularly for the Estuary samples, and clear grouping of 2010/11 samples by subregion (Figure 6).

Table 4. PERMANOVA results for fish assemblage comparison based on seine net data (log transformed data) between years and subregions in the Coorong. Bold p values are significant.

	Assemblage structure (Seine)		
Source of Variation	df	MS	P(perm)
Year	1	42948	**0.001**
Subregion	2	83873	**0.013**
Year x Subregion	2	23058	**0.001**
Residuals	216	1088.1	

Table 5. PERMANOVA pair-waise test factor level year, results for fish assemblage comparison based on seine net data (log transformed data) between years and subregions in the Coorong. Bold p values are significant.

Subregions	Groups	t	P(perm)
Estuary	2006/07 & 2010/11	7.6839	**0.001**
Northern Lagoon	2006/07 & 2010/11	2.8553	**0.001**
Southern Lagoon	2006/07 & 2010/11	4.7814	**0.001**

Table 6. PERMANOVA pair-waise test factor level region, results for fish assemblage comparison based on seine net data (log transformed data) between years and subregions in the Coorong. Bold p values are significant.

2006/07	Groups	t	P(perm)
	Estuary, Northern Lagoon	5.0931	**0.001**
	Estuary, Southern Lagoon	6.5414	**0.001**
	Northern Lagoon, Southern Lagoon	6.1812	**0.001**
2010/10	Groups	t	P(perm)
	Estuary, Northern Lagoon	9.0422	**0.001**
	Estuary, Southern Lagoon	9.8965	**0.001**
	Northern Lagoon, Southern Lagoon	4.7779	**0.001**

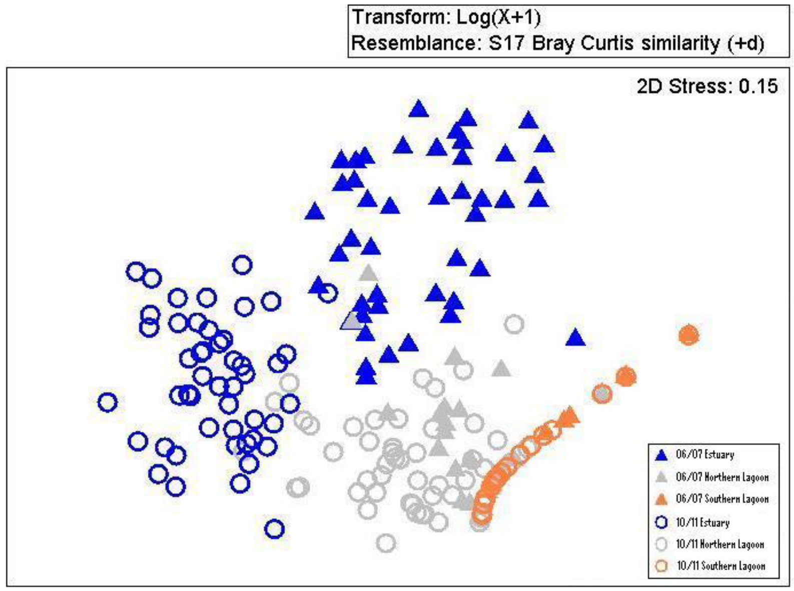

Figure 6. MDS plot (2-dimensional) for fish assemblages sampled by seine net in 2006/07 and 2010/11 across Estuary, Northern Lagoon and Southern Lagoon of the Coorong.

SIMPER analysis reveals, for the Estuary, variation in fish assemblage structure between 2010/11 and 2006/07 was largely driven by an increase in the abundance of bony herring, sandy sprat, Australian smelt, smallmouthed hardyhead and Tamar goby as well as the presence of two freshwater species that were not collected in 2006/07 (redfin perch and flat-headed gudgeon) (Table 7). In addition, the decline in abundance of yelloweye mullet and the absence of Australian salmon also contributed to the assemblage difference. For the Northern Lagoon, the difference in 2010/11 was mainly driven by an increase in the abundance of smallmouthed hardyhead and yelloweye mullet, and the presence and high abundance of two freshwater species (i.e. bony herring and Australian smelt) that were absent in 2006/07 (Table 7).

In 2010/11, the significant difference in fish assemblage between Estuary and Northern Lagoon was mainly attributed to more abundant sandy sprat, redfin perch, bony herring, Australian smelt, flat-headed gudgeon, Tamar goby and greenback flounder, and less abundant smallmouthed hardyhead and yelloweye mullet in the Estuary (Table 8). The difference between Southern Lagoon and the other two subregions was apparent given only a single species (i.e. smallmouthed hardyhead) was caught in this the Southern Lagoon.

Table 7. SIMPER analysis for fish assemblage comparison between 2006/07 and 2010/11 for seine net samples from the Murray Estuary, Northern Lagoon and Southern Lagoon. Results are based on log transformed data. Mean abundance is number of fish per seine net shot. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. A cumulative cut-off of 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Estuary	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2010/11	CR		Mean dissimilarity = 79.88
Bony herring	0.04	3.46	1.82	11.5	11.5
Sandy sprat	2.15	3.93	1.36	10.22	21.73
Australian smelt	0.02	3.05	2.23	10.07	31.8
Redfin perch	0	3.01	1.89	9.53	41.33
Yelloweye mullet	2.29	0.76	1.33	6.88	48.21
Flat-headed gudgeon	0	2.06	1.55	6.79	55
Smallmouthed hardyhead	1.55	2.14	1.34	6.51	61.51
Tamar goby	0.35	2.2	1.54	6.35	67.86
Western Australian salmon	1.57	0	0.91	5.38	73.24
Greenback flounder	0.93	1	1.24	4.02	77.26
River garfish	0.92	0.56	0.96	3.39	80.65
Carp	0	0.94	0.89	2.91	83.55
Toadfish species group	0.73	0.01	0.77	2.63	86.19
Longsnout flounder	0.34	0.46	0.66	2.19	88.38
Bridled goby	0.02	0.77	0.68	2.18	90.55
Northern Lagoon	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2010/11	CR		Mean dissimilarity = 50.94
Smallmouthed hardyhead	4.73	5.55	0.81	28.34	28.34
Bony herring	0	1.61	1.09	15.11	43.45
Yelloweye mullet	0.49	0.88	0.86	10.27	53.72
Greenback flounder	0.81	0.43	0.89	8.73	62.46
Australian smelt	0	0.78	0.56	7.07	69.53
Sandy sprat	0.46	0.39	0.53	5.74	75.26
Tamar goby	0.34	0.16	0.52	4.15	79.41
Redfin perch	0	0.53	0.46	4.14	83.56
Longsnout flounder	0.45	0.05	0.53	3.97	87.53
River garfish	0.21	0.29	0.62	3.81	91.34
Southern Lagoon	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2010/11	CR		Mean dissimilarity = 83.76
Smallmouthed hardyhead	0.56	4.01	3.09	100	100

Table 8. SIMPER analysis for fish assemblage comparison between the Estuary, Northern and Southern Lagoon of the Coorong for seine net samples during 2010/11. Results are based on log transformed data. Mean abundance is number of fish per seine net shot. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. A cumulative cut-off of 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar). MM=Murray Mouth and NL = Northern Lagoon.

	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	**MM**	**NL**	CR		Mean dissimilarity = 72.14
Smallmouthed hardyhead	2.11	5.55	1.42	14.76	14.76
Sandy sprat	3.85	0.39	1.62	13.99	28.75
Redfin perch	3.03	0.53	1.68	10.1	38.85
Bony herring	3.49	1.61	1.29	9.72	48.58
Australian smelt	3.02	0.78	1.66	9.71	58.29
Flat-headed gudgeon	2.09	0.1	1.52	7.63	65.92
Tamar goby	2.16	0.16	1.56	7.51	73.43
Yelloweye mullet	0.74	0.88	0.93	4.29	77.72
Greenback flounder	0.98	0.43	0.94	3.81	81.52
Carp	1	0.04	0.85	3.55	85.07
Congolli	0.65	0.33	0.92	2.61	87.68
Bridled goby	0.75	0	0.66	2.37	90.06
Species names	**MM**	**SL**	CR		Mean dissimilarity = 90.21
Sandy sprat	3.85	0	1.67	14.84	14.84
Bony herring	3.49	0	1.67	13.43	28.27
Smallmouthed hardyhead	2.11	4.01	1.27	12.13	40.39
Australian smelt	3.02	0	2.23	11.24	51.63
Redfin perch	3.03	0	1.94	10.69	62.32
Flat-headed gudgeon	2.09	0	1.53	7.82	70.14
Tamar goby	2.16	0	1.64	7.64	77.78
Carp	1	0	0.85	3.5	81.28
Greenback flounder	0.98	0	0.78	3.29	84.57
Yelloweye mullet	0.74	0	0.6	2.54	87.11
Bridled goby	0.75	0	0.67	2.28	89.38
Congolli	0.65	0	0.79	2.14	91.52
Species names	**NL**	**SL**	CR		Mean dissimilarity = 56.49
Smallmouthed hardyhead	5.55	4.01	1.01	42.55	42.55
Bony herring	1.61	0	1.12	16.33	58.87
Yelloweye mullet	0.88	0	0.74	10.84	69.71
Australian smelt	0.78	0	0.56	7.56	77.27
Redfin perch	0.53	0	0.47	4.34	81.6
Greenback flounder	0.43	0	0.58	4.2	85.8
Congolli	0.33	0	0.53	3.09	88.89
Sandy sprat	0.39	0	0.35	2.78	91.67

When PCO ordination was applied to the fish abundance dataset, the total variation was relatively successfully captured by PCO1 and PCO2 (59.31% combined). There was clear separation of samples from the Estuary in 2006/07 and 2010/11, whilst for the Northern Lagoon and Southern Lagoon, samples from both years were interspersed. The pattern of the distribution of 2010/11 Estuary samples appears to be influenced mainly by freshwater species (ie. flathead gudgeon (PHI GRA), carp (CYP CAR), redfin perch (PER FLU), Australian smelt (RET SEM), bony herring (NEM ERE)) and an estuarine opportunist species, sandy sprat (HYP VIT), whilst smallmouthed hardyhead (ATH MIC) has a strong influence on variation in fish assemblages between the three subregions (Figure 7).

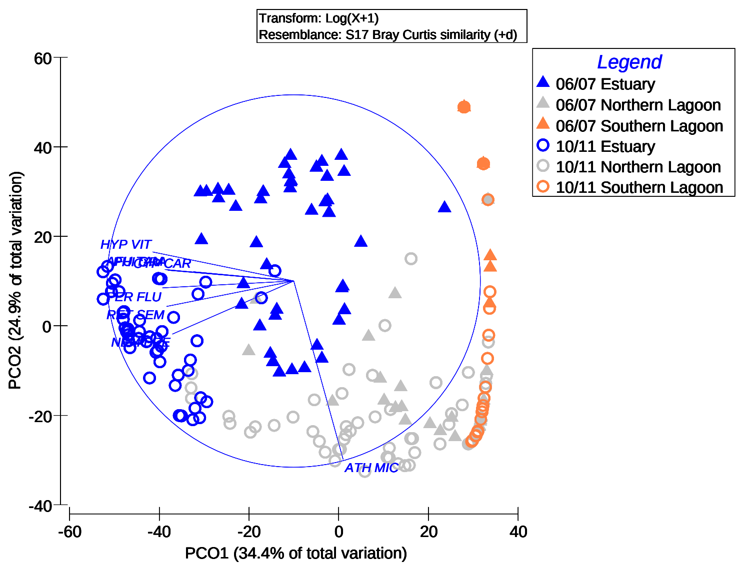

Figure 7. PCO ordination of samples on the basis of the Bray-Curtis measure of log transformed abundances of fish species collected by seine net. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle). Species abbreviations are listed in the text above.

DistLM routine and the model-building criteria of forward R2 showed that DO, salinity and turbidity were the best predictor variables to explain the dispersion of the data cloud (34% of the samples variation) (Table 9). Ordination of fitted values for the DistLM was achieved through distance-based redundancy analysis (dbRDA). DO, salinity and turbidity vectors were overlayed to show how they were driving variation along dbRDA axes. There was a clear separation of samples collected in the Estuary in 2010/11, which were negatively correlated to salinity. In contrast, the 2006/07 Southern Lagoon samples were mainly driven by high salinities whilst Estuary samples were mainly driven by turbidity (Figure 8).

Table 9. DistLM sequential results indicating which environmental variable significantly contributed most to the relationship with the multivariate data cloud, (biological data). Proportion of the variation explained (Prop) and cumulative variation explained (Cumul).

Variable	R^2 res.df	Pseudo-F	P	Prop.	Cumul.
Salinity	0.23981	69.403	**0.001**	0.2398	0.23981
Secchi	0.32339	27.051	**0.001**	0.0836	0.32339
DO	0.33621	4.2101	**0.003**	0.0128	0.33621
pH	0.34527	3.0031	0.007	0.0091	0.34527
Temperature	0.35042	1.7121	0.102	0.0051	0.35042

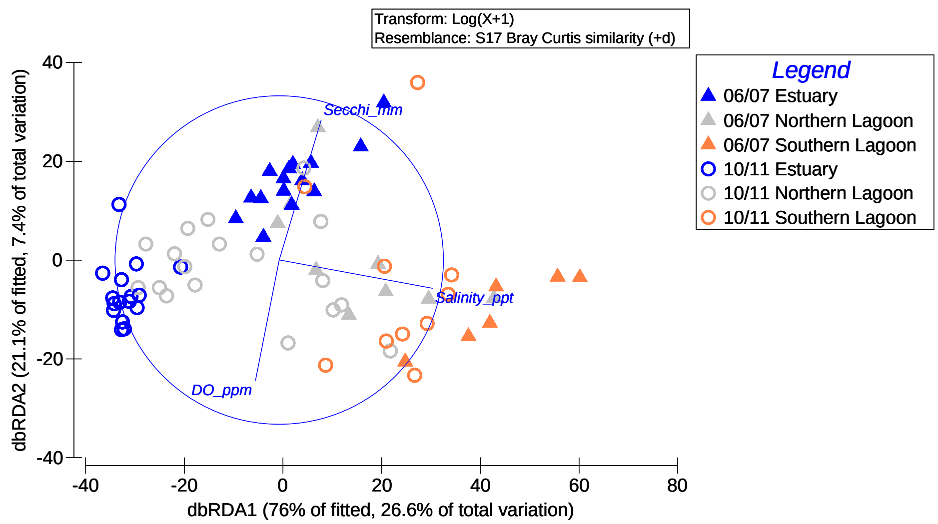

Figure 8. dbRDA ordination of the fitted model of species-abundance data collected by seine net (based on Bray-Curtis measure of log transformed abundances) *versus* the predictor variables DO, salinity and turbidity. The vector overlay indicates multiple partial correlations between the predictor variables and dbRDA axes 1 and 2.

3.4.2. Gill net samples

PERMANOVA indicated a significant interaction (P=0.001) when comparing fish assemblages between the current and the previous drought year (i.e. 2006/07) between two subregions (i.e. Estuary and Northern Lagoon) (Table 10). Pairwise comparisons revealed that, in each subregion, fish assemblage differed significantly (P=0.001) between 2006/07 and 2010/11. Similarly, there was a significant spatial difference in fish assemblage structure in both 2006/07 (P=0.002) and 2010/11 (P=0.001). The MDS plot also showed distinct groupings of samples from drought year (2006/07) and flow year 2010/11 (Figure 9).

Table 10. PERMANOVA results for fish assemblage comparison based on gill net data (square root transformed data) between years and subregions in the Coorong. Bold p values are significant.

	Assemblage structure (Gill)		
Source of Variation	df	MS	P(perm)
Year	1	39142	**0.001**
Subregion	1	7249.4	0.647
Year x Subregion	1	13068	**0.001**
Residuals	64	1137.3	

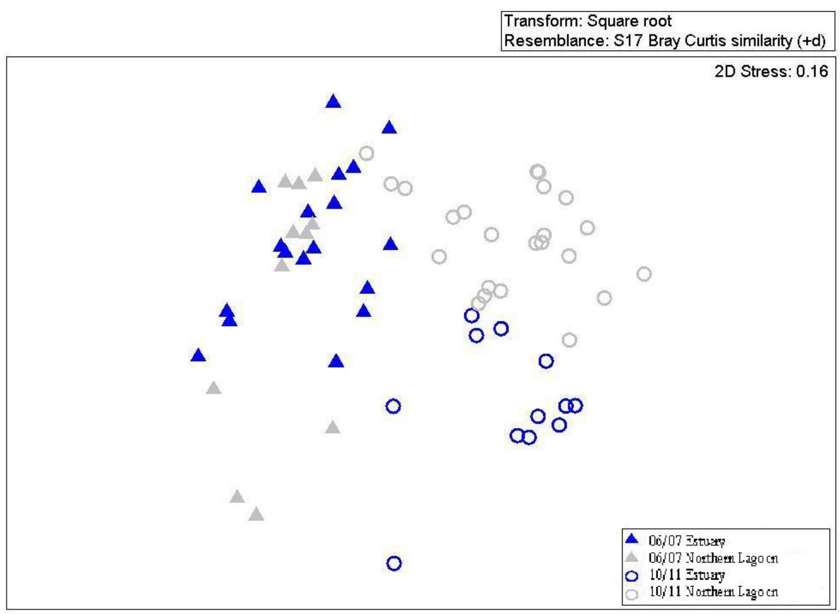

Figure 9. MDS plot (2-dimensional) for fish assemblages sampled by gill nets 2006/07 and 2010/11 in the Estuary and Northern Lagoon of the Coorong.

SIMPER analysis indicated that, for the Estuary, the difference in fish assemblage in 2010/11, compared to 2006/07, was mainly driven by an increase in abundance and presence of previously absent freshwater species (i.e. bony herring, redfin perch and carp) and a decrease in the abundance of Australian salmon, mulloway, and yelloweye mullet (Table 11). For the Northern Lagoon, the difference in 2010/11 was mostly attributed to an increase in abundance of bony herring, yelloweye mullet and Australian salmon and a decrease of mulloway (Table 11).

In 2010/11, the results of SIMPER analysis indicated that the spatial difference in fish assemblage between the Estuary and Northern Lagoon was mainly attributed to high abundances of bony herring, yelloweye mullet and Australian salmon, and low abundances of carp, redfin perch and mulloway in Northern Lagoon (Table 12).

Table 11. SIMPER analysis for fish assemblage comparison between 2006/07 and 2010/11 for gill net samples from the Murray Estuary and Northern Lagoon. Results are based on square root transformed data. Mean abundance is number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. A cumulative cut-off of 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

Estuary	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2010/11	CR		Mean dissimilarity = 84.46
Bony herring	0.57	4.88	2.1	30.63	30.63
Australian salmon	2.72	0.12	1.6	16.92	47.55
Mulloway	2.38	0.53	1.63	14.75	62.3
Yelloweye mullet	2.01	0.68	1.44	12.56	74.86
Carp	0	1.07	1.13	8.38	83.24
Redfin perch	0	0.73	1	4.8	88.05
Black bream	0.06	0.32	0.51	2.55	90.59
Northern Lagoon	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2010/11	CR		Mean dissimilarity = 79.91
Bony herring	0.08	11.2	1.99	52.47	52.47
Yelloweye mullet	2.64	4.5	1.13	19.25	71.72
Australian salmon	0.26	2.36	1.03	12.23	83.95
Mulloway	1.6	0.43	1.13	7.67	91.62

Table 12. SIMPER analysis for fish assemblage comparison between Northern Lagoon and Southern Lagoon for gill net samples during 2010/11. Results are based on square root transformed data. Mean abundance is number of fish per net. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between years (shown by PERMANOVA) attributable to individual species. A cumulative cut-off of 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	MM	NL	CR		Mean dissimilarity = 62.8
Bony herring	4.88	11.2	1.48	40	40
Yelloweye mullet	0.68	4.5	1.49	24.66	64.66
Australian salmon	0.12	2.36	1.15	13.38	78.04
Carp	1.07	0.35	1.22	7.26	85.31
Redfin perch	0.73	0.31	1.02	4.33	89.63
Mulloway	0.53	0.43	0.78	4.05	93.68

The total variation was relatively successfully captured by PCO1 and PCO2 (64.16% both combined) when PCO ordination was applied to the fish abundance dataset. There was a clear separation of samples from the drought and flow years (2006/07 and 2010/11), respectively. Six out of the fourteen species collected seem to be influencing the spatiotemporal patterns of distribution: mulloway (ARG JAP) is influencing samples collected in both subregions in 2006/07, whilst carp (CYP CAR) and redfin perch (PER FLU), both freshwater species, are driving the pattern of distribution of the Estuary samples in the flow year (2010/11). Bony herring (NEM ERE) appears in both subregions in 2010/11 and yelloweye mullet (ALD FOR) and Australian salmon (ARR TRU) were more correlated to samples collected in the Northern Lagoon 2010/11 (Figure 10).

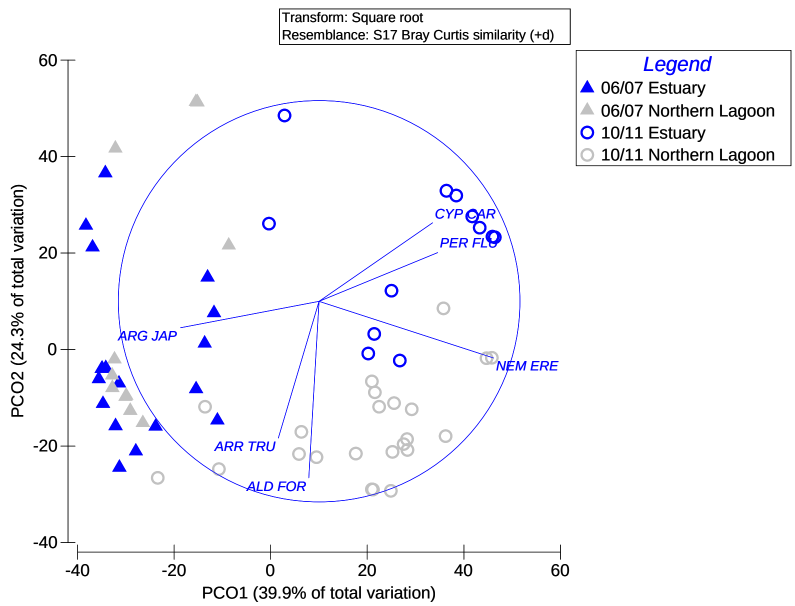

Figure 10. PCO ordination of samples on the basis of the Bray-Curtis measure of square root transformed abundances of fish species collected by gill net. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

DistLM routine and the model-building criteria of forward R2 showed that salinity, DO and turbidity were the best predictor variables to explain the dispersion of the data cloud (40.3% of the samples variation) (Table 13). Ordination of fitted values for the DistLM was achieved through distance-based redundancy analysis (dbRDA). DO, salinity and turbidity vectors were overlayed to show how they were driving variation along dbRDA axes. There was a clear separation of samples collected in both subregions between the drought and the flow years, mainly (Figure 11). The 2010/11 samples are correlated to low salinities, high DO and high turbidities (i.e. low Secchi disc depths), which were results of freshwater releases to the Coorong.

Table 13. DistLM sequential results indicating which environmental variable significantly contributed most to the relationship with the multivariate data cloud, (biological data). Proportion of the variation explained (Prop) and cumulative variation explained (Cumul).

Variable	R^2 res.df	Pseudo-F	P	Prop.	Cumul.
Salinity	0.309	15.396	**0.001**	0.172	0.172
DO	0.138	10.051	**0.001**	0.138	0.310
Secchi	0.410	7.365	**0.001**	0.074	0.384
pH	0.333	2.196	0.053	0.024	0.408
Temperature	0.336	0.242	0.925	0.003	0.411

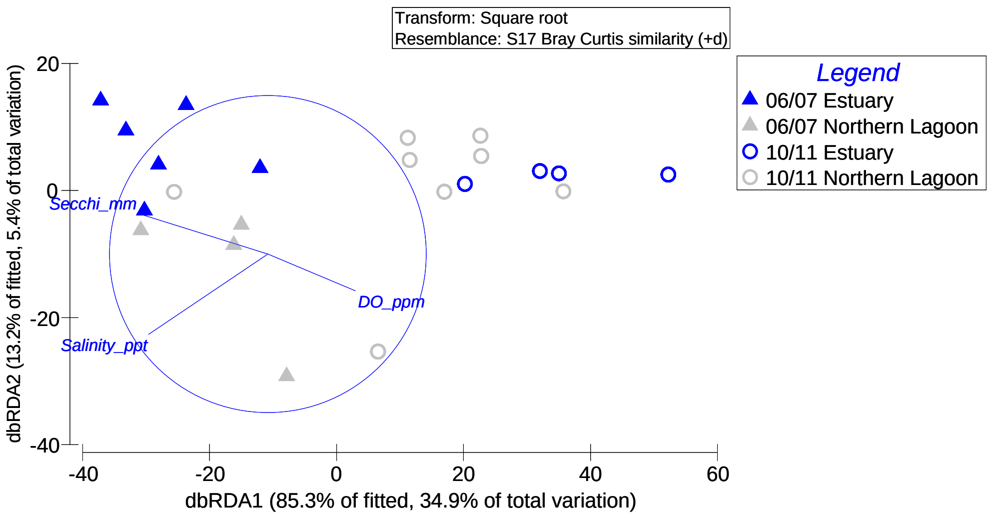

Figure 11. dbRDA ordination of the fitted model of species-abundance data collected by gill net (based on Bray-Curtis measure of square root transformed abundances) *versus* the predictor variables DO, salinity and turbidity. The vector overlay indicates multiple partial correlations between the predictor variables and dbRDA axes 1 and 2.

3.5. Temporal changes in distribution, abundance and length frequency distributions of key species

Length measurement data was obtained from both seine and gill net samples. Seine netting from the shore was efficient for sampling small-bodied species and juveniles of large-bodied species, whilst the gill nets were set near the main channel, targeting adults of large-bodied species. It is assumed that both methods collectively sampled most size classes of the fish population. Length-frequency data can enable the identification of cohorts (that can sometimes be inferred as year classes) to investigate recruitment of key species; modal progression of cohorts can be traced with successive samples to analyse fish growth.

3.5.1. Black Bream

Black bream was sampled in low numbers during both drought and flow years in the Coorong. Fourteen fish were collected with size ranging from 113 to 484 mm in 2006/07 and eight collected ranging from 154 to 400 mm in 2010/11. Despite low abundance, black bream exhibited an extensive range expansion in 2010/11. In 2006/07, this species was only found within the Estuary (from Goolwa Channel to Pelican Point) in both seine and gill net samples, whilst in 2010/11, it was also collected in the Northern Lagoon, 27.4 km southwards at Noonameena, although only in gill nets (Figures 12 and 13). It was not clear whether there has been recruitment success in the current year. Also no apparent modal progression was observed, however the sample size was very small.

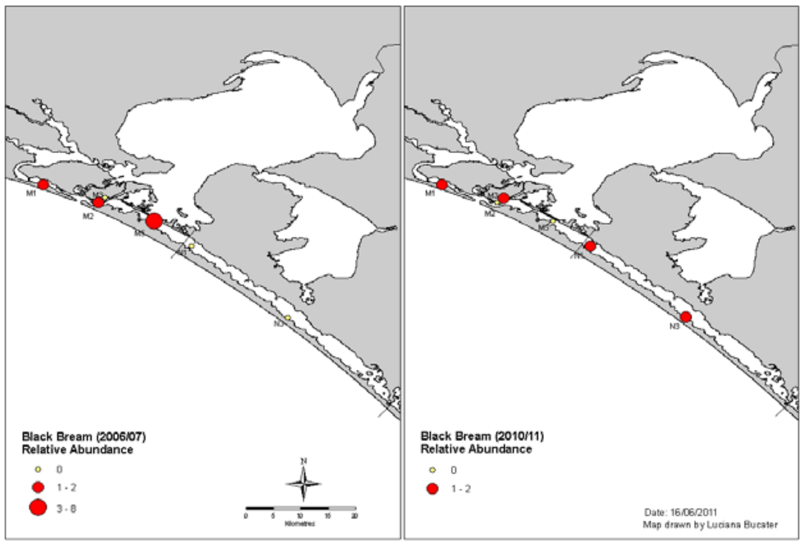

Figure 12. Coorong map showing black bream relative abundance and distribution in 2006/07 (left) and 2010/11 (right).

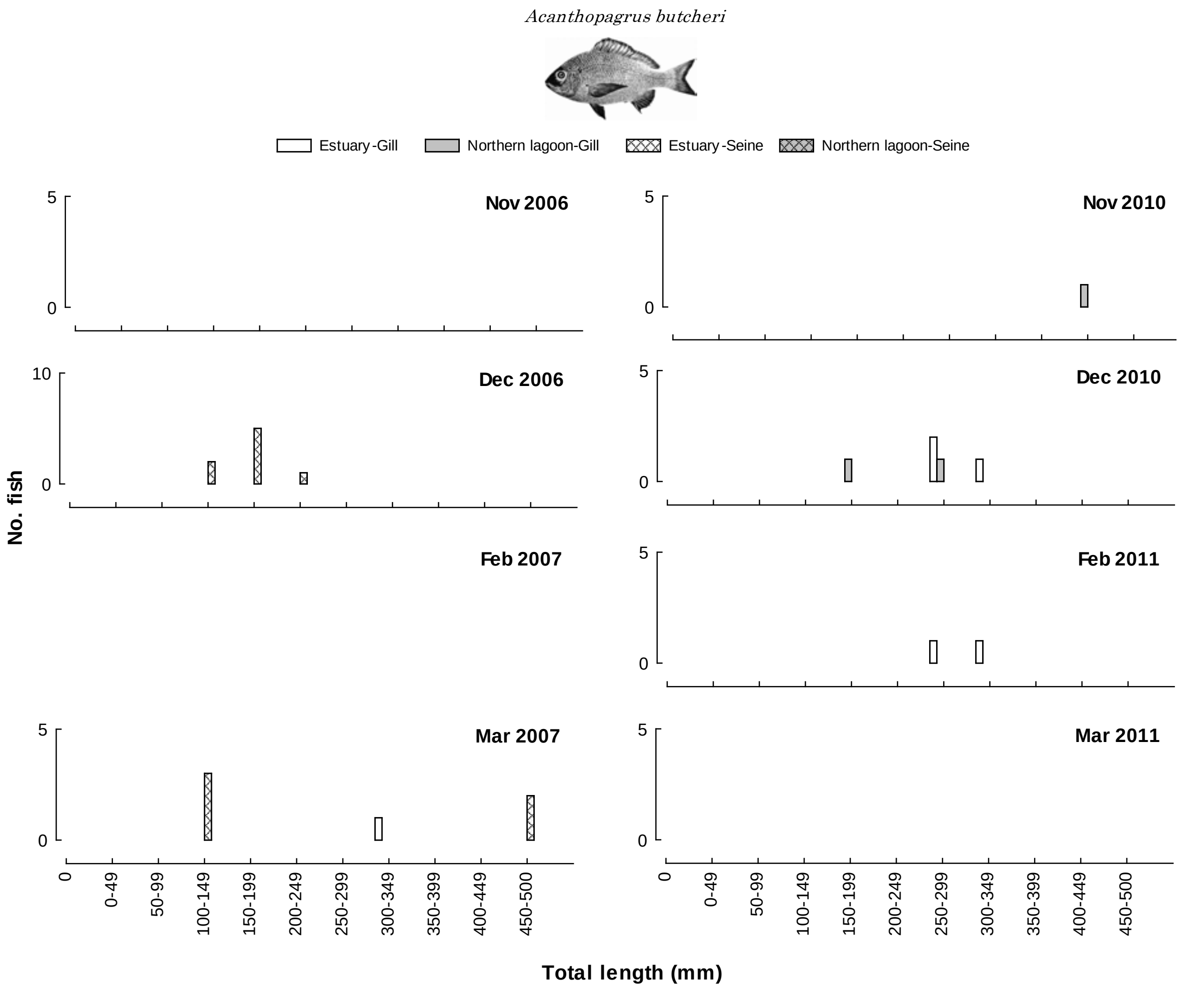

Figure 13. Length frequency distribution of juvenile and adult black bream from gill and seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

3.5.2. Congolli

The catches of congolli in 2010/11 were almost an order of magnitude higher at various sites along the Coorong than in 2006/07. Mt Anderson was the most southern site where congolli was collected in 2010/11, nevertheless, this site was not sampled in the drought year, and therefore we can not make an inference about the change in distribution (Figure 14).

In 2006/07, ten fish were measured ranging from 40 to 260 mm, whilst in 2010/11, a subsample of 146 fish was measured ranging from 31 to 340 mm. Congolli was collected in both gear types in both years (Figure 15). The length frequency distributions showed no apparent modal progression in either year, however, new recruits were present during every sampling occasion in 2010/11, indicating a significant recruitment success in the current.

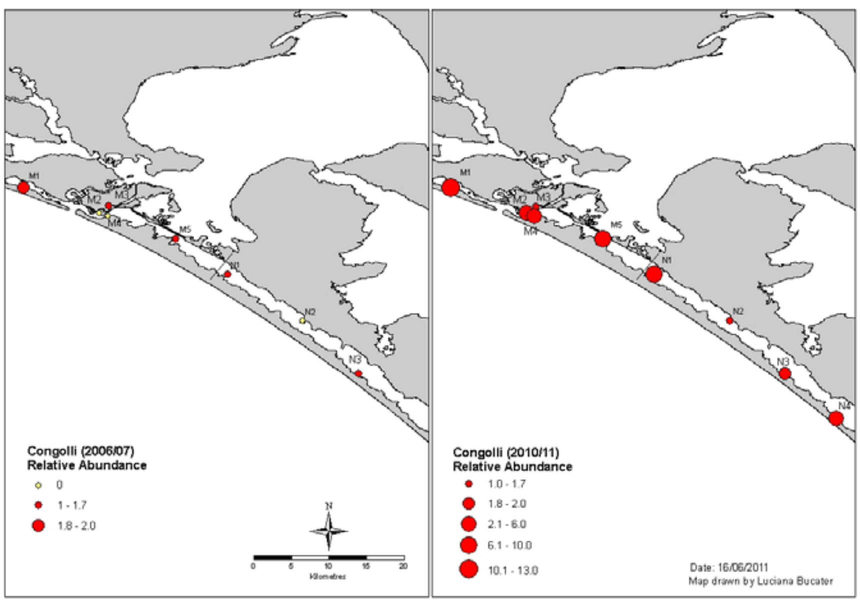

Figure 14. Coorong map showing congolli relative abundance and distribution in 2006/07 (left) and 2010/11 (right). Note the different scale of relative abundance.

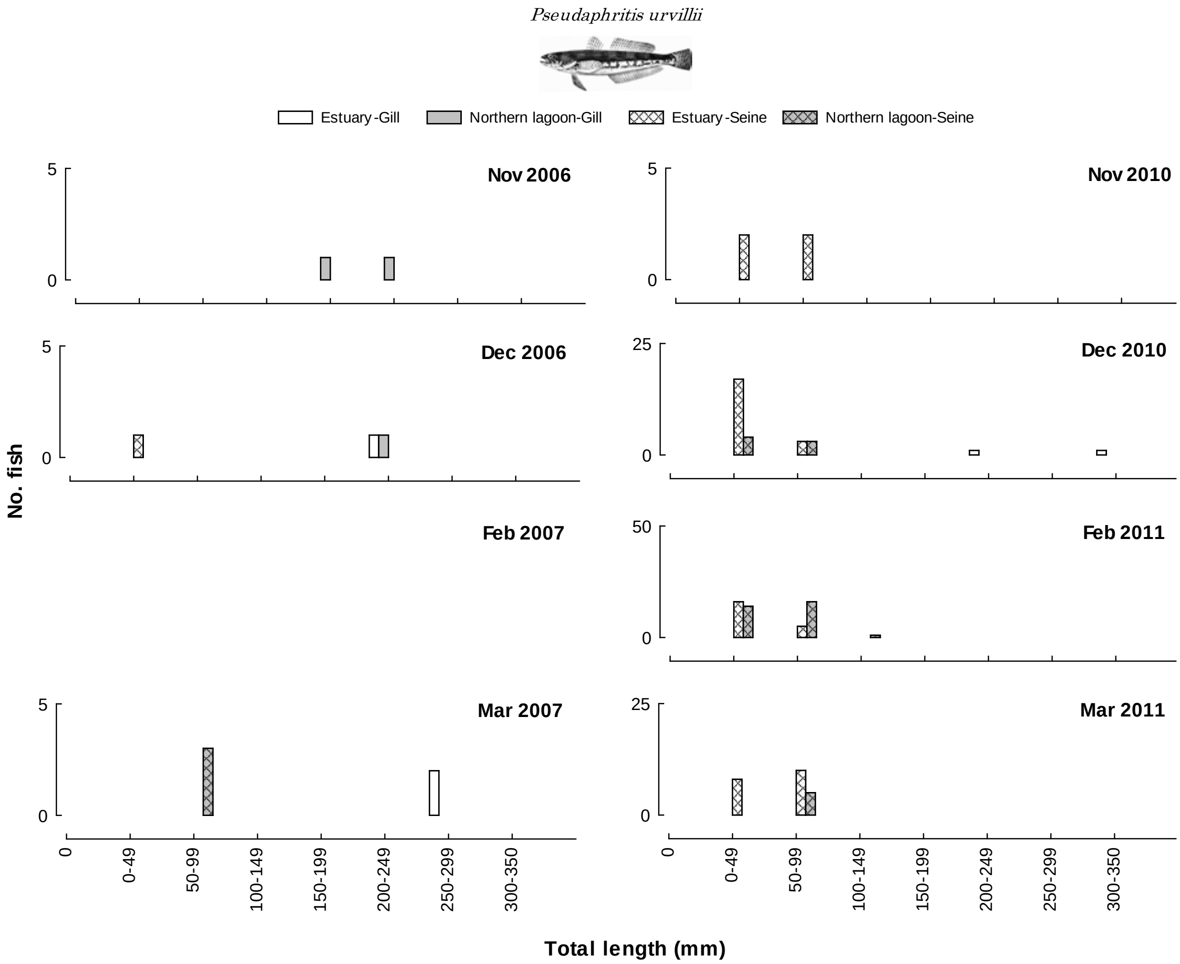

Figure 15. Length frequency distributions of juvenile and adult congolli from gill and seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

3.5.3. Greenback flounder

Greenback flounder had a slight increase in abundance in 2010/11 compared to 2006/07, particularly in the Estuary. This species was found in both Estuary and Northern Lagoon subregions in both years. Although fish appeared to have distributed further southward to Mt Anderson in the current year, this site was not sampled in 2006/07.

A subsample of 206 fish was measured ranged from 22 to 340 mm in 2006/07, and 294 measured sized from 22 to 295 mm in 2010/11 (Figure 17). Seine netting appeared to be effective for sampling greenback flounder, particularly juveniles. Length frequency distributions show the presence of new recruits in both years. From December 2010 to February 2011, there was a distinct modal progression coinciding with spatial shift of the juvenile greenback flounder from the Estuary to the Northern Lagoon subregion.

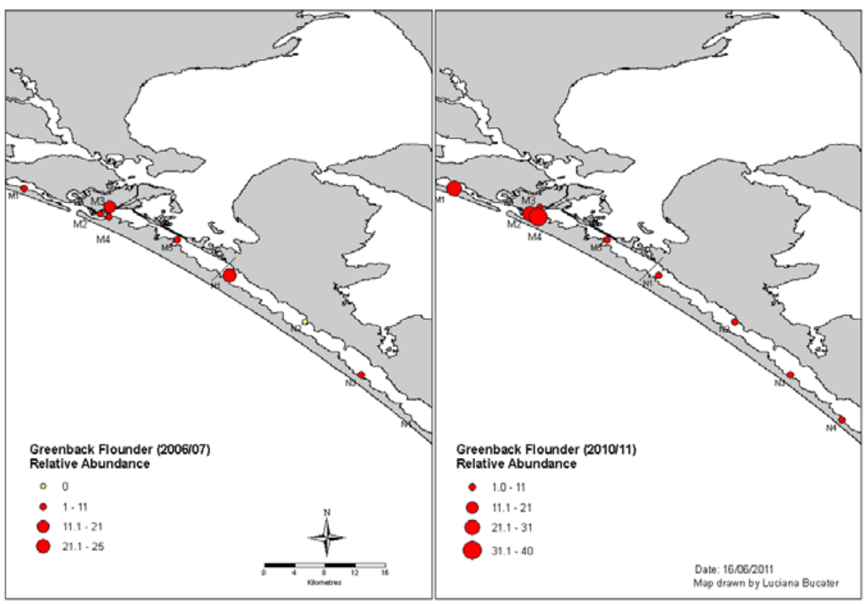

Figure 16. Coorong map showing greenback flounder relative abundance and distribution in 2006/07 (left) and 2010/11 (right).

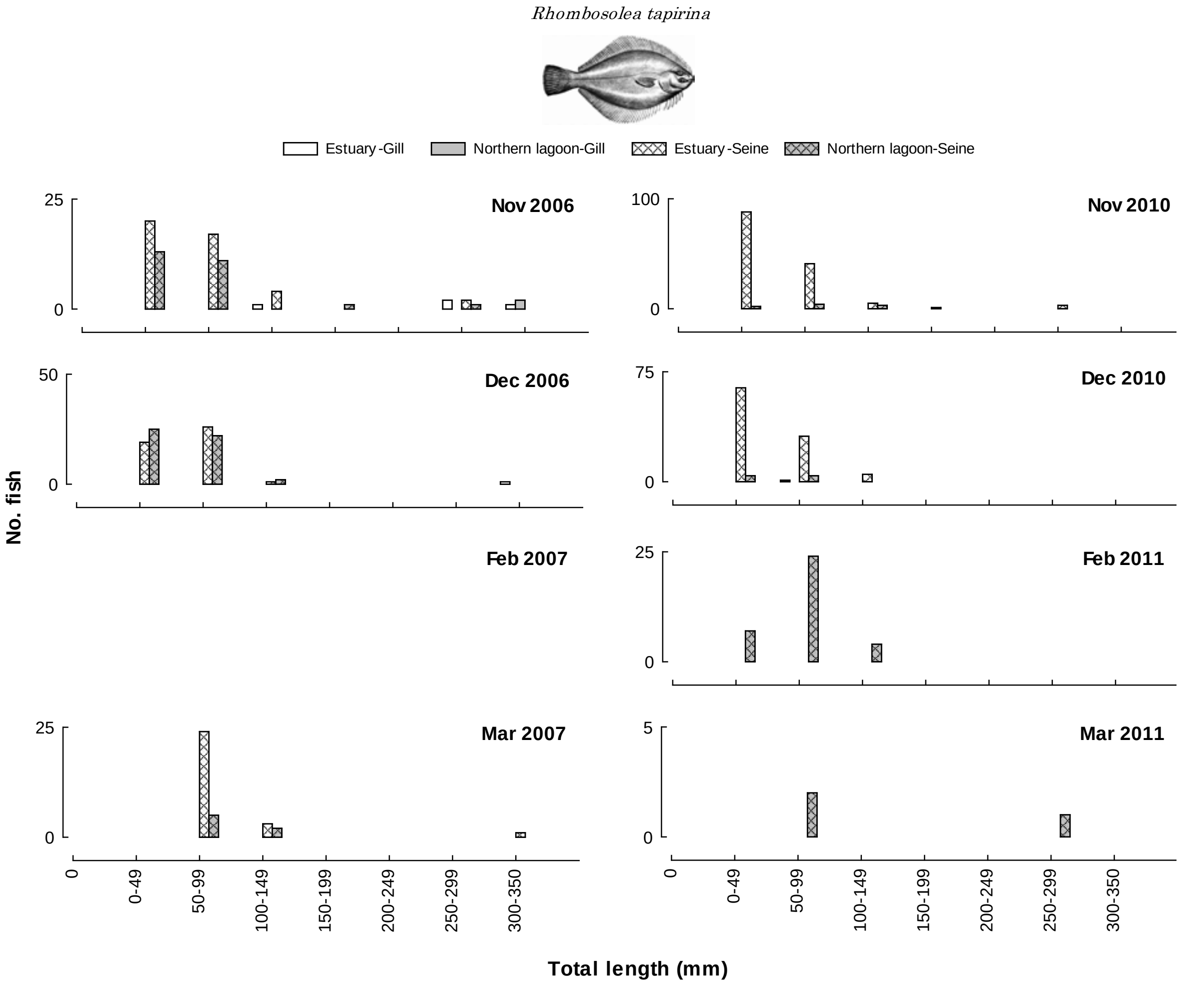

Figure 17. Length frequency distributions of juvenile and adult greenback flounder from gill and seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

3.5.4. Mulloway

The abundance of Mulloway appears to be negatively influenced by the flow in 2010/11, although its distribution appeared similar to 2006/07 (Figure 18). In 2006/07, a subsample of 209 fish was measured with size ranging from 128 to 710 mm whilst in 2010/11 only 27 fish were measured ranging from 208 to 460 mm. Mulloway were found in both subregions in both years, however all 2010/11 samples were from gill nets (Figure 19). There was no apparent modal progression in the length frequency distribution in both years.

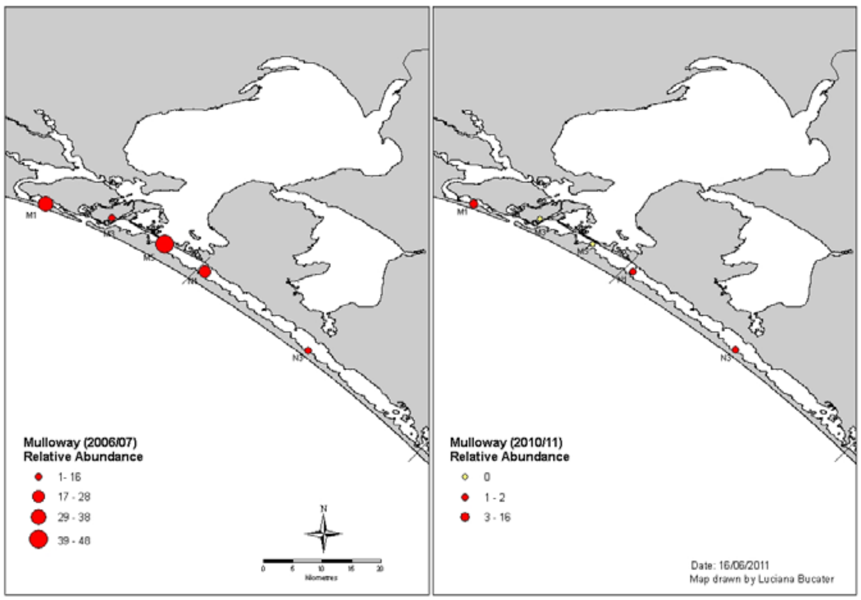

Figure 18. Coorong map showing mulloway relative abundance and distribution in 2006/07 (left) and 2010/11 (right). Note the different scale of relative abundance.

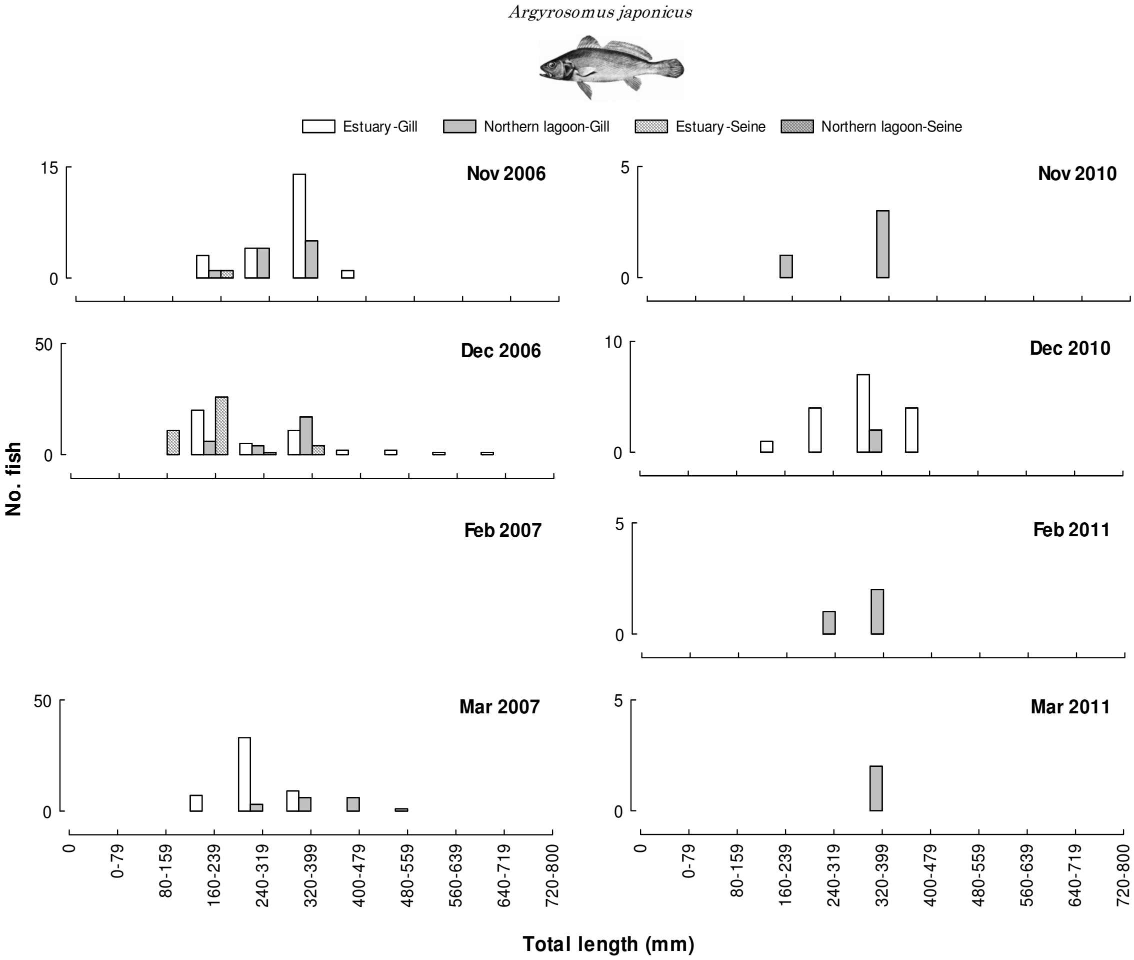

Figure 19. Length frequency distributions of juvenile and adult mulloway from gill and seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

3.5.5. Sandy sprat

Sandy sprat was present in both Estuary and Northern Lagoon subregion. There was an increase in sandy sprat abundance in 2010/11 compared to 2006/07 (Figure 20). No fish were measured in 2006/07, whilst a subsample of 751 fish was measured ranging from 23 to 61 mm in 2010/11 (Figure 21). The modal progression showed the dominant size class (30-39 mm) in November 2010 growing to 40-49 mm in December 2010.

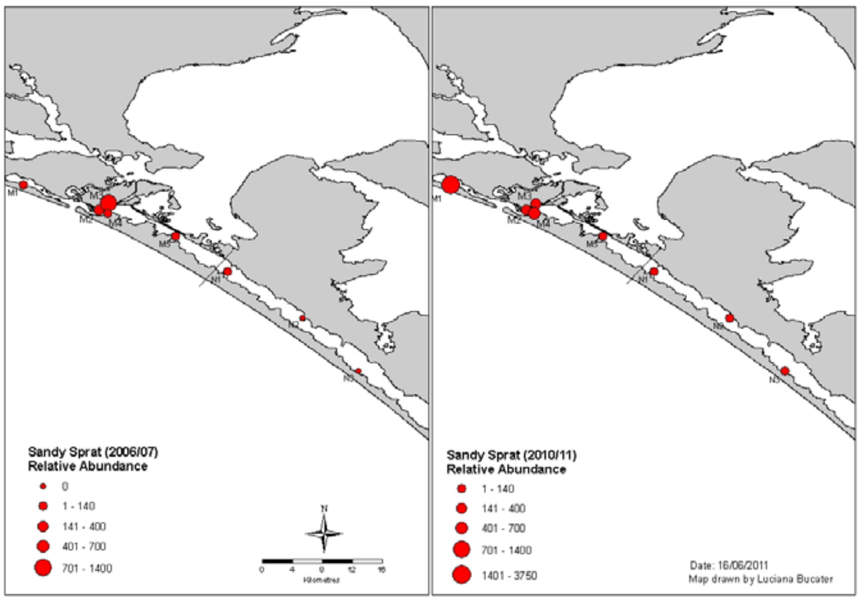

Figure 20. Coorong map showing sandy sprat relative abundance and distribution in 2006/07 (left) and 2010/11 (right).

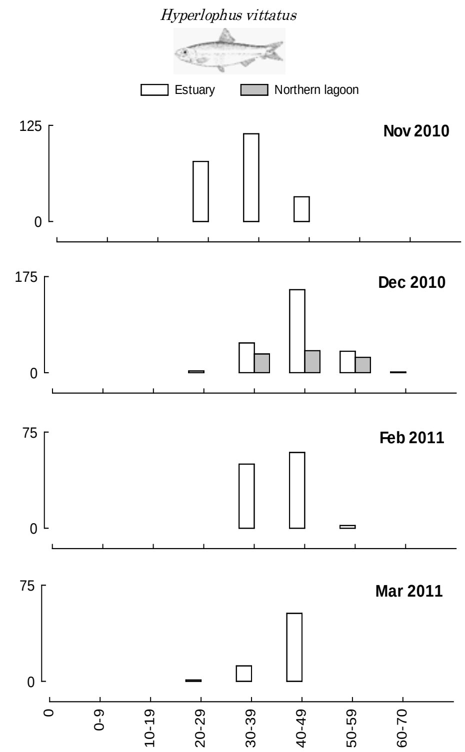

Figure 21. Length frequency distributions of juvenile and adult sandy sprat from seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2010/11.

3.5.6. Smallmouthed hardyhead

Smallmouthed hardyhead had a broad distribution across three subregions in the Coorong. There was a considerable increase in abundance in 2010/11 when compared to 2006/07 (Figure 22). A subsample of 581 fish was measured with size ranging from 17 to 91 mm in 2006/07, and 1,631 fish were measured ranging from 12 to 96 mm in 2010/11. The length frequency distributions show broad ranges in size distribution and a cohort of small fish seem to appear in December, and become apparent in February/March 2011, indicating fish recruitment (Figure 23).

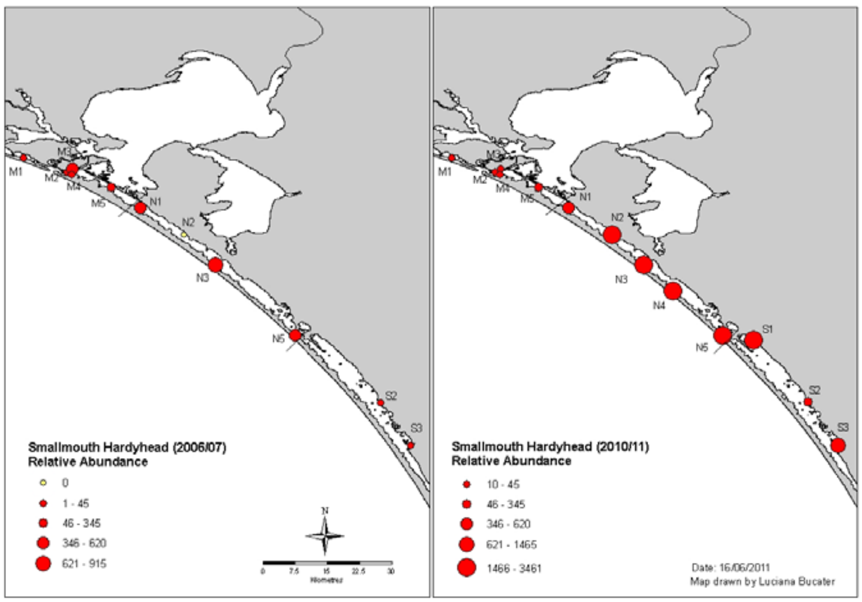

Figure 22. Coorong map showing smallmouthed hardyhead relative abundance and distribution in 2006/07 (left) and 2010/11 (right). Note the different scale of relative abundance.

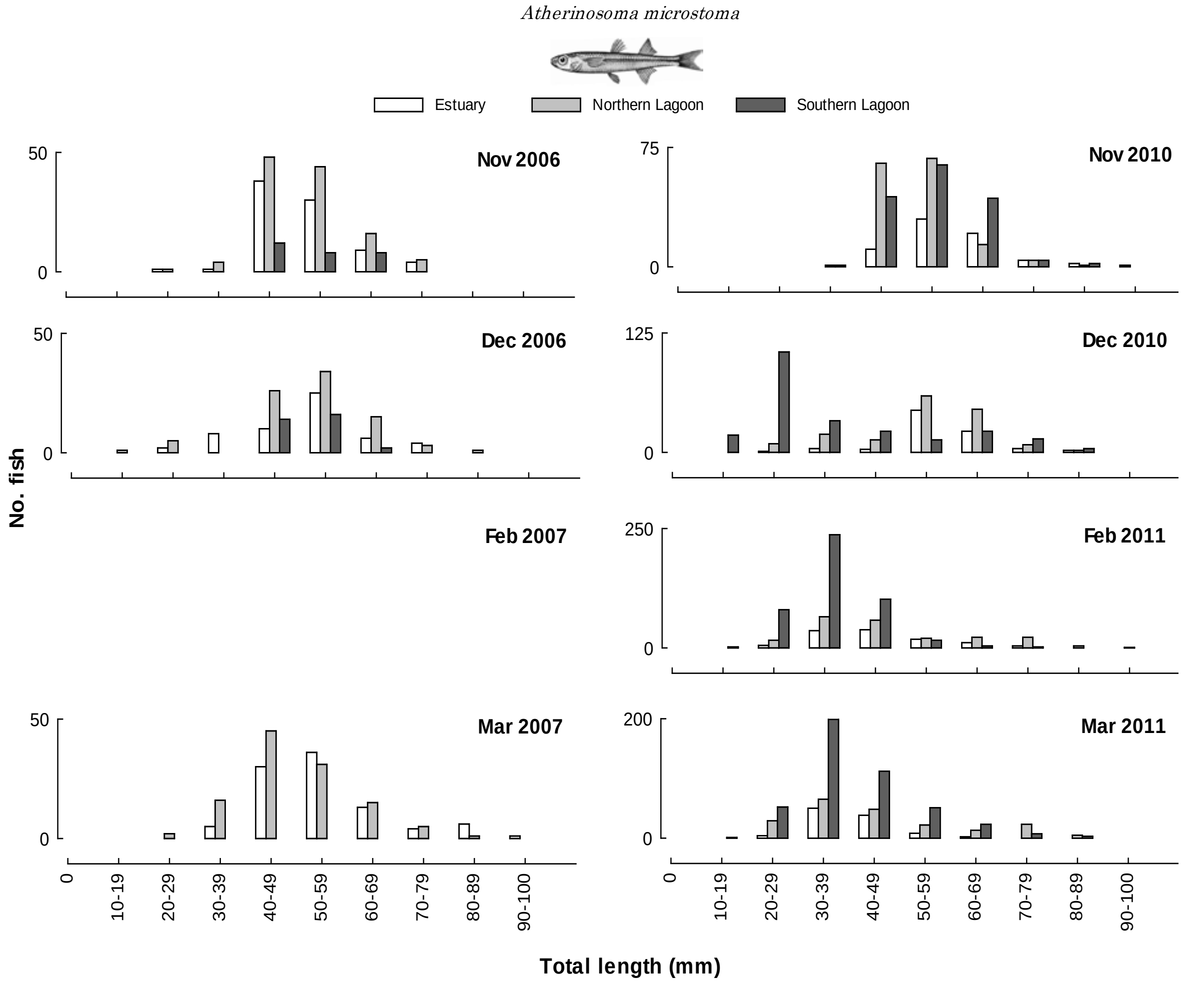

Figure 23. Length frequency distributions of juvenile and adult smallmouthed hardyhead from seine net samples in the Estuary, Northern Lagoon and Southern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

3.5.7. Tamar goby

Tamar goby dramatically increased in abundance in the Estuary in 2010/11 compared to 2006/07 (Figure 24), 63 fish were measured with size ranging from 24 to 77 mm in 2006/07 and a subsample of 519 was measured with size ranging from 22 to 90 mm in 2010/11 (Figure 25). The length frequency distributions show a cohort of small fish seem to appear in November/December 2010, indicating fish recruitment (Figure 23). The modal progression showed the dominant size class (30-39 mm) in December 2010 growing to 40-49 mm in February 2011.

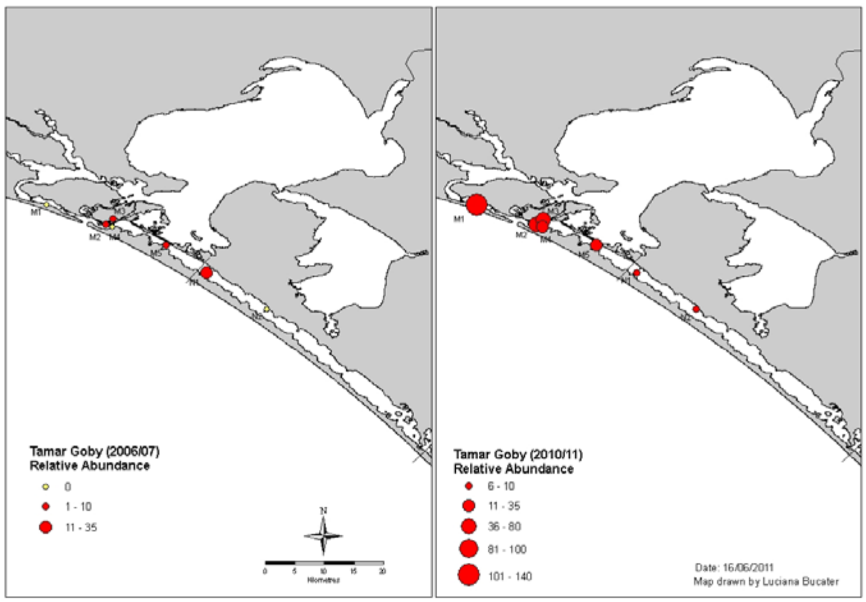

Figure 24. Coorong map showing Tamar goby relative abundance and distribution in 2006/07 (left) and 2010/11 (right). Note the different scale of relative abundance.

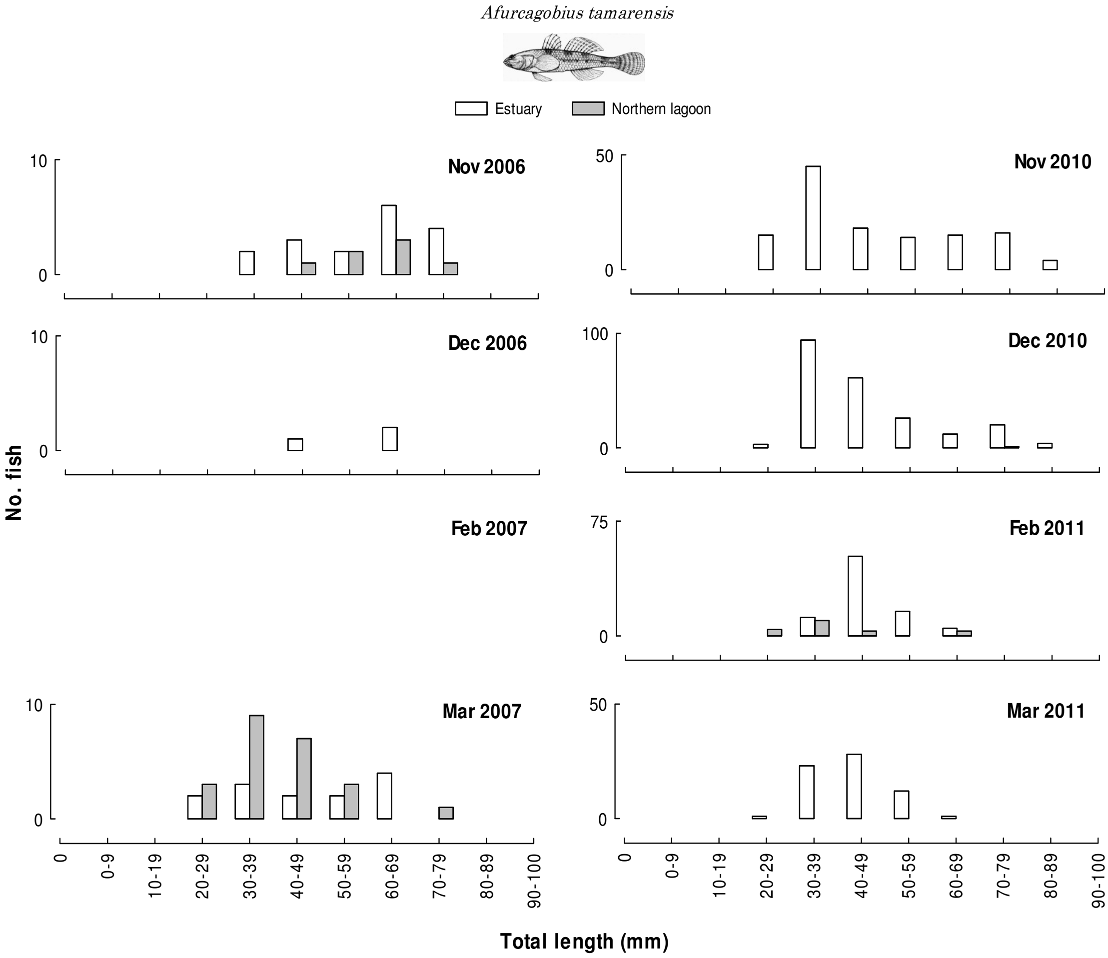

Figure 25. Length frequency distributions of juvenile and adult Tamar goby from seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

3.5.8. Yelloweye mullet

The abundance of both juvenile and adult yelloweye mullet generally decreased in the Estuary but increased in the Northern Lagoon in 2010/11 relative to 2006/07 (Figure 27). A subsample of 790 fish was measured with size ranging from 30 to 355 mm in 2006/07 and 705 fish were measured ranging from 31 to 316 mm in 2010/11. Length frequency data show broad size distributions, and the collection of a small cohort fish (< 80 mm) in most sampling occasions suggest recruitment success of this species in both years (Figure 27).

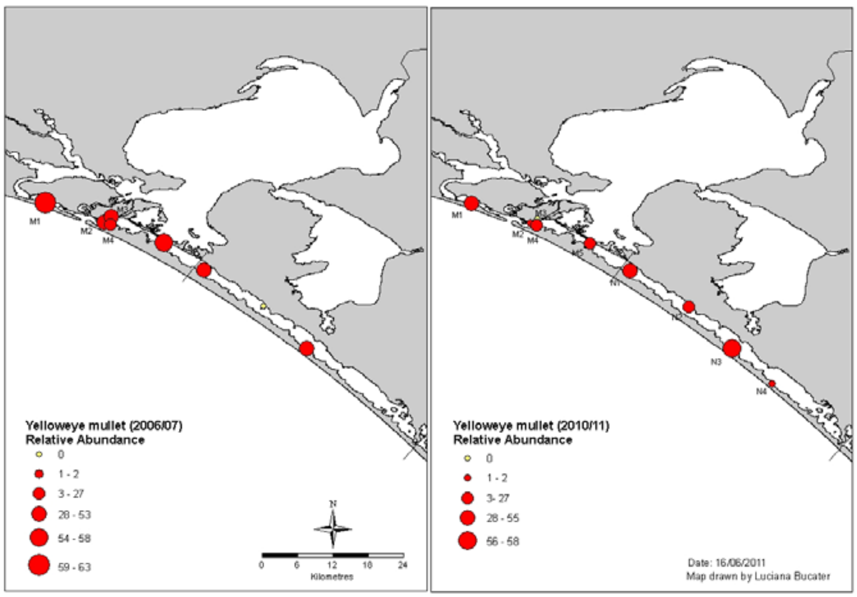

Figure 26. Coorong map showing yelloweye mullet relative abundance and distribution in 2006/07 (left) and 2010/11 (right). Note the different scale of relative abundance).

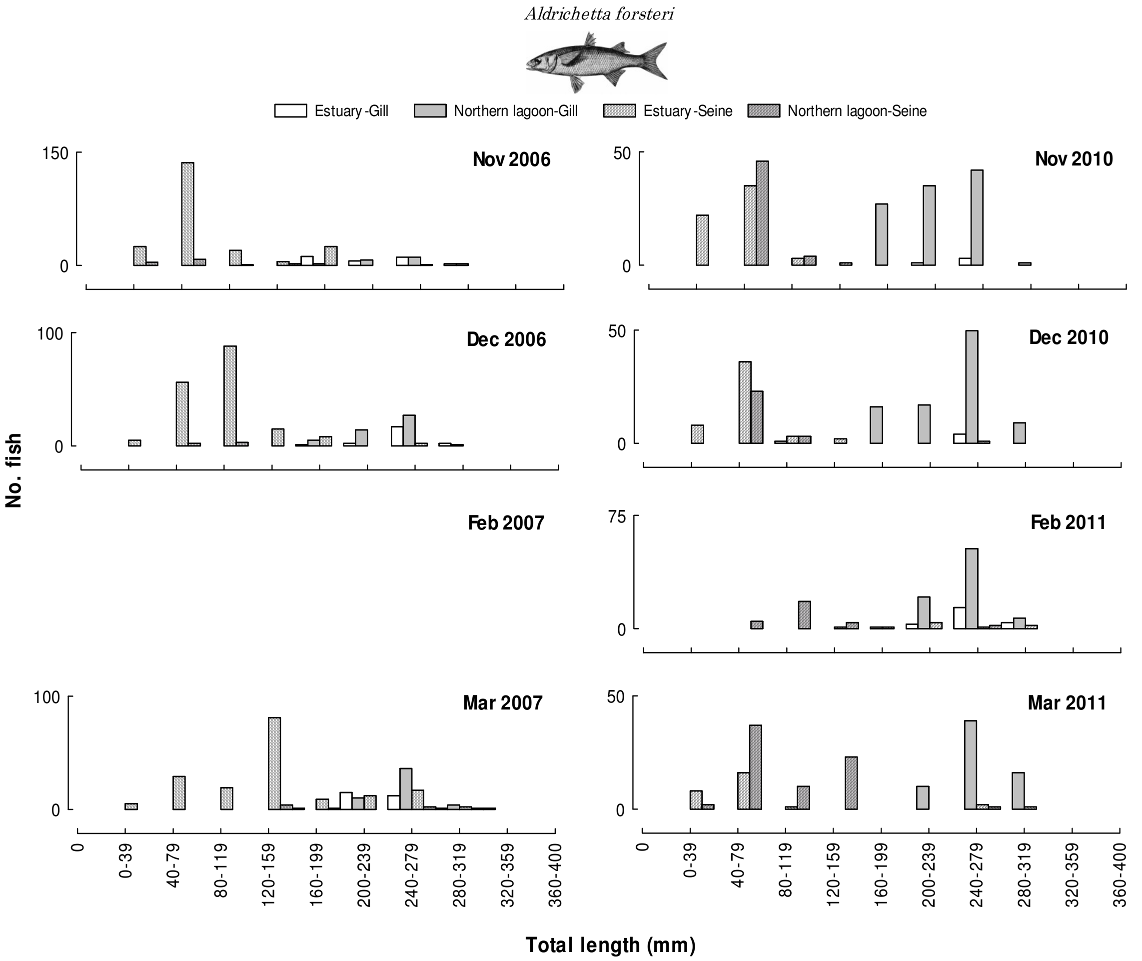

Figure 27. Length frequency distributions of juvenile and adult yelloweye mullet from gill and seine net samples in the Estuary and Northern Lagoon subregions of the Coorong in 2006/07 and 2010/11.

4. DISCUSSION

4.1. Barrage flow and salinity

There has been a substantial reduction in the annual freshwater flow to the Coorong in the recent years due to the impact of drought in the MDB. Between 2000/01 and 2006/07, the annual barrage discharge did not exceed 1,000 GL y^{-1}, which was well below the post-regulation mean annual flow (~4,723 GL y^{-1}). From September 2006 to March 2007, all barrage gates were shut and only small amounts of freshwater releases occurred through the barrage fishways (Goolwa ~20 ML day^{-1}; Tauwitchere 20-40 ML day^{-1}) (Zampatti *et al.* 2010). There were no freshwater releases to the Coorong in the subsequent three years (i.e. 2007/08, 2008/09 and 2009/10). In 2010/11, a significant increase in rainfall and flow in the River Murray led to the refill of the Lower Lakes and barrage releases of more than 10,000 GL since September 2010.

Salinities in the Coorong are highly variable, mainly driven by freshwater flows from the River Murray and tidal seawater exchanges through the Murray Mouth (Geddes and Butler 1984). There is typically a strong north to south gradient with increasing salinities. During the previous fish assemblage study in the Coorong (October 2006 to September 2008), with almost no barrage release, the Coorong essentially became a marine/hypersaline environment: mean salinities were 30-43‰ in the Murray Mouth subregion, 61-86‰ in the Northern Lagoon, and 105-164‰ in the Southern Lagoon (Noell *et al.* 2009). These values are higher than those recorded during the 1982 drought, which included a 16-month period of no freshwater inflows (Geddes and Butler 1984), resulting in salinities reaching 80‰ in the Northern Lagoon and 90-100‰ in the Southern Lagoon.

During the current intervention monitoring, freshwater input caused a significant reduction in salinity; between November 2010 and March 2011, mean salinities were 1-5‰ in the Murray Estuary, 8-76‰ in the Northern Lagoon, and 54-98‰ in the Southern Lagoon. These levels were somewhat comparable to those in the 1983/84 flow year, when, following a period of substantial flows from the River Murray, the Northern Lagoon became brackish (<30‰) and the Southern Lagoon moderately hypersaline (55-70‰) (Geddes 1987).

4.2. Fish assemblages, species richness and abundance

4.2.1. Total species

A grand total of 29 species was recorded from both seine and gill net samples during the monitoring for barrage releases in 2010/11. The total number of species is similar to that collected during the 2006-2008 study (31 species) over a 24-month period (Noell *et al.* 2009) (Appendix I). Nevertheless, there was a substantial increase in the number of freshwater species (from two to seven species) while a decline of marine species (from fifteen to ten) in this study. The two catadromous species, *Galaxias maculatus* and congolli, and six solely estuarine species were sampled in both studies however there was a slight reduction in species number of estuarine/marine fish. Importantly, all key estuarine species identified by Higham *et al.* (2002) as characteristic of the Murray Estuary and Coorong region were collected in this study.

4.2.2. Seine net samples

During the barrage releases in 2010/11, a total of 80,448 fish were sampled representing 24 species by seine netting, across a total area of ~78,144 m². The overall species richness is comparable to that in the previous study conducted during 2006-2008 (i.e. 26 species) in the Murray Mouth and Coorong region, when a total area sampled was 150,000 m² (Noell *et al.* 2009), whilst the total number of fish collected is higher in the current study. An increase of total fish abundance also occurred at most of the sampling sites in 2010/11, mainly attributed to the increased number and abundance of freshwater species (e.g. bony herring, redfin perch and Australian smelt) and enhanced recruitment of small-bodied estuarine species (e.g. smallmouthed hardyhead). The observed greater species richness at several sites in this study also owes to the presence of freshwater fish that were not collected during 2006/07 (i.e. redfin perch, flat-headed gudgeon, carp, golden perch and goldfish). The collection of juvenile golden perch during this study is particularly significant. As a flood/flow cued spawner, this species was not found to spawn successfully in the lower River Murray during the recent drought years (i.e. 2006-2008) with low/no river flows and stable water levels (Cheshire and Ye 2008; Bucater *et al.* 2009).

Similar to previous studies in the Coorong, a general decline in species richness and diversity with increasing distance from the Murray Mouth was observed in this study, which is likely a response to the strong salinity gradient. Given the increasing osmoregulatory stress and/or diminishing food resources, certain fish taxa were probably forced out of the more saline area (Whitfield 1999). This allows a low number of species that are able to tolerate such environmental conditions to have a broader access to food resource, habitat and space and expand their ecological niche (Colburn 1988).

Smallmouthed hardyhead, an estuarine species that is tolerant of hypersaline and highly variable salinities (Lui 1969; McNeil *et al.* 2011), was the most abundant fish in seine net samples in this study. It comprised 63% of the total number of fish collected and was the only species present in the Southern Lagoon. The dominance of smallmouthed hardyhead was also reported in previous fish studies in the Coorong (Molsher *et al.* 1994; Noell *et al.* 2009; Zampatti *et al.* 2010). This and other small atherinids are important and often dominant species in many temperate Australian estuaries, particularly where salinities are near or above that of seawater (e.g. Potter *et al.* 1993; Potter and Hyndes 1994; Valesini *et al.* 1997; Griffiths and West 1999; Young and Potter, 2002; Hoeksema and Potter 2006).

The second most abundant species was the small-bodied clupeid, sandy sprat, a marine estuarine opportunist species that regularly enter estuaries in large numbers (Potter and Hyndes 1999; Whitfield 1999), and numerically constituted 20% of the total catch. This species spawn in inshore waters of marine environments, with larvae and juveniles entering the Coorong and using the estuary as an important nursery ground (Rogers and Ward 2007).

The next three abundant species, bony herring, redfin perch and Australian smelt, are all freshwater fish, which entered or were displaced into the Murray Estuary and Coorong during the current barrage releases. Freshwater species are commonly present in the upper reaches of estuaries, contributing to species richness and diversity of estuarine fish assemblages (Barletta-Bergan *et al.* 2002; Whitfield *et al.* 2006). In contrast, only a few individuals of the two native freshwater fish (i.e. bony herring and Australian smelt) were caught below the barrages and no redfin perch was sampled throughout the

2006-2008 drought period, when there was lack of freshwater inflows to the Coorong (Noell *et al.* 2009).

A substantial increase of the freshwater exotic species, redfin perch, collected in this study is of concern as a biological threat to the native fish communities in the Lower Lakes and the River Murray. Redfin perch is a predator species that can prey on small native fish (Morgan *et al.* 2002), and it also carries a virus (i.e. Epizootic haematopoietic necrosis) that is potentially damaging to native species (Langdon and Humphrey 1987). Nevertheless, as previously mentioned, the presence of juvenile golden perch indicating spawning success of this iconic native flow/flood-cued species, is a significant, positive environmental outcome of this flow/flood event. There is no doubt that many other native fish species in the River Murray, Lower Lakes and Coorong would have benefited from the recent floods through the increase of fish habitats (extent and diversity), improved connectivity and enhanced productivity.

4.2.3. Gill net samples

The catches by gill nets, which targeted medium-large bodied species, were much less than those by the smaller mesh seine net. Of the 14 species caught using gill nets, nine were adult representatives of species that were also collected using the seine net. The five other species in the gill net samples included two estuarine species and three marine estuarine opportunist species. The seine net, on the other hand, collected 15 species (out of 24) that were not caught using gill nets, 13 of which are small-bodied and/or slender fish.

The most abundant species in gill net samples was the freshwater bony herring, numerically accounting for 82% of the total catch. More than 90% of bony herring were collected from the Northern Lagoon, probably relating to the substantial decline of salinities in this subregion following barrage releases. Although a common freshwater species, bony herring is known to be tolerant of high salinities (as well as high temperatures, high turbidities and low dissolved oxygen) (Briggs and McDowall 1996; Lintermans 2007). Nevertheless, its occurrence in the Northern Lagoon, in this study, at salinities as high as 68‰ probably represents the upper salinity tolerance for this species.

The second and third most abundant species were marine estuarine opportunist yelloweye mullet and Western Australian salmon. These two species were also common in several south-western Australian estuaries (Potter and Hyndes 1999). For yelloweye mullet, the majority (96%) of the gill net catch (adult representatives) came from the Northern Lagoon, likely reflecting a greater southward distribution of this species following barrage releases and salinity decreases. Although yelloweye mullet is known to tolerate high salinities, Noell *et al.* (2009) recorded the maximum salinity of 74‰ where this species was collected in the Coorong.

The general increase in species richness and fish abundance across most sites was mainly due to the presence and increased abundance of freshwater species in the Coorong following barrage releases. In the 2006-2008 study, only one freshwater species, bony herring, was collected in small numbers using gill nets in the Coorong. In contrast, five large-bodied freshwater species were present in this study and three of them occurred in the Northern Lagoon, where salinities ranged from 8-76‰.

4.3. Spatiotemporal variation in fish assemblage structure and link to salinity

During the current barrage releases, fish assemblages changed significantly for both seine net and gill net samples in the Coorong compared to data collected during the drought year (i.e. 2006/07). In general species richness and abundance of freshwater fish increased, and the abundance of several small-bodied estuarine species (e.g. smallmouthed hardyhead and Tamar goby) and estuarine opportunist species (e.g. sandy sprat) increased during 2010/11. The composition of fish assemblages in the Coorong changed from the typical drought marine/estuarine assemblages of 2006-2008 (Noell *et al.* 2009) to freshwater/estuarine dominant assemblages during the current flow event. With the barrage opening and the significant reduction of salinities, the Murray Estuary and a large part of the Northern Lagoon became brackish (<35‰). In estuaries with freshwater influence, it is typical that fish communities consist of estuarine residents along with freshwater and marine species that penetrate into the brackish reaches of systems, which often results in high species diversity and richness (Potter and Hyndes 1999; Whitfield *et al.* 2006). The increased abundance of several small-bodied estuarine species (resident or opportunist) in this study indicated enhanced recruitment, which was likely a result of reduced salinities in the Coorong and the restoration/extension of estuarine habitats. These biological responses may suggest an initial recovery of the estuarine fish assemblages following the flow event, which addresses the first question regarding ecological response and recovery for fish intervention monitoring.

The importance of freshwater inflow and the responses of estuarine communities to variable inflows have been documented (e.g. Copeland 1966; Drinkwater 1986; Drinkwater and Frank 1994; Loneragan and Bunn 1999; Galindo-Bect *et al*. 2000; Quiñones and Montes 2001; Robins *et al*. 2005; Zampatti *et al.* 2010). Freshwater flows can influence fish species that inhabit estuaries directly through changes in physico-chemical conditions (e.g. turbulence, water quality variables, nutrient status), or indirectly through affecting primary and secondary productivity, habitat availability and quality, thereby influencing fish growth and recruitment (and subsequent abundance) (Whitfield 2005; Robins and Ye 2007). It is generally recognised that freshwater inflows have positive impacts on estuarine dependent fish species in regard to necessary biological processes such as spawning, nursery and protection, food availability, and recruitment (Drinkwater and Frank 1994; Gillanders and Kingsford 2002).

In the current study, salinity was identified, in concert with other water quality variables, as the main driver influencing spatiotemporal patterns of fish assemblage structure in the Coorong. The effects of a large salinity gradient, ranging from saline (~30‰) in the Estuary to extreme hypersaline (168‰) in the Southern Lagoon, on the fish assemblages along the length of the Coorong were also described by Noell *et al.* (2009) during an extended drought period for the region, indicating the influence of this spatial gradient under varying flow conditions. It has been recognized for some time that salinity is an overwhelmingly important factor influencing the ecological health of the Coorong (e.g. Geddes and Butler 1984; Geddes 1987, 2003, 2005; Brookes *et al.* 2009).

4.4. Temporal changes in distribution, abundance, and recruitment of key species

Following the barrage releases and salinity reductions in the Coorong, there was a southward extension in the distribution of adult black bream, and also likely congolli and yelloweye mullet, and possibly greenback flounder. The black bream data support the hypothesis regarding a greater southward distribution of some species following salinity reductions. For the later three species, comparisons and definitive conclusions cannot be made regarding range extensions because the most southerly site where they were present in the Northern Lagoon in this study was not sampled in 2006/07. Black bream, congolli and yelloweye mullet were also reported to occur in the northern part of the Southern Lagoon during 1983/84 when salinities fell as low as 55‰ following above average barrage flows (Geddes 1987).

Several small-bodied estuarine/opportunist species (e.g smallmouthed hardyhead, Tamar goby and sandy sprat) and the catadromous congolli showed a strong recruitment response to the current flow event and subsequently their abundances increased remarkably in the Coorong, with many new recruits occurring in the Northern Lagoon where they were formerly absent or less abundant. The results address the second question regarding the recruitment response of key species for the intervention monitoring and support the hypotheses linking to the third question regarding the restoration of nursery grounds for estuarine fish species in the Northern Lagoon. Although smallmouthed hardyhead were still the sole species caught in the Southern Lagoon, their abundance was more than two orders of magnitude greater in this study than that in 2006/07 with a salinity reduction from the previous 105-164‰ to the current 54-98‰. Such a response of this keystone species has a high ecological significance, given smallmouthed hardyhead provide important ecological services, in particular as a major food item for various piscivorous fish and water birds in this Ramsar region (Paton 1982; Rogers and Paton 2009; Deegan *et al.* 2010). As an obligate migratory catadromous species, recruitment success in congolli is strongly dependent upon the connectivity between marine, estuarine and freshwater habitats, and river inflows to the Coorong that likely produce favourable environmental conditions (Zampatti *et al.* 2010). The importance of freshwater flows for the recruitment of congolli and other catadromous species (i.e. *Galaxias maculatus*) has been previously documented in the Murray Estuary (Bice *et al.* 2007; Jennings *et al.* 2008; Zampatti *et al.* 2010).

The recruitment of greenback flounder appeared to be slightly improved in the Estuary subregion, where salinities dropped to less than 5‰ during the barrage releases. In contrast, the estuarine opportunist yelloweye mullet seemed to have moved into the Northern Lagoon (salinities 8-76‰), where their abundance increased. Yelloweye mullet have a relatively high salinity tolerance (McNeil *et al.* 2011), probably allowing them to explore more saline environments. It should be noted that while the adult black bream exhibited a range expansion into the Northern Lagoon, no juvenile black bream were collected during this study. This might be an artifact of reduced sampling efficiency during the high flows (e.g. reduced fish density, dispersion or re-distribution, shifted location of favorable estuarine habitats). If this was the case, it is hypothesised that future fish monitoring would detect this cohort in subsequent years. Several studies have related recruitment success of black bream to freshwater inflows and associated factors such as the 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). Interestingly, Ye *et al.* (2011) found that the two strong cohorts (i.e. 1997/98 and 2003/04) of the Coorong population were associated with 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 regimes are probably crucial as 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. Therefore, environmental flow management should consider flow regimes (i.e. timing, frequency, duration, etc) in concert with water allocation.

Whilst many estuarine associated species, particularly small-bodied fish, have shown signs of a positive response to the current barrage outflow, mulloway, a marine estuarine opportunist species, had a reduction in abundance in the Coorong during the current sampling event. This is not unexpected given the very low salinities in the Murray Estuary following substantial freshwater inflows over an unusually long period in 2010/11. Nevertheless, freshwater flows are believed to be important for the recruitment of mulloway (Ferguson *et al.* 2008), which attract spawning aggregations of reproductively mature and sub-mature adults at the interface of the River Murray plume during the spring-summer (November to March) period (Hall 1984; Ferguson *et al.* 2008). Larval development is thought to occur at sea with juveniles entering the Murray Mouth several months later at 100-150 mm total length (Hall 1986). Therefore, it was probably too early to detect recruitment response of this species during the current study. Given that the Coorong represents an important nursery and feeding ground for mulloway (Ferguson *et al.* 2008), it is hypothesised that future fish monitoring would detect the 2010/11 cohort in subsequent months/years in the region.

5. CONCLUSIONS

Freshwater inflows play an important role in structuring fish assemblages in the Murray Estuary and Coorong, maintaining estuarine habitats and facilitating the recruitment of estuarine and catadromous species. Following the barrage releases in 2010/11, salinities fell significantly from previously ranging between marine and extremely hypersaline (up to 168‰) to the current levels of 1-5‰ in the Estuary, 8-76‰ in the Northern Lagoon, and 54-98‰ in the Southern Lagoon. Broadly decreased salinities, coupled with other freshwater induced environment changes, have elicited significant ecological responses in fish assemblages in the region. The fish assemblage composition changed significantly compared to that of the drought years, mainly attributed to an increase in the diversity and abundance of freshwater species, and increased abundances of small-bodied estuarine/opportunist species (smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (congolli) following enhanced recruitment. The freshening of the Coorong also resulted in a southward range expansion of some key species, such as black bream (adult), probably yelloweye mullet and congolli, and possibly greenback flounder. For the later three species, comparisons and definitive conclusions cannot be made because the most southerly site where they were present in the Northern Lagoon in 2010/11 was not sampled in 2006/07. Length frequency distributions indicated successful recruitment for most of the key species (i.e. smallmouthed hardyhead, Tamar goby, yellow-eye mullet, sandy sprat, congolli and greenback flounder), and many new recruits occurred in the Northern Lagoon where they were formerly absent or less abundant. The dramatic increase in smallmouthed hardyhead abundance in the Southern Lagoon following salinity reductions (to <100‰) was likely a combined result of a range extension of this species from the Northern Lagoon, enhanced recruitment, and the dispersion of the remnant population and new recruits from the Salt Creek into the Southern Lagoon. This is of particular ecological significance, given the important role this keystone species plays in the trophic ecology of the region.

Current intervention monitoring for barrage releases indicated some signs of early ecological recovery, particularly in respect to the responses of small-bodied estuarine fish and catadromous congolli, following years of no/low freshwater inflows into the Murray Estuary and Coorong. The results support the hypotheses regarding the recovery of estuarine fish assemblages, enhanced recruitment and a southward range expansion for some species. However, it is uncertain how/whether some important large-bodied estuarine dependent species (e.g. black bream and mulloway) will benefit from the current and potentially future freshwater inflows to the Coorong. Further monitoring will be required in subsequent years to continue to investigate the response and recovery of the estuarine fish assemblage and assess the recruitment response of key large-bodied estuarine species to flow events. Data collected in this and future studies will form an important basis for environmental water allocation and adaptive management to ensure the long-term ecological sustainability of the CLLMM region.

6. REFERENCES

Akaike, H. (1973). Information theory as an extension of the maximum likelihood principle. In Proceedings, *2nd International Symposium on Information Theory* (Petrov, B. N. & Caski, F., eds), 267-281. Akademiai Kiado, Budapest.

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

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

Barletta-Bergan, A., Barletta, M., and Saint-Paul, U. (2002). Structure and seasonal dynamics of larval fish in the Caete River Estuary in North Brazil. *Estuarine, Coastal and Shelf Science* **54**, 193–206.

Bice, C. M., Jennings, P. R. and Zampatti, B. P. (2007). *Fish movement and recruitment in the Coorong and Lower Lakes: 2006/07 progress report.* South Australian Research and Development Institute (Aquatic Sciences): Adelaide, South Australia. SARDI Aquatic Sciences Publication No. 2007/000555-1, SARDI Research Report Series No. 232.

Briggs, I. C. and McDowall, R. M. (1996). Family Clupeidae: Herrings. *In Freshwater Fishes of Southeastern Australia* (McDowall, R. M., ed.), 44-47. Reed Books: Sydney.

Brookes, J.D., Lamontagne, S., Aldridge, K. T., Benger. S., Bissett, A., Bucater, L., Cheshire, A.C., Cook, P.L.M., Deegan, B.M., Dittmann, S., Fairweather, P.G., Fernandes, M.B., Ford, P.W., Geddes, M.C., Gillanders, B.M. , Grigg, N.J., Haese, R.R., Krull, E., Langley, R.A., Lester, R.E., Loo, M., Munro, A.R., Noell, C.J., Nayar, S., Paton, D.C., Revill, A.T., Rogers, D.J., Rolston, A., Sharma. S.K., Short, D.A., Tanner, J.E., Webster, I.T., Wellman, N.R. and Ye, Q. (2009). *An Ecosystem Assessment Framework to Guide Management of the Coorong.* Final Report of the CLLAMMecology Research Cluster. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Bucater, L., Cheshire, K. and Ye, Q. (2009). *Fish spawning in the Lower River Murray icon sites, South Australia: With reference to drought intervention monitoring.* SARDI research report series number: 377, SARDI Aquatic Sciences Publication Number F2009/000360-1, SARDI Aquatic Sciences, Adelaide, South Australia.

Burnham, K. P. and Anderson, D. R. (2002). *Model Selection and Multi-model Inference: a Practical Theoretic-Information Approach,* 2nd Edition. Springer, New York.

Cheshire, K. and Ye, Q. (2008). *Spatial and temporal variations in larval fish assemblages between Locks 1 and 6 in the River Murray, South Australia: with reference to drought intervention monitoring 2007.* SARDI research report series number: 304, SARDI Aquatic Sciences Publication Number F2008/000685-1, SARDI Aquatic Sciences, Adelaide, South Australia.

Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18**, 117-143.

Clarke, K. R. and Warwick, R. M. (2001). *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation.* PRIMER-E Ltd: Plymouth, UK.

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

Copeland, B.J. (1966). Effects of decreased river flow on estuarine ecology. *Water Pollution Control Federation* **38**, 1831-1839.

Deegan, B. M., Lamontagne, S., Aldridge, K.T. and Brookes, J.D. (2010). *Trophodynamics of the Coorong. Spatial variability in food web structure along a hypersaline coastal lagoon*. CSIRO: Water for a Healthy Country National Research Flagship.

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

Drinkwater, K.F. (1986). On the role of freshwater outflow on coastal marine ecosystems - a workshop summary. *In Proceedings of the NATO Advanced Research Workshop on The Role of Freshwater Outflow in Coastal Marine Ecosystems*. (Ed. S. Skreslet.) pp. 429-438. (Springer-Verlag: Heidelberg, Germany.)

Drinkwater, K.F. and Frank, K.T. (1994). Effects of river regulation and diversion on marine fish and invertebrates. Aquatic Conservation: *Freshwater and Marine Ecosystems* **4**, 135-151.

DWLBC (2008). *Murray Mouth Sand Pumping Program – Progress Report 2002 to 2008*. South Australia. Department of Water, Land and Biodiversity Conservation, June 2008, p. 1-14.

Ferguson, G. J., Ward, T. M. and Geddes, M. C. (2008). Do recent age structures and historical catches of mulloway, Argyrosomus japonicus (Sciaenidae), reflect freshwater inflows in the remnant estuary of the Murray River, South Australia? *Aquatic Living Resources* **21**, 145–152.

Galindo-Bect, M.S., Glenn, E.P., Page, H.M., Fitzsimmons, K., Galindo-Bect, L.A., Hernandez-Ayon, J.M., Petty, R.L., Garcia-Hernandez, J. and Moore, D. (2000). Penaeid shrimp landings in the upper Gulf of California in relation to Colorado River freshwater discharge. *Fishery Bulletin* **98**, 222-225.

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

Geddes, M. C. (2003). *Survey to investigate the ecological health of the North and South Lagoons of the Coorong, June/July 2003*. Report prepared for the Department of Environment and Heritage and the Department of Water, Land and Biodiversity Conservation. South Australian Research and Development Institute (Aquatic Sciences): Adelaide, South Australia. SARDI Aquatic Sciences Publication No. RD03/0103.

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

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

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

Griffiths, S. P. and West, R. J. (1999). Preliminary assessment of shallow water fish in three small intermittently open estuaries in south-eastern Australia. *Fisheries Management and Ecology* **6**, 311-321.

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

Hall, D. A. (1986). *An assessment of the mulloway (Argyrosomus hololepidotus) fishery in South Australia with particular reference to the Coorong lagoon*. Department of Fisheries, South Australia.

Higham, J., Hammer, M. and Geddes, M. (2002). *Fish and invertebrates, In The Murray Mouth: Exploring the Implications of Closure or Restricted Flow* (Murray-Darling Basin Commission), pp. 53-63. Murray-Darling Basin Commission: CanberraHoeksema.

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

Hoeksema, S. D., Chuwen, B. M., Hesp, S. A., Hall, N. G. and Potter, I. C. (2006). *Impact of the environmental changes on the fish faunas of Western Australia south-coast estuaries'*. Perth, Centre for Fish and Fisheries Research. Murdock University:1-191.

Jennings, P. R., Zampatti, B. P. and Bice, C. M. (2008). *Fish movement and recruitment in the Coorong and Lower Lakes: 2007/08 progress report.* South Australian Research and Development Institute (Aquatic Sciences): Adelaide, South Australia. SARDI Aquatic Sciences Publication No. F2007/000555-2, SARDI Research Report Series No. 302.

Langdon, J.S. and Humphrey, J.D. (1987). Epizootic haematopoietic necrosis, a new viral disease in redfin perch, Perca fluviatilis L., in Australia. *Journal of Fisheries Disease* **10**, 289–297.

Lintermans, M. (2007). *Fishes of the Murray-Darling Basin: An Introductory Guide*. Murray-Darling Basin Commission: Canberra, Australia.

Loneragan, N.R. and Bunn, S.E. (1999). River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. *Australian Journal of Ecology* **24**, 431-440.

Lui L. (1969). Salinity tolerance and osmoregulation of Taeniomembers microstomus (Gunther, 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. *Marine and Freshwater Research* 20(2), 157-162. (doi: 10.1071/MF9690157).

McNeil D. G., Westergaard S., Cheshire K. J. M., Ye Q. and Noell, C. J. (2011). *Chapter 4: Effects of hyper-saline conditions upon six estuarine fish species from the Coorong and Murray Mouth. In Flow related fish and fisheries ecology in the Coorong, South Australia.* (Eds Q. Ye, K.J. Cheshire and C. J. Noell) pp. 150-173. (South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. TBA. SARDI Research Report Series No. TBA).

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

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

Morgan, D.L., Hambleton, S.J., Gill, H.S. and Beatty, S.J. (2002) Distribution, biology and likely impacts of the introduced redfin perch (Perca fluviatilis) (Percidae) in Western Australia. *Marine and Freshwater Research* **53**, 1211–1221.

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

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

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

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

Paton, P. (1982). *Biota of the Coorong.* (South Australian Department of Environment and Planning, Publication No. 55, Adelaide).

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

Potter, I. C. and Hyndes, G. A. (1994). Composition of the fish fauna of a permanently open estuary on the southern coast of Australia, and comparisons with a nearby seasonally closed estuary. *Marine Biology* **121**, 199-209

Potter, I. C. and Hyndes, G. A. (1999). Characteristics of the ichthyofaunas of southwestern Australian estuaries, including comparisons with holarctic estuaries and estuaries elsewhere in temperate Australia: A review. *Australian Journal of Ecology* **24**, 395-421.

Potter, I. C., Hyndes, G. A. and Baronie, F. M. (1993). The fish fauna of a seasonally closed Australian estuary. Is the prevalence of estuarine-spawning species high? *Marine Biology* **116**, 19-30.

Quiñones, R.A. and Montes, R.M. (2001). Relationship between freshwater input to the coastal zone and the historical landings of the benthic/demersal fish Eleginops maclovinus in central-south Chile. *Fisheries Oceanography* **10**, 311-328.

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

Robins J.B., Halliday I.A., Staunton-Smith J., Mayer D.G. and Sellin, M.J. (2005). Freshwater-flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach. *Marine and Freshwater Research* **56**, 343-360.

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

Rogers, P. J., and Ward, T. M. (2007). Life history strategy of sandy sprat Hyperlophus vittatus (Clupeidae): a comparison with clupeoids of the Indo–Pacific and southern Australia. *Journal of Applied Ichthyology* **23**,583–591.

Valesini, F. J., Potter, I. C., Platell, M. E. and Hyndes, G. A. (1997). Ichthyofaunas of a temperate estuary and adjacent marine embayment. Implications regarding choice of nursery area and influence of environmental changes. *Marine Biology* 128, 317-328.

Whitfield, K. A. (1999). Ichthyofaunal assemblages in estuaries: a South African case study. *Reviews in Fish Biology and Fisheries* **9**, 151-186.

Whitfield, K. A. (2005). Fishes and freshwater in southern African estuaries – a review. *Aquatic Living Resources* 18, 275-289.

Whitfield, A. K., Taylor, R. H., Fox, C., and Cyrus, D. P. (2006). Fishes and salinities in the St Lucia estuarine system – a review. *Reviews in Fish Biology and Fisheries* **16**, 1–20.

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.

Young, G. C. and Potter, I. C. (2002). Influence of exceptionally high salinities, marked variations in freshwater discharge and opening of estuary mouth on the characteristics of the ichthyofauna of a normally-closed estuary. *Estuarine, Coastal and Shelf Science* **55**, 223-246.

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

APPENDIX I.

A comparison of fish species collected during the 2010/11 barrage releases intervention monitoring and in the 2006-08 drought years in the Coorong. Red – species only collected in 2010/11; blue – species only collected in the 2006-2008 study. Life history classification: 'C' catadromous; 'E' solely estuarine; 'E&M' estuarine and marine; 'FE' freshwater exotic; 'FN' freshwater native; 'O' marine estuary opportunist; 'S' marine straggler.

Year	2010/11		2006-2008	
ID	**Scientific Name**	**Classification**	**Scientific Name**	**Classification**
1	*Galaxias maculatus*	C	*Galaxias maculatus*	C
2	*Pseudaphritis urvilli*	C	*Pseudaphritis urvillii*	C
3	*Acanthopagrus butcheri*	E	*Acanthopagrus butcheri*	E
4	*Afurcagobius tamarensis*	E	*Afurcagobius tamarensis*	E
5	*Atherinosoma microstoma*	E	*Atherinosoma microstoma*	E
6	*Hyporhamphus regularis*	E	*Hyporhamphus regularis*	E
7	*Pseudogobius olorum*	E	*Pseudogobius olorum*	E
8	*Tasmanogobius lasti*	E	*Tasmanogobius lasti*	E
9	*Arenigobius bifrenatus*	E&M	*Arenigobius bifrenatus*	E&M
10	*Contusus brevicaudus*	E&M	Family Tetraodontidae	E&M
11	*Liza argentea*	E&M	*Liza argentea*	E&M
12	*Rhombosolea tapirina*	E&M	*Rhombosolea tapirina*	E&M
13	*Carassius auratus*	FE	*Engraulis australis*	E&M
14	*Cyprinus carpio*	FE	*Hyporhamphus melanochir*	E&M
15	*Perca fluviatilis*	FE	*Nematolosa erebi*	F
16	*Macquaria ambigua*	FN	*Retropinna semoni*	F
17	*Nematolosa erebi*	FN	*Aldrichetta forsteri*	O
18	*Philypnodon grandiceps*	FN	*Ammotretis rostratus*	O
19	*Retropinna semoni*	FN	*Argyrosomus hololepidotus*	O
20	*Aldrichetta forsteri*	O	*Arripis georgianus*	O
21	*Ammotretis rostratus*	O	*Arripis truttaceus*	O
22	*Argyrosomus hololepidotus*	O	*Gymnapistes marmoratus*	O
23	*Arripis georgianus*	O	*Heteroclinus heptaeolus*	O
24	*Arripis truttaceus*	O	*Hyperlophus vittatus*	O
25	*Favonigobius lateralis*	O	*Myliobatis australis*	O
26	*Gymnapistes marmoratus*	O	*Mugil cephalus*	O
27	*Hyperlophus vittatus*	O	*Pomatomus saltatrix*	O
28	*Mugil cephalus*	O	*Pelates octolineatus*	O
29	*Sillago schomburgkii*	O	*Sardinops neopilchardus*	S
30			*Stigmatopora argus*	S
31			*Pseudocaranx dentex*	S