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Fish response to barrage releases in 2011/12, and recovery following the recent drought in the Coorong

Qifeng Ye, Luciana Bucater, David Short and Juan Livore

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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 an 'Icon Site' under the Murray-Darling Basin (MDB) Authority's *Living Murray* program. From 2001 to 2010, the Coorong ecosystem became increasingly degraded due to the protracted drought in the MDB, and subsequent lack of freshwater inflows, increases in salinity, and loss of connectivity between freshwater and estuarine/marine habitats. Many native fish that reside in the Coorong estuary and depend upon its habitat as a breeding, nursery and feeding area were negatively impacted. In 2010/11, increased flows in the River Murray led to significant barrage releases (~13,000 GL y^{-1}) into the Coorong. Broadly decreased salinities in the Coorong, coupled with other freshwater induced environment changes, elicited significant ecological responses in fish assemblages in the region. These included an increase in the diversity and abundance of freshwater species; enhanced recruitment and subsequent abundances of small-bodied estuarine/opportunist species (smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (congolli); and a southward range expansion for several key species, such as black bream (Ye *et al.* 2011a). Ongoing high flow conditions and barrage releases in 2011/12 provided a unique opportunity to continue investigating the responses of estuarine fish assemblages and their recovery following the recent drought. The monitoring undertaken in this study augments the data collected during 2010/11 and was compared against fish baseline information collected during the severe drought in 2006/07 (Noell *et al.* 2009).

With further barrage releases in 2011/12, salinities in the Coorong remained similar to 2010/11 with mean values ranging between 0-14 psu in the Murray Estuary, 11-71 psu in the North Lagoon, and 86-94 psu in the South Lagoon. In comparison with 2010/11, freshwater species continued to be present in the Murray Estuary and Coorong region, although abundance declined and ranges contracted to the Estuary subregion except for bony herring. Furthermore, fish assemblage structure (seine net catch) changed in the Murray Estuary in 2011/12 due to the greater abundances of estuarine opportunistic species (sandy sprat, yelloweye mullet and Australian salmon) than the previous year; whilst in the North Lagoon the change in 2011/12 was due to the dominance of sandy sprat, estuarine resident species (Tamar goby and river garfish) and catadromous congolli. For large-bodied species (gill net catch), increased abundance of Australian salmon was the key driver for the between year fish assemblage difference in the Estuary; whilst the change from 2010/11 to 2011/12 was not as distinct in the North Lagoon.

During 2011/12, fish populations of most key species (including native freshwater species) in the Coorong maintained similar distributional ranges to those observed in 2010/11, while others extended their distribution further southward (black bream, yelloweye mullet, sandy sprat and Tamar goby). Diadromous and estuarine fish continued to recruit in 2011/12; importantly the recruitment success of congolli and mulloway was confirmed by age structure data, showing strong year classes for 2010/11 and 2011/12. Estuarine condition (i.e. salinity) was maintained in the North Lagoon, which provides suitable nursery grounds for many fish species (catadromous, small-bodied and large-bodied estuarine resident and opportunistic species). In 2011/12, smallmouthed hardyhead maintained their presence and further increased in abundance in the South Lagoon; spawning and recruiting successfully in this subregion.

The positive responses in fish assemblages following the significant flows of 2010/11, and further flows in 2011/12 indicate some early signs of recovery in the Coorong ecosystem. However, it is of concern that black bream, an iconic estuarine resident species, showed no signs of population recovery in the Coorong, and the overall population trajectory was uncertain for other large-bodied species (i.e. greenback flounder and mulloway). Population recovery for such relatively long-lived large-bodied species could take years. Further monitoring will be required in subsequent years to continue to investigate the biological performance of these commercially important species and evaluate the effects and potential benefits of freshwater inflows on these species in the Coorong. The current study suggests that environmental water management should consider the importance of flow regimes incorporating small to moderate freshwater releases which could enhance recruitment for some species (as implied by strong cohorts of black bream produced in low-moderate flow years). In addition, conservation management should seek to protect the remnant populations of these species and rebuild the age structures to improve capacity for egg production and thus enhance population resilience.

Further research is required to determine the environmental factors and/or mechanisms, including flow regimes, critical habitat and food resources that contribute to recruitment success for key estuarine fish species. In addition, research is needed to improve our understanding of the dynamic movement patterns of estuarine and marine/estuarine opportunistic species within the Coorong and between the Coorong, freshwater and marine environments under different flow conditions. Such knowledge will facilitate the development of well-informed ecologically sustainable management strategies for estuarine fish populations in the dynamic ecosystem of the Coorong. Finally, it should be emphasised that long-term monitoring data and robust science are important to underpin adaptive management, including the use of environmental flows, 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 as a wetland of international importance under the Ramsar convention, 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 and economic and cultural values (Murray-Darling Basin Commission 2006).

The Coorong is a long (~110 km) and narrow (<4 km wide) estuarine lagoon system with a strong north-south salinity gradient, generally ranging from brackish/marine in the Murray Mouth area to hypersaline in the North and South Lagoons (Geddes and Bulter 1984; Geddes 1987). Salinities are spatio-temporally variable and highly dependent on freshwater inflows from the River Murray, with varied salinities supporting different ecological communities (Brookes *et al.* 2009). In addition, the southern end of the South Lagoon receives small volumes of fresh/brackish water (~10.2 GL y^{-1}) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek.

As the terminal system of the Murray-Darling Basin (MDB), the Coorong region has been heavily impacted by river regulation and water extraction since European settlement. The average annual flow at the Murray Mouth has declined by 61% (from 12,333 GL y^{-1} to 4,733 GL y^{-1}; CSIRO 2008). The construction of five tidal barrages in the 1940s significantly reduced the extent of the original Murray Estuary, establishing an abrupt physical and ecological barrier between the marine and freshwater systems. In past years, the impact of river regulation and water extraction was exacerbated by severe drought in the Basin, with very low or no flow releases through the barrages since 2002 (DFW 2010). Subsequently, the Murray Mouth was closed due to siltation, and regular dredging was required to maintain its opening from 2002 (DWLBC 2008) until December 2010. During this period, the Coorong was transformed into a marine/hypersaline environment, with extreme salinities in the South Lagoon leading to severe and continual degradation of critical habitats for nationally listed bird species (Rogers and Paton 2009). Such changes had severe impacts on the region's ecology, compromising the Ramsar ecological character of the system (Brookes *et al.* 2009). Many native fish species that depend on the Coorong Estuary as a refuge, breeding, nursery and feeding ground have been negatively affected

(Noell *et al.* 2009), and recruitment of catadromous fish failed due to lack of connectivity between freshwater, estuarine and marine environments (Zampatti *et al.* 2010).

Since winter 2010, flows in the River Murray have increased significantly, leading to the refilling of the Lower Lakes and substantial barrage releases (12,849 GL y^{-1}) into the Coorong. Intervention monitoring conducted during 2010/11 indicated that broadly decreased salinities in the Coorong, coupled with other freshwater induced environment changes, elicited significant ecological responses in fish assemblages in the region (Ye *et al.* 2011a). These responses included an increase in the diversity and abundance of freshwater species, enhanced recruitment and subsequent abundances of small-bodied estuarine/opportunist species (smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (congolli), and a southward distributional range expansion for several key species, such as black bream (Ye *et al.* 2011a).

In 2011/12, the high flow conditions continued with ongoing freshwater releases to the Coorong. The intervention monitoring was also continued during this period to assess the responses of fish assemblages to barrage releases and investigate any recovery of estuarine and diadromous fish assemblages following the recent drought. The monitoring undertaken in this study augments the data collected during 2010/11 (Ye *et al.* 2011a), and was compared against fish baseline information collected during the severe drought in 2006/07 (Noell *et al.* 2009).

1.2. Objectives

The aim of this project was to conduct intervention monitoring in the Murray Estuary and Coorong to assess fish assemblage responses to barrage releases in 2011/12 and recovery following the recent drought. The specific objectives were:

1. to determine the changes in fish assemblage structure;
2. to determine the abundance and distribution of key species;
3. to investigate recruitment response of key species; and
4. to assess the extent of estuarine fish habitat, including the suitability of the North Lagoon as a nursery ground for key species.

Key species were black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*), smallmouthed hardyhead (*Atherinosoma microstoma*), Tamar goby (*Afurcagobius tamarensis*), yelloweye mullet (*Aldrichetta forsteri*), congolli (*Pseudaphritis urvilli*), mulloway (*Argyrosomus japonicus*) and sandy sprat (*Hyperlophus vittatus*).

Key questions and hypotheses included,

- Would further barrage flows in 2011/12 maintain the presence of freshwater fish species in the Murray Mouth and Coorong region, or would fish assemblage structure change and be dominated by more estuarine species? (**assemblage structure**).
- Fish populations would maintain the ranges observed in the Coorong in 2010/11 (**distribution**).
- Diadromous and estuarine fish would continue to recruit in 2011/12 (**recruitment**).
- Estuarine fish habitat would be maintained in the North Lagoon and serve as a nursery ground for several species (**estuarine habitat**).
- Would smallmouthed hardyhead maintain their presence and abundance in the South Lagoon; would they spawn and recruit in the South Lagoon? (**abundance, distribution, spawning and recruitment**).
- Were there indications of system recovery in 2011/12 following the significant flows of 2010/11 and further flows in 2011/12? (**system recovery**).

2. METHODS

2.1. Field Sampling

Fish sampling was conducted at thirteen sites in the Murray Estuary and Coorong region on four occasions (November 2011, December 2011, February 2012 and March 2012), following the same regime used for the 2010/11 fish intervention monitoring (Ye *et al.* 2011a). Five sites were located near (within 15 km) the Murray Mouth within the Estuary subregion, five in the North Lagoon, and three in the South Lagoon (Table 1 and Figure 1). Each site was sampled during the day with a standard seine net (61 m net length, 29 m wing length (22 mm mesh), 3 m bund length (8 mm mesh); *n* = 3 hauls). The seine net was deployed in a semi-circle, which sampled to a maximum depth of 2 m and swept an area of ~592 m^2. In addition, four of the thirteen sites (two in the Estuary and two in the North Lagoon) were also sampled overnight using sinking composite multi-panel gill nets (five 9 m panels: 38, 50, 75, 115 and 155 mm stretched mesh; *n* = 3). Gill nets were set in the afternoon or night (at 1500-2000 hours), and retrieved the next day 11-19 hours later. Two sites in the South Lagoon were sampled using gill nets on one occasion (March 2012) as exploratory sampling only, due to the likely absence of large-bodied fish species in that subregion. The gill nets had a drop of 2 m and were generally set in water depths less than 2 m and therefore often sampled the entire water column.

All fish collected using seine and gill nets were identified to species level, and the total number of individuals of each species recorded. For the key species, total length measurements were taken to the nearest 1 mm for up to 50 individuals per species per sampling gear type, on each sampling occasion, at each site. Sub-samples of black bream, greenback flounder, mulloway and congolli were collected for age determination by analysis of their otoliths. For black bream, otoliths were prepared using the 'break and burn' method, as described in Ye *et al.* 2002. For greenback flounder, mulloway and congolli, transverse sections were made from the otoliths (Ye *et al.* 2002). For black bream and greenback flounder, fish were also collected from commercial fishers to complement those collected from the fishery-independent sampling, to increase sample sizes and enable more accurate assessment of population age structures. For congolli <80 mm total length (TL) (Cheshire 2005) and greenback flounder <100 mm TL (Earl unpublished data), age determination using otoliths was not undertaken; these fish were assumed to be young of year (0+ year old fish).

On each sampling occasion, a series of physico-chemical parameters (i.e. water temperature, salinity and pH) were measured at 30 cm beneath the water surface using a TPS water quality meter (model 90FL). Water transparency was estimated based on measurements obtained using a Secchi disk. The extreme salinities encountered during the sampling period were beyond the range in which the water quality meter is reliable for dissolved oxygen (DO) readings. Therefore, an equation of state that incorporates temperature and salinity (Sherwood *et al.* 1992) was used to estimate DO for all sites. This estimate provides maximum DO at equilibrium and does not account for potential biological use of oxygen at the time of sampling.

Table 1. Fish sampling sites and methods for barrage release intervention monitoring in the Coorong during 2010-2012.

Site	Latitude (°S)	Longitude (°E)	Distance from mouth (km)	Sampling gear
Murray Estuary (ME)				
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
North 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
South 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

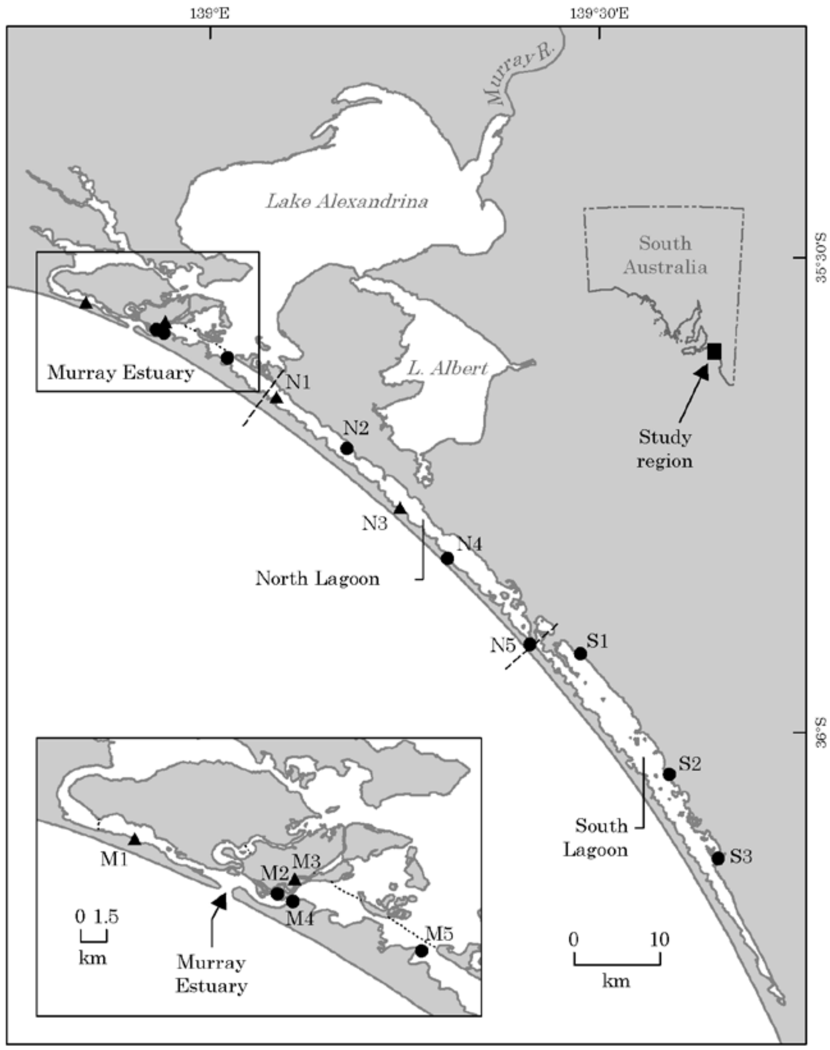

Figure 1. Fish sampling sites for barrage release intervention monitoring in the Coorong. ▲both seine and gill netting ● seine netting only. Dotted lines represent the five barrages and dashed lines show approximate boundaries between the three subregions.

2.2. Life-cycle designations

Each species was categorised as either a marine straggler (S), marine estuarine opportunist (O), estuarine resident (E), estuarine and marine (E&M), catadromous (C) or freshwater native (FN) and exotic (FE), using similar criteria to 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. Estuarine resident 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 biological knowledge for species that occur in the Coorong.

2.3. Multivariate Analysis

Fish assemblage data collected during barrage releases in 2010/11 and 2011/12 were compared with those collected in 2006/07 during the drought period (Noell *et al.* 2009). All multivariate analyses were performed using the PRIMER v6 package (Clarke and Warwick 2001). Note that, the last two years' data (November, December, February and March) were compared against samples collected in November, December and March during 2006/07.

For each gear type, the mean 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, data transformation was performed on the mean relative abundances of fish from both seine net and gill net samples in order to down-weight excessive influence of highly abundant species. Log(x+1) transformation was used for the seine net data because a few species strongly dominated the assemblages with extremely high numbers (e.g. >3000); while square-root transformation was applied for the gill net data to allow the intermediate abundance species to play a part in the similarity. In addition, a dummy species was added to adjust for samples with no catch, and the Bray-Curtis similarity measure was 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. All PERMANOVA analyses used 999 unrestricted permutations of raw data.

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 dissimilarities between groups (Clarke and Warwick 2001).

To model the relationship(s) between fish assemblage structure, as described by the Bray-Curtis resemblance matrix, and one or more water quality predictor variables, we used the DistLM (distance-based linear models) routine based on the *forward* selection procedure using R^2 as the selection criterion (Akaike 1973; Burnham and Anderson 2002). *Forward* selection begins with a null model, containing no predictor variables. The predictor variable with the best value for the selection criterion is chosen first, followed by the variable that, together with the first, improves the selection criterion the most, and so on. Note that it was not necessary to normalise the environmental data prior to running DistLM, because normalisation was 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 parameters that were important in driving variation along dbRDA axes. Four water quality parameters (i.e. salinity, transparency, temperature and pH) were included in the DistLM analysis; DO was not included because no *in situ* measurement data were available.

3. RESULTS

3.1. Barrage Releases

From 1984 – 2012, the Murray Estuary and Coorong experienced substantial fluctuations in freshwater inflows (Figure 2). Between 1989/90 and 1993/94, freshwater inflows to the Estuary were consistently high, with annual discharge ranging between 10,500 and 12,500 GL y^{-1} and peak monthly inflows during spring >2,000 GL m^{-1}. After 1993/94, inflows to the Coorong generally declined, with annual discharges of ~9,000 GL, ~3,000 GL and ~5,000 GL in 1996/97, 1998/99 and 2000/01, respectively. The total discharge from 2001/02 to 2009/10 was below 800 GL per year. In 2006/07, only 78 GL of freshwater flowed into the Coorong. Between 2007/08 and 2009/10, no freshwater was discharged. Following significant increases in inflows in the MDB, there were significant barrage releases in 2010/11 and 2011/12 of ~13,000 GL and ~6,500 GL, respectively. Peak monthly inflow of ~2,400 GL occurred in March 2011 (Figure 2). Monthly inflow remained below 800 GL m^{-1} between October 2011 and March 2012.

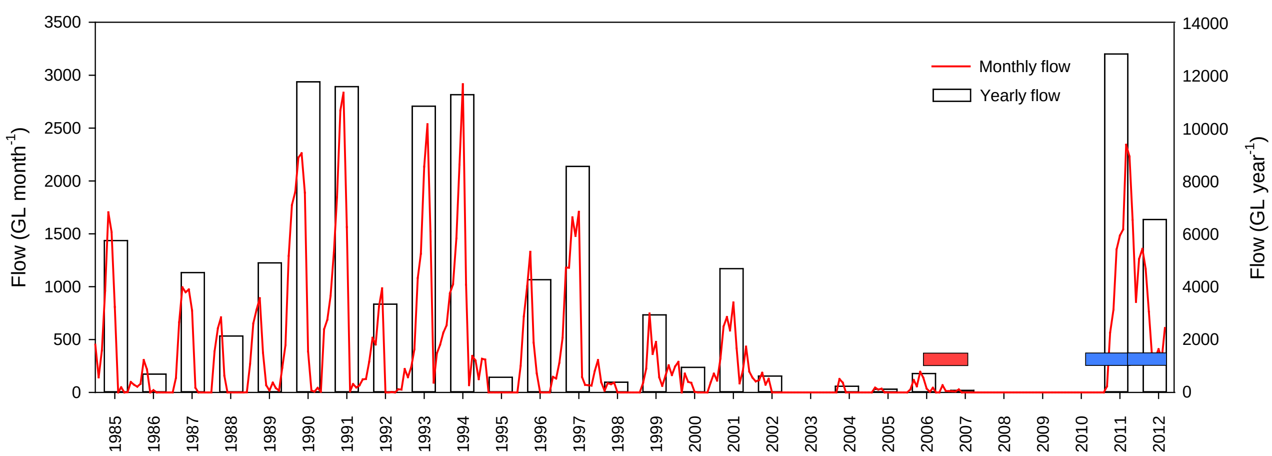

Figure 2. Average annual and monthly freshwater inflows across the barrages from July 1984 to March 2012 (source: MDBA). Red bar indicates sampling period during the drought period in 2006/07 and blue bars indicate intervention monitoring following barrage releases from 2010–12.

3.2. Water Quality

Mean temperature, salinity, DO, pH and transparency (Secchi disk depth) for each sampling site are presented and compared with records for 2006-2007 (Noell *et al.* 2009) (Figure 3). A north-south gradient of increasing salinity was present in all years, however, there were substantial reductions in mean salinity at all sampling sites during the barrage releases in 2010/11 and 2011/12 compared to 2006/07. In 2011/12, salinity increased slightly at some sites in the Estuary and South Lagoon compared to the previous year. During 2006–2008, mean salinities ranged from 32-42 psu in the Murray Estuary, 44-113 psu in the North Lagoon, and 123-129 psu in the South Lagoon. In contrast, salinities declined to 1-5 psu, 8-76 psu and 54-98 psu in 2010/11 and 0-14 psu, 11-71 psu and 86-94 psu in 2011/12, in the respective north to south subregions.

Accompanying River Murray inflows, a decline in transparency and an increase in DO was observed in the Estuary in 2010/11, and in 2011/12 a reduction in transparency occurred throughout the entire Coorong Lagoon (Figure 3). In addition, there was a general increase in pH in the region in 2010/11 and 2011/12 compared to drought years, as well as an increase in water temperature in the South Lagoon in 2011/12.

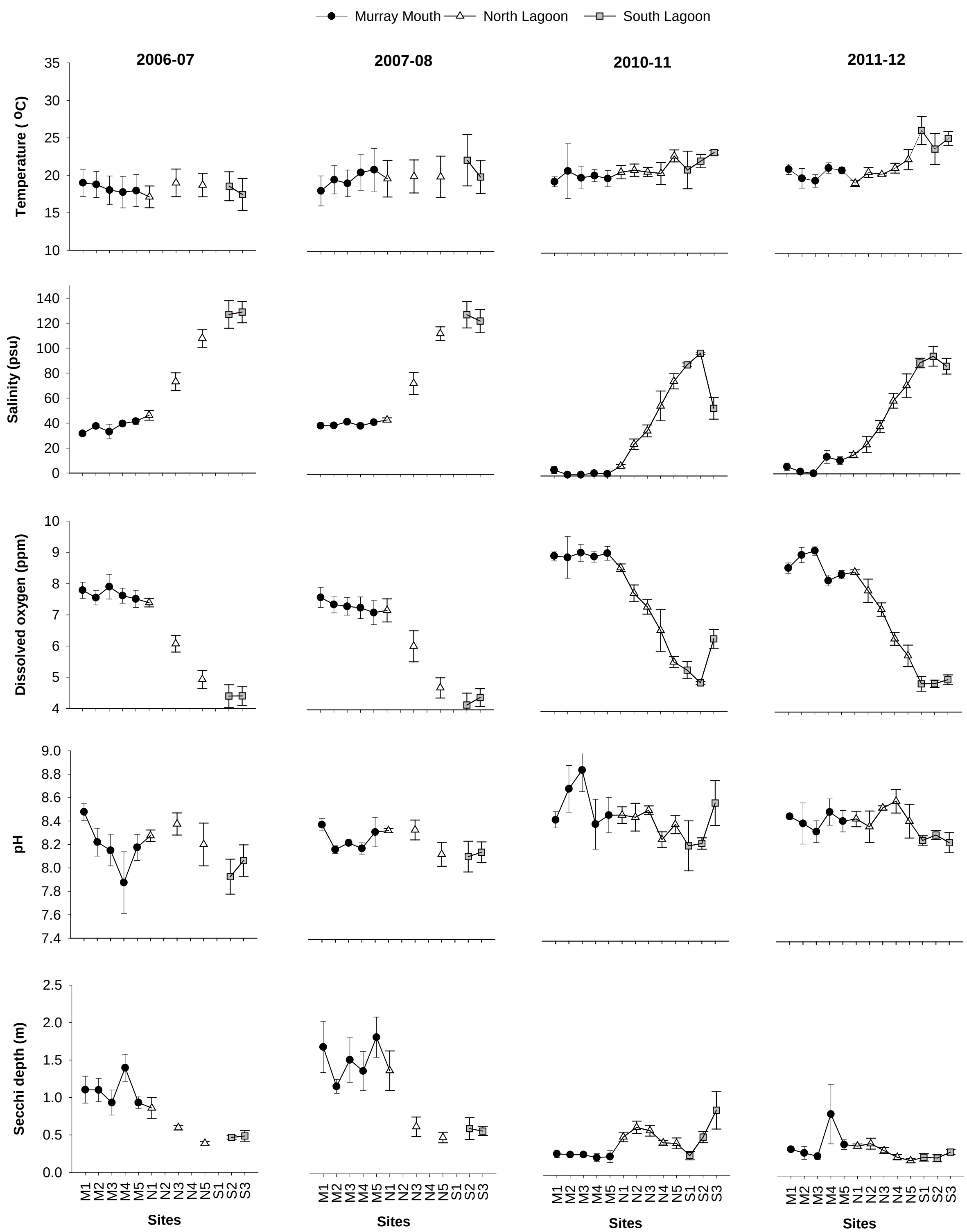

Figure 3. Mean values ± S.E. for water temperature, salinity, dissolved oxygen, pH and Secchi depth for each sampling site (sampling occasions pooled) within the Murray Estuary and Coorong region during 2006/07, 2007/08, 2010/11 and 2011/12 (2006/07 and 2007/08 data sourced from Noell *et al.* 2009).

3.3. Catch summary, species richness and abundance

3.3.1. Seine net samples

A total of 101,389 fish representing 24 species were sampled using seine nets in the Murray Estuary and Coorong in 2011/12 (Table 2). The number of species sampled in 2011/12 was the same as for 2006/07 and 2010/11, although the presence of specific species varied considerably between years. Five out of seven freshwater species were only found during 2010/11 and 2011/12 whilst several marine/estuarine and estuarine opportunistic species were only present during 2006/07.

Smallmouthed hardyhead and sandy sprat were the most abundant species collected in 2011/12, as they were in 2006/07 and 2010/11 (Table 2). The next most abundant were the freshwater species, bony herring and redfin perch, although their abundances were much lower in 2011/12 compared to 2010/11. Several other freshwater species (i.e. Australian smelt, flatheaded gudgeon, carp and golden perch) also had a reduced abundance in this year. In the North Lagoon, only two freshwater species remained in 2011/12 in comparison to six in 2010/11. Nevertheless, almost none of these freshwater fish were present in the Coorong in 2006/07. It is worth noting that in 2011/12, black bream and yelloweye mullet were sampled in the South Lagoon in addition to smallmouthed hardyhead, which was the single species present in this subregion in 2006/07 and 2010/11.

Overall, species richness had a declining trend along the north to south salinity gradient of the Coorong, with no more than two species caught in the South Lagoon at any one time (i.e. smallmouthed hardyhead and either black bream or yelloweye mullet) (Figure 4). In contrast, total abundance of fish generally showed a north to south increasing trend.

Inter-annual variation in species richness and abundance was evident for all sites across the three subregions (Figure 4). There was an increase in the number of species caught at several sites in the North and South Lagoons from 2006/07 to 2011/12; whilst species richness showed an increase from 2006/07 to 2010/11 and then a decrease from 2010/11 to 2011/12 in the Estuary. This pattern was also observed in total abundance in the North Lagoon and at the southern end of the South Lagoon (Salt Creek, S3). Nevertheless, fish numbers showed a remarkable increase over three years at Villa dei Yumpa (S1) and Jack Point (S2) in the South Lagoon.

Table 2. Species and number of fish sampled using a standard seine net during 2010/11 and 2011/12 barrage release intervention monitoring in the Coorong. 2006/07 fish data for relevant months are also presented for comparison. ME = Murray Estuary, NL = North Lagoon and SL = South Lagoon.

				2006/07				2010/11				2011/12			
Common Name	**Scientific Name**	**Species code**	**Classification**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**
Common galaxias	*Galaxias maculatus*	GAL MAC	C	10			10	48	1		49	6			6
Congolli	*Pseudaphritis urvilli*	PSE URV	C	1	3		4	101	45		146	30	48		78
Black bream	*Acanthopagrus butcheri*	ACA BUT	E	13			13					1		1	2
Bluespot goby	*Pseudogobius olorum*	PSE URV	E	3			3	12	2		14		4		4
River garfish	*Hyporhamphus regularis*	HYP REG	E	290	16		306	90	37		127	39	90		129
Scary's Tasman goby	*Tasmanogobius lasti*	TAS LAS	E	8	1		9	68	60		128	69	45		114
Smallmouthed hardyhead	*Atherinosoma microstoma*	ATH MIC	E	1209	12557	35	13801	1,488	33,819	15,636	50,943	330	27,190	30,184	57,704
Tamar goby	*Afurcagobius tamarensis*	AFU TAM	E	35	39		74	941	26		967	41	2		43
Australian anchovy	*Engraulis australis*	ENG AUS	E&M	12			12								
Bridled goby	*Arenigobius bifrenatus*	ARE BIF	E&M	1			1	307			307	23	2		25
Goldspot mullet	*Liza argentea*	LIZ ARG	E&M	2			2	4			4		1		1
Greenback flounder	*Rhombosolea tapirina*	RHO TAP	E&M	127	105		232	242	59		301	103	45		148
Southern garfish	*Hyporhamphus melanochir*	HYP MEL	E&M	6			6								
Carp	*Cyprinus carpio*	CYP CAR	FE					262	3		265	22			22
Goldfish	*Carassius auratus*	CAR AUR	FE					1			1	1			1
Redfin perch	*Perca fluviatilis*	PER FLU	FE					2,900	253		3,153	743			743
Australian smelt	*Retropinna semoni*	RET SEM	FN	1			1	1,148	330		1,478	364	12		376
Bony herring	*Nematolosa erebi*	NEM ERE	FN	3			3	4,267	818		5,085	2,052	69		2,121
Flat-headed gudgeon	*Philypnodon grandiceps*	PHI GRA	FN					844	16		860	6			6
Golden perch	*Macquaria ambigua*	MAC AMB	FN					19	2		21	1			1
Australian herring	*Arripis georgianus*	ARR GEO	O	70			70					3			3
Longsnout flounder	*Ammotretis rostratus*	AMM ROS	O	52	54		106	78	5		83	15	25		40
Sandy sprat	*Hyperlophus vittatus*	HYP VIT	O	3949	287		4236	15,506	246		15,752	17,002	21,740		38,742
Sea mullet	*Mugil cephalus*	MUG CEP	O						1		1				
Soldier	*Gymnapistes marmoratus*	GYM MAR	O	6			6	1	6		7				
Southern eagle ray	*Myliobatis australis*	MYL AUS	O	1			1								
Southern longfin goby	*Favonigobius lateralis*	FAV LAT	O					81	2		83				
Toadfishes	Family Tetraodontidae	-	O	123	1		124	1	3		4	5	7		12
Australian salmon	*Arripis truttaceus*	ARR TRU	O	853	9		862					372	17		389
Yelloweye mullet	*Aldrichetta forsteri*	ALD FOR	O	918	29		947	484	185		669	383	295	1	679
Mulloway	*Argyrosomus japonicus*	ARG JAP	O	57			57								
Total				**7,750**	**13,101**	**35**	**20,886**	**28,893**	**35,919**	**15,636**	**80,448**	**21,611**	**49,592**	**30,186**	**101,389**
% catch				**37**	**63**	**0**		**36**	**45**	**19**		**21**	**49**	**30**	

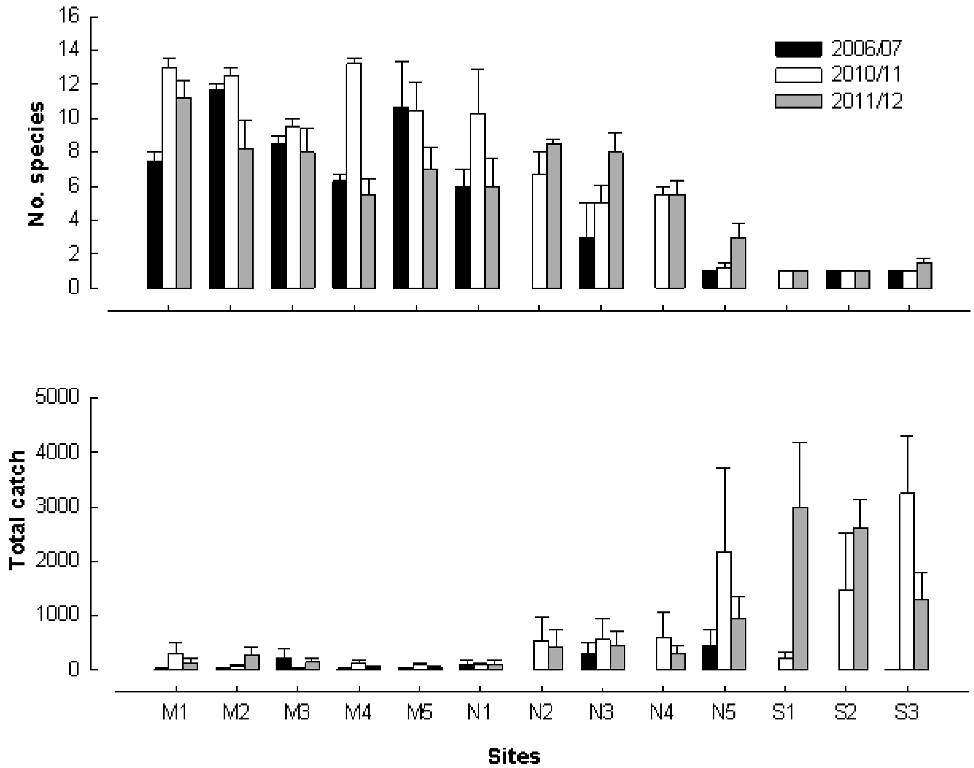

Figure 4. Mean number of species (top) and fish ± S.E. (bottom) sampled by seine net at different sites in the Estuary, North Lagoon and South Lagoon of the Coorong in 2006/07, 2010/11 and 2011/12.

3.3.2. Gill net samples

A total of 7,833 fish representing 12 medium-large bodied species were sampled using gill nets in the Murray Estuary and North Lagoon in 2011/12 (Table 3). Fish collected included freshwater (native and exotic), catadromous, estuarine resident, estuarine and marine to marine estuarine opportunist species. Similar to 2010/11, bony herring was the most abundant species collected, accounting for 72% of the catch by number, followed by yelloweye mullet and Australian salmon. The number of mulloway sampled in 2011/12 was considerably higher compared to 2010/11, particularly in the North Lagoon. Bony herring was the only one of the five freshwater species collected in the last two years that was present in very low numbers in the Coorong during 2006/07.

Species richness was similar between sites and among years except for a significant increase at Noonameena (N3) in the North Lagoon over the three sampling years (Figure 5). Total abundance of fish showed a significant increase in the Estuary in 2011/12 compared to previous years; whilst in the North Lagoon, the abundance was greater in both 2010/11 and 2011/12 than in 2006/07.

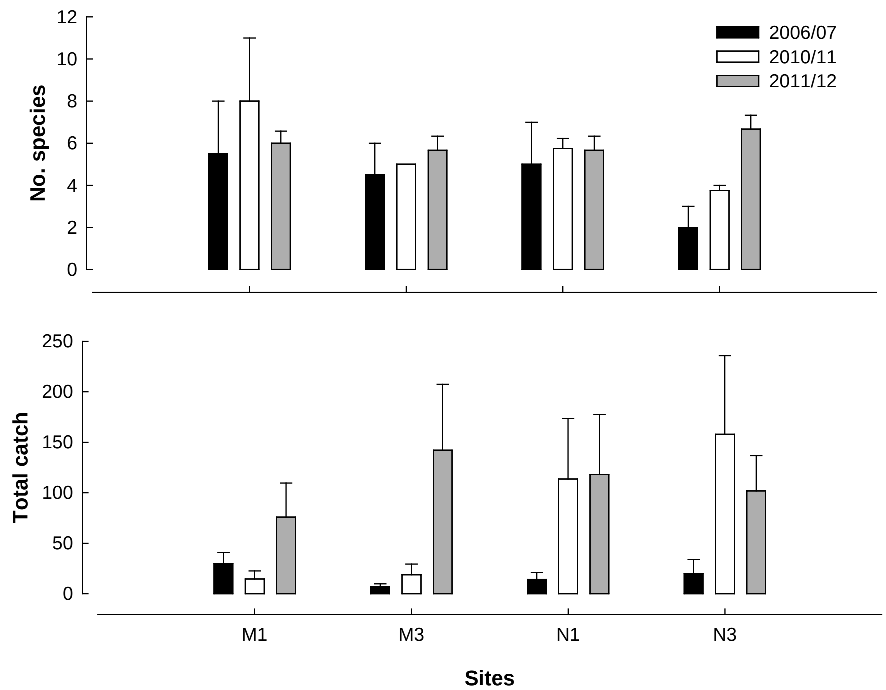

Figure 5. Mean number of species (top) and fish ± S.E. (bottom) sampled by gill net at different sites in the Estuary and North Lagoon of the Coorong in 2006/07, 2010/11 and 2011/12.

Table 3. Species and number of fish sampled using gill nets during 2010/11 and 2011/12 barrage release intervention monitoring in the Coorong. 2006/07 fish data for relevant months are also presented for comparison. MM = Murray Estuary, NL = North Lagoon and SL = South Lagoon.

				2006-07			2010-11			2011-12		
Common_Name	**Scientific Name**	**Species Code**	**Classification**	**ME**	**NL**	**Total**	**ME**	**NL**	**Total**	**ME**	**NL**	**Total**
Congolli	*Pseudaphritis urvilli*	PSE	C	3	4	7			2	3	33	36
Black bream	*Acanthopagrus butcheri*	ACA	E	1		1		3	8			
River garfish	*Hyporhamphus regularis*	HYP	E	1		1					6	6
Greenback flounder	*Rhombosolea tapirina*	RHO	E&M	6	2	8			1		7	7
Goldspot mullet	*Liza argentea*	LIZ	E&M							25	4	29
Carp	*Cyprinus carpio*	CYP	FE				21	22	43	119	2	121
Goldfish	*Carassius auratus*	CAR	FE						1	1		1
Redfin perch	*Perca fluviatilis*	PER	FE				12	9	21	32	12	44
Bony herring	*Nematolosa erebi*	NEM	FN	20	1	21	336	4,109	4,445	2742	2889	5631
Golden perch	*Macquaria ambigua*	MAC	FN						1	3	1	4
Australian herring	*Arripis georgianus*	ARR	O	11		11		2	2			
Mulloway	*Argyrosomus japonicus*	ARG	O	135	54	189	16	11	27	53	275	328
Sea mullet	*Mugil cephalus*	MUG	O	1	2	3			2			
Toadfishes	Family Tetraodontidae	-	O		2	2						
Australian salmon	*Arripis truttaceus*	ARR	O	209	5	214		207	209	620	189	809
Western striped grunter	*Pelates octolineatus*	PEL	O	4		4						
Yelloweye mullet	*Aldrichetta forsteri*	ALD	O	104	153	257	24	627	651	190	627	817
Yellowfin whiting	*Sillago schomburgkii*	SIL	O						1			
Total				**495**	**223**	**718**	**424**	**4,990**	**5,414**	**3,788**	**4,045**	**7,833**
% catch				**69**	**31**		**8**	**92**		**48**	**52**	

3.4. Spatio-temporal 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 among years (2006/07, 2010/11 and 2011/12) across three subregions (Estuary, North Lagoon and South Lagoon) (Table 4), suggesting different inter-annual patterns among subregions. Pairwise comparisons revealed a significant difference in fish assemblage between all years (*P*=0.001) in each subregion. Similarly, a significant spatial difference was detected between all subregions (*P*=0.001) in each year.

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	2	37801	**0.001**
Subregion	2	126470	**0.002**
Year x Subregion	4	23291	**0.001**
Residuals	369	1107	

For the Estuary, SIMPER analysis indicated that the greatest dissimilarity (80.2%) in fish assemblage structure occurred between 2006/07 and 2010/11 (Table 5). This was largely driven by an increase in abundance of bony herring, sandy sprat, Australian smelt, smallmouthed hardyhead and Tamar goby, as well as the presence of two freshwater species (redfin perch and flatheaded gudgeon) that were only present in 2010/11 (Table 5). In addition, the decline in abundance of yelloweye mullet and the absence of Australian salmon in 2010/11 also contributed to the dissimilarity between assemblages. The change in fish assemblage structure from 2010/11 to 2011/12 was mainly due to the reduced abundance of sandy sprat, Tamar goby, smallmouthed hardyhead and several freshwater species, as well as an increased number of yelloweye mullet.

Table 5. SIMPER analysis for fish assemblage pairwise comparisons between 2006/07, 2010/11 and 2011/12 for seine net samples from the Murray Estuary. 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).

Murray Estuary	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2010/11	CR		Mean dissimilarity = 80.21
Bony herring	0.04	3.49	1.83	11.65	11.65
Sandy sprat	2.15	3.85	1.35	10.14	21.79
Australian smelt	0.02	3.02	2.21	9.94	31.73
Redfin perch	0	3.03	1.9	9.63	41.37
Yelloweye mullet	2.29	0.74	1.33	6.9	48.27
Flatheaded gudgeon	0	2.09	1.56	6.9	55.17
Smallmouthed hardyhead	1.55	2.11	1.33	6.46	61.62
Tamar goby	0.35	2.16	1.52	6.25	67.87
Australian salmon	1.57	0	0.91	5.38	73.25
Greenback flounder	0.93	0.98	1.24	4	77.25
River garfish	0.92	0.55	0.96	3.37	80.63
Carp	0	1	0.85	3.16	83.79
Toadfishes	0.73	0.01	0.77	2.63	86.42
Longsnout flounder	0.34	0.45	0.66	2.17	88.59
Bridled goby	0.02	0.75	0.67	2.12	90.71
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2011/12	CR		Mean dissimilarity = 73.26
Sandy sprat	2.15	3.51	1.27	17.73	17.73
Bony herring	0.04	2.28	1.43	13.15	30.88
Yelloweye mullet	2.29	0.95	1.43	11.29	42.17
Australian salmon	1.57	0.88	1.09	9.44	51.61
Smallmouthed hardyhead	1.55	0.66	1.03	9.11	60.72
Greenback flounder	0.93	0.58	1.13	5.59	66.32
Australian smelt	0.02	1	0.75	5.42	71.74
River garfish	0.92	0.19	0.92	5.24	76.98
Toadfishes	0.73	0.04	0.79	4.72	81.7
Redfin perch	0	0.59	0.47	2.89	84.59
Tamar goby	0.35	0.29	0.77	2.85	87.44
Longsnout flounder	0.34	0.14	0.51	2.6	90.04
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2010/11	2011/12	CR		Mean dissimilarity = 64.31
Sandy sprat	3.85	3.51	1.27	11.42	11.42
Redfin perch	3.03	0.59	1.71	11.12	22.54
Australian smelt	3.02	1	1.56	9.91	32.45
Bony herring	3.49	2.28	1.27	9.15	41.6
Flatheaded gudgeon	2.09	0.06	1.54	8.39	49.99
Tamar goby	2.16	0.29	1.54	7.93	57.92
Smallmouthed hardyhead	2.11	0.66	1.31	7.91	65.83
Yelloweye mullet	0.74	0.95	0.89	5.1	70.93
Greenback flounder	0.98	0.58	1.03	4.45	75.38
Carp	1	0.15	0.89	3.97	79.35
Australian salmon	0	0.88	0.73	3.85	83.2
Bridled goby	0.75	0.12	0.71	2.84	86.05
Congolli	0.65	0.26	0.92	2.73	88.77
Scary's Tasman goby	0.47	0.26	0.72	2.57	91.34

For the North Lagoon, the greatest dissimilarity (56.3%) was found between 2006/07 and 2011/12, and was driven mainly by the increased abundance of smallmouthed hardyhead and sandy sprat (Table 6). The change in fish assemblage from 2010/11 to 2011/12 was primarily attributed to the increased abundance of sandy sprat and a decrease in smallmouthed hardyhead and bony herring numbers.

Table 6. SIMPER analysis for fish assemblage pairwise comparisons between 2006/07, 2010/11 and 2011/12 for seine net samples from the North 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).

North 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
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2011/12	CR		Mean dissimilarity = 56.33
Smallmouthed hardyhead	4.73	4.74	0.87	28.23	28.23
Sandy sprat	0.46	3.01	1.11	26.5	54.74
Yelloweye mullet	0.49	0.85	0.79	9.2	63.94
Greenback flounder	0.81	0.3	0.86	7.69	71.63
River garfish	0.21	0.5	0.63	5.82	77.45
Longsnout flounder	0.45	0.16	0.57	4.6	82.05
Bony herring	0	0.48	0.69	4.5	86.55
Congolli	0.08	0.32	0.56	3.47	90.03
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2010/11	2011/12	CR		Mean dissimilarity = 53.68
Sandy sprat	0.39	3.01	1.09	23.42	23.42
Smallmouthed hardyhead	5.55	4.74	0.91	21.59	45.01
Bony herring	1.61	0.48	1.18	11.84	56.85
Yelloweye mullet	0.88	0.85	0.97	9.67	66.52
Australian smelt	0.78	0.08	0.61	6.07	72.59
River garfish	0.29	0.5	0.71	5.07	77.66
Greenback flounder	0.43	0.3	0.78	4.64	82.3
Congolli	0.33	0.32	0.71	4.2	86.5
Scary's Tasman goby	0.25	0.27	0.6	3.44	89.94
Redfin perch	0.53	0	0.47	3.44	93.38

In the South Lagoon, the greatest dissimilarity (86.5%) in assemblage structure occurred between 2006/07 and 2011/12, when there was the greatest difference in smallmouthed hardyhead abundance (Table 7). The increase in smallmouthed hardyhead abundance was also the key driver for change in fish assemblages from 2010/11 to 2011/12.

Table 7. SIMPER analysis for fish assemblage pairwise comparisons between 2006/07, 2010/11 and 2011/12 for seine net samples from the South 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).

South 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
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
	2006/07	2011/12	CR		Mean dissimilarity = 86.46
Smallmouthed hardyhead	0.56	6.39	4.02	99.69	99.69
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
	2010/11	2011/12	CR		Mean dissimilarity =36.90
Smallmouthed hardyhead	4.01	6.39	1.02	99.47	99.47

During 2011/12, the significant difference in fish assemblage between the Estuary and North Lagoon was mainly attributed to a higher abundance of sandy sprat, bony herring and yelloweye mullet, and lower abundance of smallmouthed hardyhead in the Estuary (Table 8). The difference between the South Lagoon and the other two subregions was driven by the greater abundance of smallmouthed hardyhead and the absence of sandy sprat in the South Lagoon.

Table 8. SIMPER analysis for fish assemblage pairwise comparisons between the Estuary, North and South Lagoons of the Coorong for seine net samples during 2011/12. 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 regions (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). ME = Murray Estuary and NL = North Lagoon.

	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species group	ME	NL	CR		Mean dissimilarity = 72.18
Smallmouthed hardyhead	0.66	4.74	1.69	26.62	26.62
Sandy sprat	3.51	3.01	1.25	19.26	45.88
Bony herring	2.28	0.48	1.31	12.31	58.19
Yelloweye mullet	0.95	0.85	0.98	7.57	65.76
Australian salmon	0.88	0.13	0.78	5.79	71.54
Australian smelt	1	0.08	0.77	5.75	77.29
Greenback flounder	0.58	0.3	0.84	4.03	81.33
River garfish	0.19	0.5	0.66	3.65	84.98
Redfin perch	0.59	0	0.47	3	87.98
Congolli	0.26	0.32	0.7	2.79	90.77
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species group	ME	SL	CR		Mean dissimilarity = 91.88
Smallmouthed hardyhead	0.66	6.39	2.7	35.79	35.79
Sandy sprat	3.51	0	1.47	20.05	55.84
Bony herring	2.28	0	1.54	13.19	69.03
Yelloweye mullet	0.95	0.02	0.77	5.83	74.87
Australian salmon	0.88	0	0.79	5.49	80.35
Australian smelt	1	0	0.76	5.26	85.61
Greenback flounder	0.58	0	0.72	3.21	88.83
Redfin perch	0.59	0	0.48	2.77	91.59
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species group	NL	SL	CR		Mean dissimilarity = 56.49
Sandy sprat	3.01	0	1.13	31.46	31.46
Smallmouthed hardyhead	4.74	6.39	0.82	30.85	62.31
Yelloweye mullet	0.85	0.02	0.78	10.09	72.4
River garfish	0.5	0	0.6	5.82	78.22
Bony herring	0.48	0	0.72	5.33	83.55
Congolli	0.32	0	0.51	3.67	87.23
Greenback flounder	0.3	0	0.54	3.55	90.78

The PCO ordination of fish assemblage data for the Estuary subregion accounted for 60% of the total variation in the first 2 axes (Figure 6a). There was clear separation of samples from each of the three years. The strongest separation occurred between 2006/07 and 2010/11, where differences were driven mainly by increased abundances of freshwater species (bony herring, Australian smelt, redfin perch, flatheaded gudgeon, etc), catadromous congolli and several small-bodied estuarine species (Tamar goby and bridled goby), as well as reduced abundances in marine/estuarine opportunists (Australian salmon, yelloweye mullet and toadfish) in 2010/11. The 2011/12 data were interspersed between the other two years, indicating some similarities in assemblage structure. However, differences in fish assemblages between 2010/11 and 2011/12 were driven mainly by greater abundance of sandy sprat, a small-bodied estuarine opportunist species.

In the North Lagoon, 56% of the total variation was captured by PCO1 and PCO2 (Figure 6b). There was separation of several 2010/11 and 2011/12 samples from the 2006/07 samples, driven mostly by increased abundances of freshwater species (bony herring), catadromous congolli, small-bodied estuarine species (Tamar goby) and estuarine opportunists (sandy sprat and sea garfish); whilst the separation between 2010/11 and 2006/07 samples was more driven by an increased abundance in smallmouthed hardyhead. In the South Lagoon, PCO1 alone captured 92% of the fish assemblage differences between years, with a clear shift from 2006/07 to 2010/11, then to 2011/12, which was driven by smallmouthed hardyhead abundance (Figure 6c).

Applying PCO ordination to the fish assemblage data collected during 2011/12 from the three subregions, 77% of the total variation was captured by PCO1 and PCO2 (Figure 7). The horizontal separation between the Estuary, North Lagoon and South Lagoon samples was strongly driven by increasing abundance in smallmouthed hardyhead from the north toward the south; whilst fish assemblage structure in the Estuary was characterised by more abundant freshwater species (bony herring and Australian smelt), estuarine species (greenback flounder) and opportunists (sandy sprat and Australian salmon).

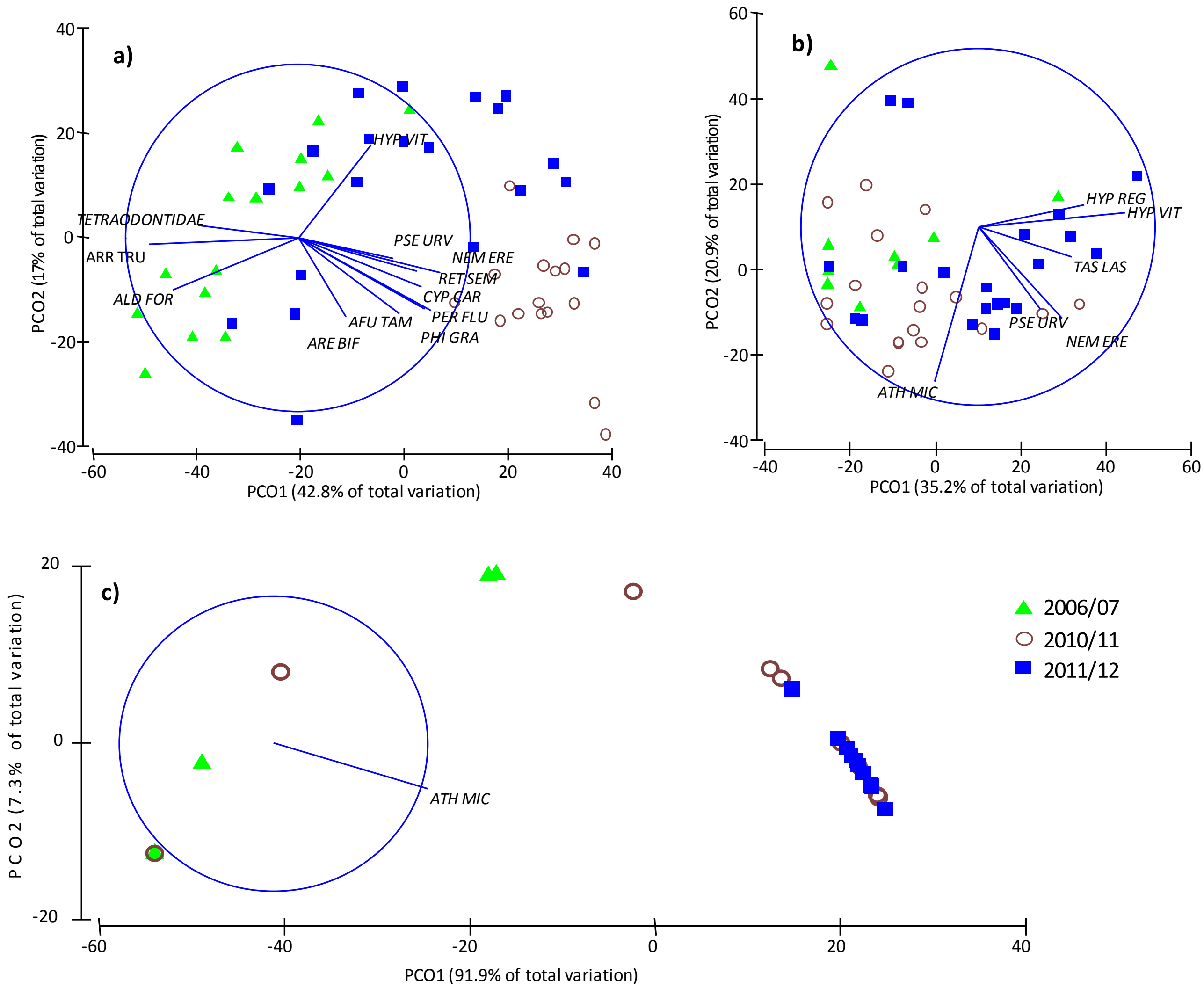

Figure 6. PCO ordination of samples on the basis of the Bray-Curtis measure of log transformed abundances of fish species collected by seine net in different years from each subregion (a) Estuary, b) North lagoon and c) South Lagoon. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle). AFU TAM: Tamar goby; ALD FOR: yelloweye mullet; ARE BIF: bridled goby; ARR TRU: Australian salmon; ATH MIC: smallmouthed hardyhead; CYP CAR: carp; HYP REG: river garfish; HYP VIT: sandy sprat; NEM ERE: bony herring; PER FLU: redfin perch; PHI GRA: flatheaded gudgeon; PSE URV: congolli; RET SEM: Australian smelt; TAS LAS: Scary's Tasman goby.

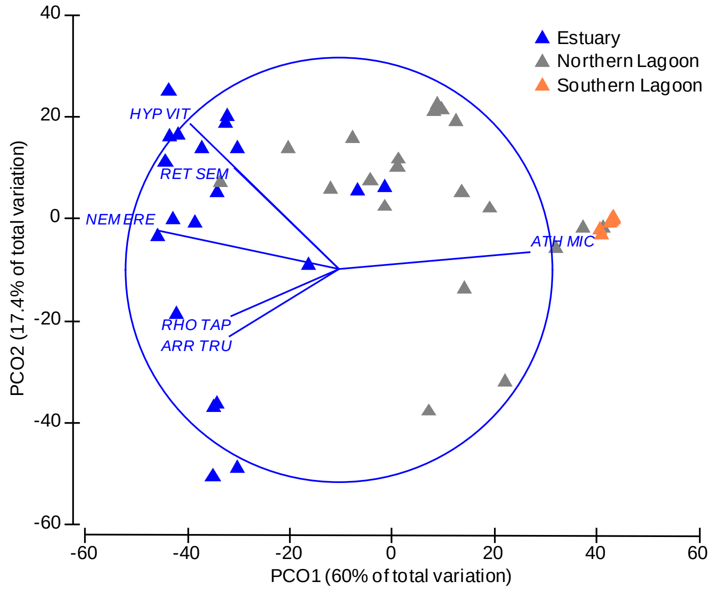

Figure 7. PCO ordination of samples on the basis of the Bray-Curtis measure of log transformed abundances of fish species collected by seine net from different subregions during 2011/12. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species group with correlations >0.5, and with respect to a unit circle). Species group abbreviations are ARR TRU: Australian salmon; ATH MIC: smallmouthed hardyhead; HYP VIT: sandy sprat; NEM ERE: bony herring; RET SEM: Australian smelt; RHO TAP: greenback flounder.

The best combination of predictors for assemblage structure of seine net samples was salinity and transparency, which together explained 28.5% of the variation; although temperature and pH were also identified as significant factors; adding these two only, improved the proportion of the variation explained to 29.8% (Table 9). The horizontal distribution of the samples from the Estuary and North Lagoon toward the South Lagoon was well explained by a positive correlation with salinity in the dbRDA (Figure 8). The vertical separation of samples was driven by a positive relationship with higher transparency. The Estuary samples in 2010/11 and 2011/12 were generally associated with low salinity and low transparency (low Secchi disc depth). Although salinity levels in the North Lagoon in 2010/11 and 2011/12 were similar to those in the Estuary in 2006/07, they were separated on the dbRDA ordination plot from 2006/07 due to lower transparency (Figure 8).

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

Variable	R^2 res.df	Pseudo-F	P	Prop.	Cumul.
Salinity	0.2296	112.0600	**0.001**	0.2296	0.2296
Transparency	0.2847	28.8800	**0.001**	0.0551	0.2847
Temperature	0.2919	3.8261	**0.010**	0.0072	0.2919
pH	0.2979	3.1836	**0.013**	0.0060	0.2979

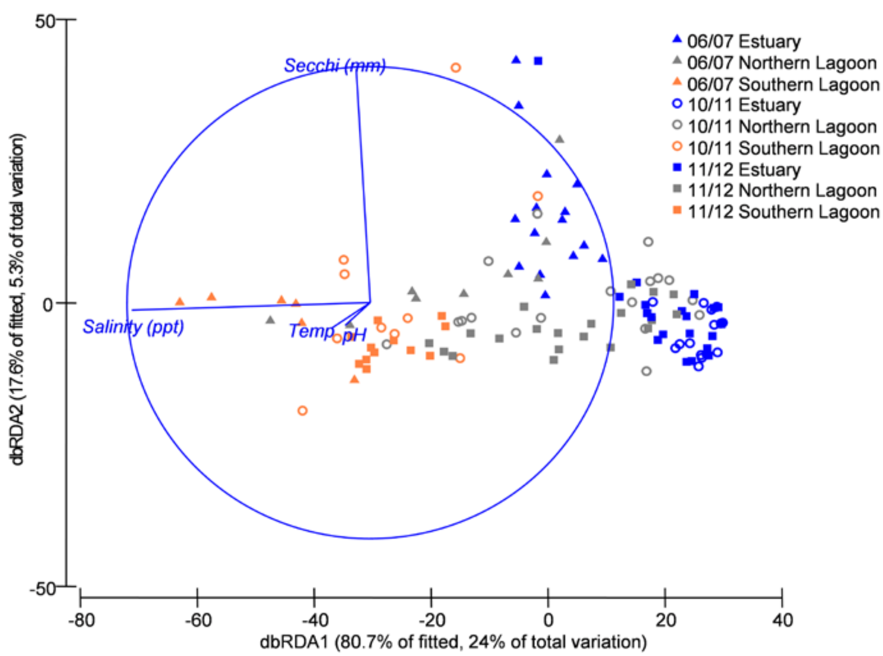

Figure 8. dbRDA ordination of the fitted model of species-abundance data collected by seine net (based on Bray-Curtis measure of log transformed abundances) *versus* the predictor variables salinity, transparency, pH and temperature. The vector overlay indicates multiple partial correlations between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

3.4.2. Gill net samples

PERMANOVA detected a significant interaction (*P*=0.001) when comparing large-bodied fish assemblages among three years (2006/07, 2010/11 and 2011/12) between the Estuary and North Lagoon (Table 10), suggesting inconsistent inter-annual variation between these subregions. Pairwise comparisons revealed a significant temporal difference in fish assemblage structure in each subregion (*P*=0.001), as well as a significant spatial difference during each year (*P*=0.001).

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

	Assemblage structure (Gill)		
Source of Variation	df	MS	P(perm)
Year	2	31029	**0.001**
Subregion	1	11047	0.374
Year x Subregion	2	7567	**0.001**
Residuals	95	989.64	

SIMPER analysis indicated that, in the Estuary, the greatest difference in fish assemblages occurred between 2006/07 and 2010/11 (dissimilarity = 84.5%), and was driven by increased abundance of bony herring, presence of carp and redfin perch, and a decrease in Australian salmon, mulloway and yelloweye mullet in 2010/11 (Table 11). Further change in the fish assemblage in 2011/12 compared to 2010/11 was attributed to greater abundances of bony herring, Australian salmon, yelloweye mullet, carp, mulloway and redfin perch.

Table 11. SIMPER analysis for fish assemblage pairwise comparisons among 2006/07, 2010/11 and 2011/12 for gill net samples from the Murray Estuary. 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
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2011/12	CR		Mean dissimilarity = 75.07
Bony herring	0.57	11.37	2.91	45.14	45.14
Australian salmon	2.72	4.62	1.42	15.71	60.85
Yelloweye mullet	2.01	1.85	1.42	10.72	71.57
Mulloway	2.38	1.09	1.3	8.39	79.96
Carp	0	1.67	0.77	7.36	87.33
Redfin perch	0	1.05	1.29	4.72	92.05
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2010/11	2011/12	CR		Mean dissimilarity = 60.60
Bony herring	4.88	11.37	1.92	36.49	36.49
Australian salmon	0.12	4.62	1.39	22.49	58.98
Yelloweye mullet	0.68	1.85	0.89	10.2	69.18
Carp	1.07	1.67	1.1	9.98	79.16
Mulloway	0.53	1.09	1.01	6.57	85.73
Redfin perch	0.73	1.05	1.11	4.83	90.55

For the North Lagoon, the greatest dissimilarity (79.9%) in fish assemblages occurred between 2006/07 and 2010/11, mostly driven by increased abundances of bony herring, yelloweye mullet and Australian salmon, and a decrease in mulloway abundance (Table 12). From 2010/11 to 2011/12, assemblage structure changed, with higher numbers of bony herring, yelloweye mullet, mulloway, Australian salmon and congolli in the later years.

Table 12. SIMPER analysis for fish assemblage pairwise comparisons amongst 2006/07, 2010/11 and 2011/12 for gill net samples from the North 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).

North 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
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2006/07	2011/12	CR		Mean dissimilarity = 75.59
Bony herring	0.08	12.21	3.58	52.63	52.63
Yelloweye mullet	2.64	5.21	1.33	16.24	68.87
Australian salmon	0.26	2.57	1.26	10.26	79.13
Mulloway	1.6	3.55	1.41	9.95	89.08
Congolli	0.33	1	1.06	4.28	93.35
	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	2010/11	2011/12	CR		Mean dissimilarity = 41.79
Bony herring	11.2	12.21	1.5	38.14	38.14
Yelloweye mullet	4.5	5.21	1.4	17.09	55.24
Mulloway	0.43	3.55	1.95	16.76	71.99
Australian salmon	2.36	2.57	1.24	11.81	83.81
Congolli	0	1	1.02	5.71	89.51
Redfin perch	0.31	0.31	0.67	2.77	92.28

In 2011/12, differences in fish assemblage composition between the Estuary and North Lagoon were mainly due to greater abundances of bony herring, yelloweye mullet, mulloway and congolli, as well as lower abundances of Australia salmon, carp and redfin perch in the North Lagoon (Table 13).

Table 13. SIMPER analysis for fish assemblage comparison between Estuary and North Lagoon for gill net samples during 2011/12. 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 subregions (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).

2011/12	Mean Abundance			Contribution (%)	Cumulative contribution (%)
Species names	Estuary	North Lagoon	CR		Mean dissimilarity = 44.25
Bony herring	11.37	12.21	1.15	24.62	24.62
Yelloweye mullet	1.85	5.21	1.46	20.92	45.55
Australian salmon	4.62	2.57	1.33	16.85	62.39
Mulloway	1.09	3.55	1.64	12.76	75.15
Carp	1.67	0.11	0.82	7.96	83.12
Redfin perch	1.05	0.31	1.32	5.03	88.14
Congolli	0.17	1	1.03	4.84	92.98

Variation in the fish assemblages in the Estuary between years was well captured by the first 2 axes of the PCO, which accounted for 72% of the variation (Figure 9a). There was a clear separation of samples between the three years. Changes in fish assemblage structure from 2006/07 to 2010/11 and 2011/12 were mainly attributed to increasing abundances of freshwater species (bony herring, carp, redfin perch) and decreasing numbers of estuarine opportunist species (mulloway, yelloweye mullet, Australia salmon). The vertical separation between 2010/11 and 2011/12 samples was driven mainly by a greater abundance of Australian salmon in 2011/12.

For the North Lagoon, PCO1 and PCO2 captured 68% of the total variation in the fish assemblage data (Figure 9b). Similar to the Estuary, increased freshwater fish abundance was the main driver for assemblage structure difference in 2010/11 and 2011/12 compared to 2006/07. Yelloweye mullet was the primary driver for the vertical separation of fish samples, although no consistent temporal pattern was evident.

The PCO ordination of the 2011/12 gill net fish assemblage data for the Estuary and North Lagoon captured 62% of the variation in the first 2 axes (Figure 10). The separation between the Estuary and North Lagoon seemed to be mainly due to a higher abundance of yelloweye mullet, mulloway and bony herring, and less abundant carp.

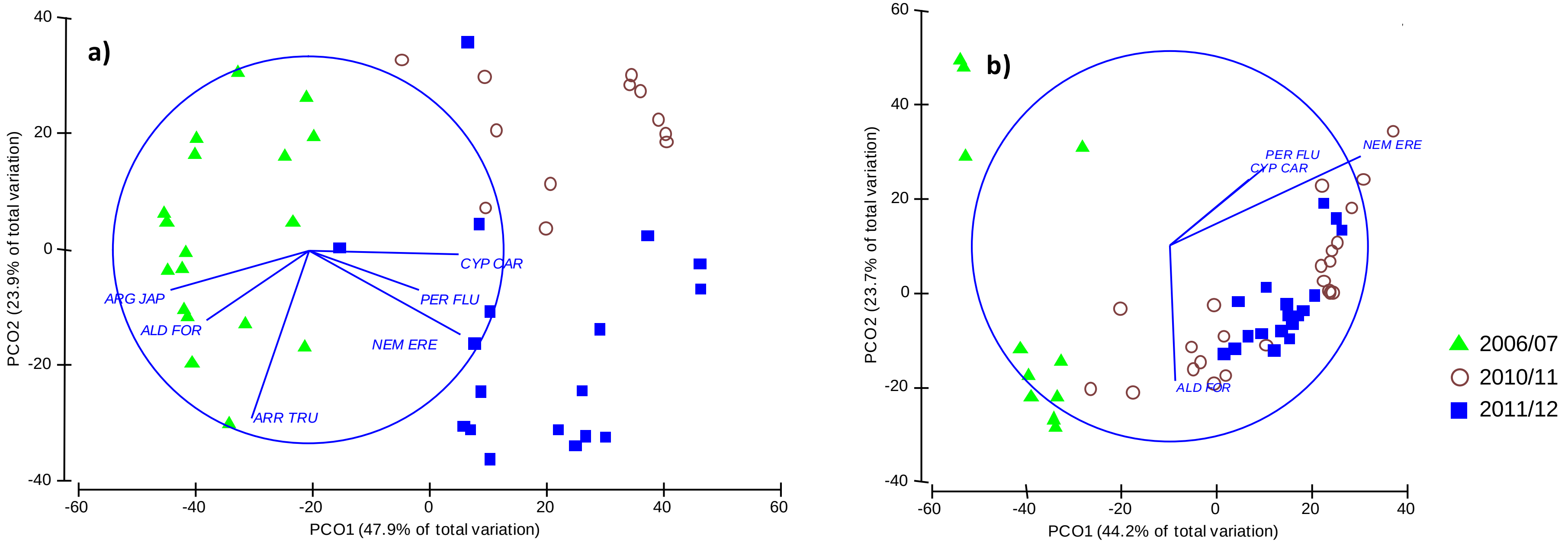

Figure 9. PCO ordination of samples on the basis of the Bray-Curtis measure of square root transformed abundances of fish species collected by gill net in different years from each region (a) Estuary and b) North Lagoon. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle). ARR TRU: Australian salmon; ARG JAP: mulloway; ALD FOR: yelloweye mullet; NEM ERE: bony herring; CYP CAR: carp; PER FLU: redfin perch.

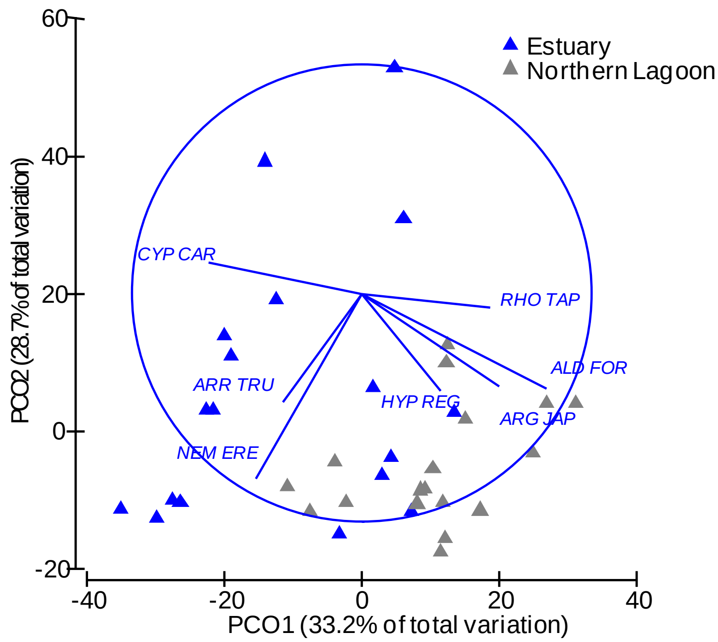

Figure 10. PCO ordination of samples on the basis of the Bray-Curtis measure of square root transformed abundances of fish species collected by gill net from different subregions during 2011/12. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle). ARR TRU: Australian salmon; ARG JAP: mulloway; ALD FOR: yelloweye mullet; NEM ERE: bony herring; CYP CAR: carp; HYP REG: river garfish; RHO TAP: greenback flounder.

Salinity and transparency (Secchi disc depth) were the best predictors of fish assemblage structure from gill net samples, however, these two factors combined only explained 18.7% of the variation (Table 14 and Figure 11). In both the Estuary and North Lagoon, the separation of 2006/07 samples from the 2010/11 and 2011/12 samples was related to higher salinity and transparency in 2006/07 (Figure 11).

Table 14. DistLM sequential results indicating which environmental variable significantly contributed most to the relationship with the multivariate data cloud (gill net fish data). Proportion of the variation explained (Prop) and cumulative variation explained (Cumul).

Variable	R^2 res.df	Pseudo-F	P	Prop.	Cumul.
Salinity	0.1225	13.8140	**0.001**	0.1225	0.1225
Transparency	0.1868	7.7586	**0.001**	0.0644	0.1868
pH	0.2043	2.1236	0.085	0.0174	0.2043
Temperature	0.2095	0.6358	0.645	0.0052	0.2095

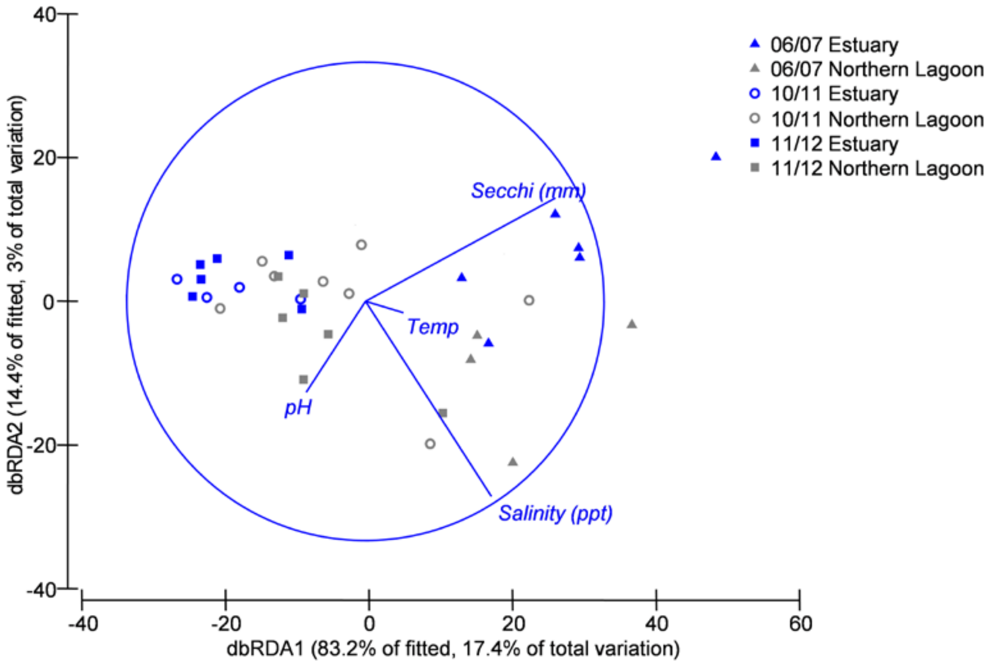

Figure 11. dbRDA ordination of the fitted model of species-abundance data collected by gill net (based on Bray-Curtis measure of square root transformed abundances) *versus* the predictor variables salinity, pH, temperature and transparency. The vector overlay indicates multiple partial correlations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

3.5. Temporal changes in distribution and abundance of key species and freshwater species

3.5.1. Small-bodied estuarine species

The small-bodied estuarine species responded well to the freshwater inflows in 2010/11 and 2011/12. Smallmouthed hardyhead and sandy sprat showed a substantial increase in abundance in both of these years compared to 2006/07 (Figures 12 and 13), whilst the abundance of Tamar goby also increased in 2010/11 in the Murray Estuary (Figure 14). Importantly, both sandy sprat and Tamar goby showed a southward extension in their distributional range in the Coorong in 2010/11 and 2011/12, whilst these species were mostly restricted to the Estuary subregion in 2006/07.

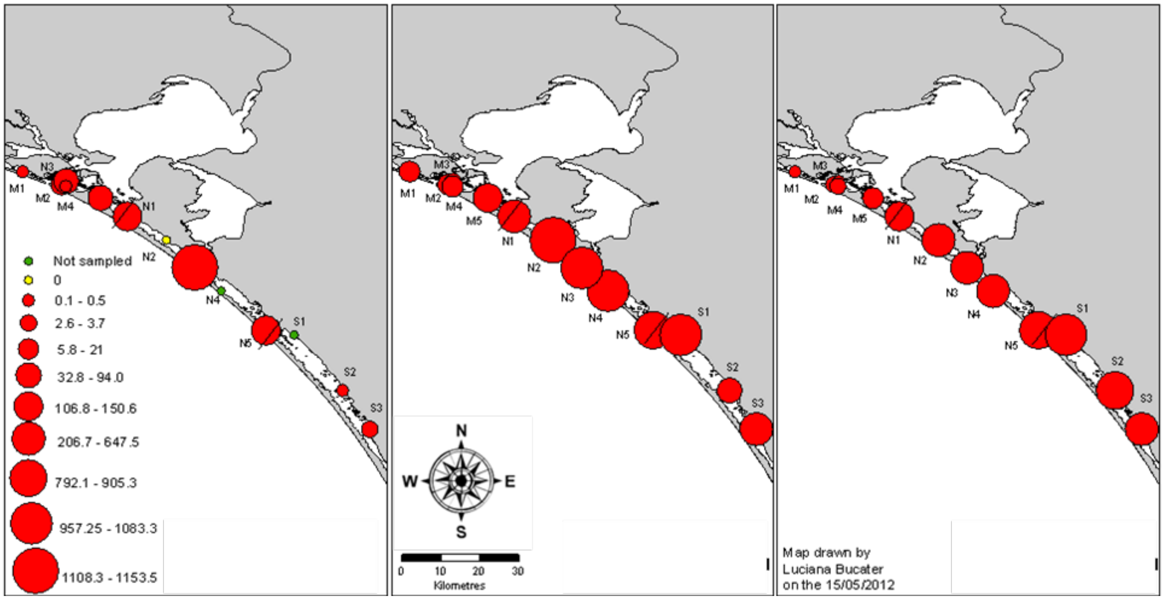

Figure 12. Smallmouthed hardyhead relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right), for Coorong.

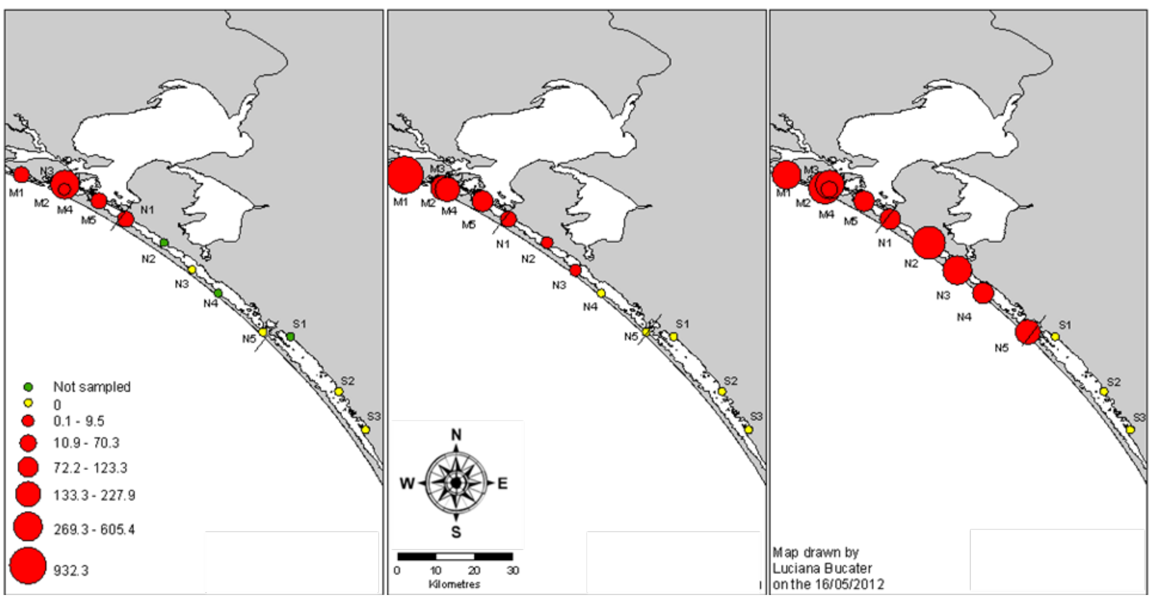

Figure 13. Sandy sprat relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right), for Coorong.

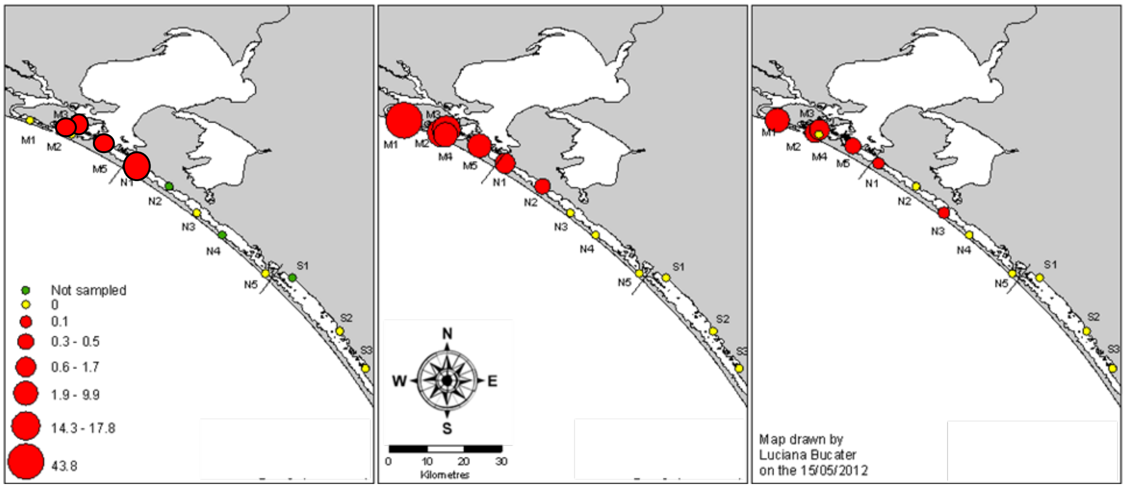

Figure 14. Tamar goby relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right), for Coorong.

3.5.2. Catadromous species

Congolli showed a positive response in 2010/11 and 2011/12. Seine net samples, which mostly collected juvenile fish, indicated an increase in abundance for this species in 2010/11 and 2011/12 with an extended distribution toward the southern end of the North Lagoon in comparison to 2006/07 (Figure 15a). In 2011/12, there was a general increase in abundance of adult congolli as represented by gill net catches (Figure 15b)

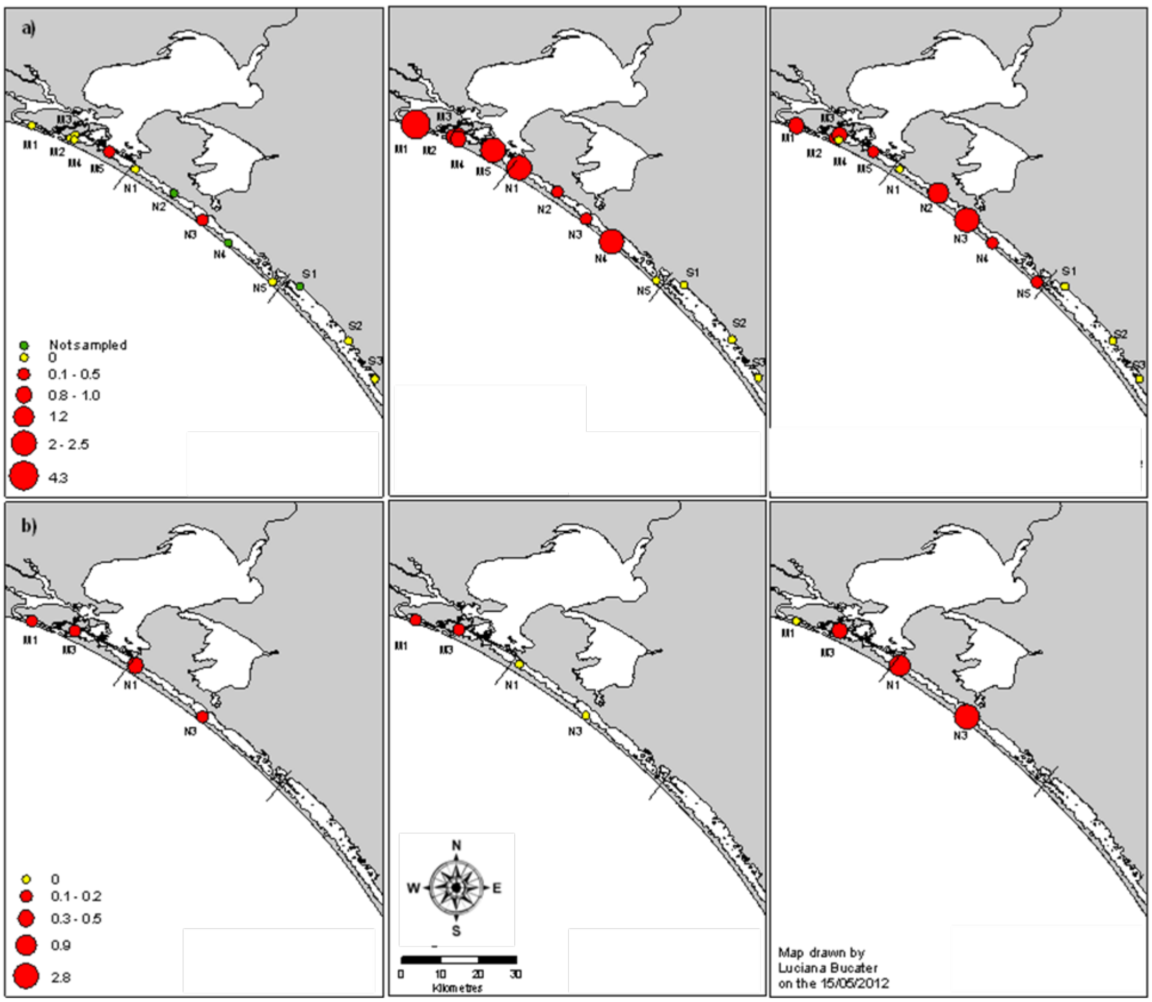

Figure 15. Congolli relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

3.5.3. Large-bodied estuarine species

Greenback flounder showed a slight increase in juvenile abundance in the Estuary during 2010/11 relative to 2006/07. In 2011/12, abundances declined, however they extended their range southward to Hells Gate (Figure 16a). Gill net catches indicated a reduction in abundance of adult and sub-adult fish in the Estuary in 2010/11 and 2011/12, whilst their abundance appeared to increase in the North Lagoon in 2011/12 (Figure 16b).

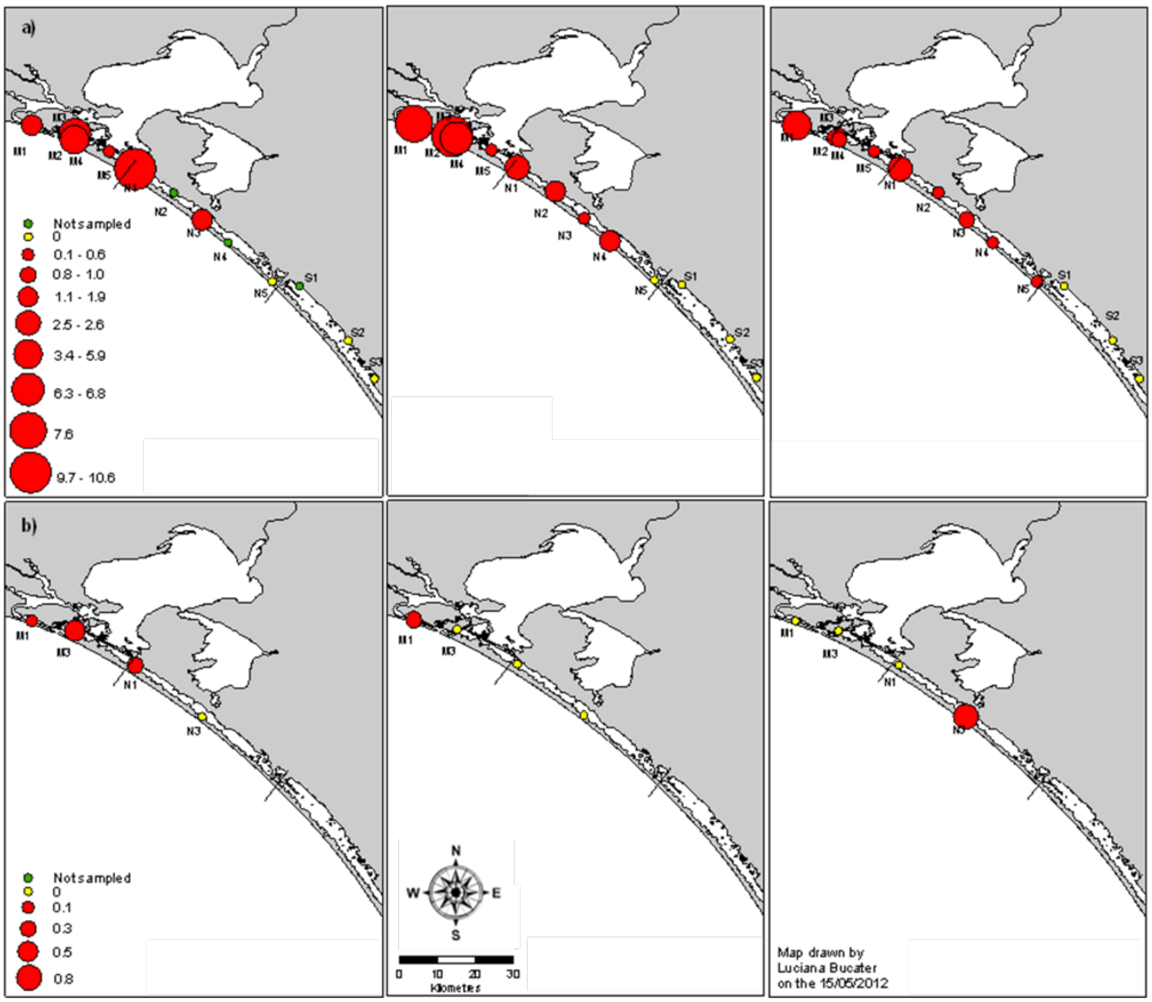

Figure 16. Ggreenback flounder relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

For yelloweye mullet, there was a clear southward range extension particularly in 2011/12 compared to 2006/07 seine net samples; remarkably, juveniles were found in the southern part of the South Lagoon (Figure 17a). The relative abundance of juveniles in the Estuary decreased in 2010/11 compared to

2006/07, but recovered slightly in 2011/12. In the North Lagoon, juvenile numbers were greater in both flow years compared to 2006/07. Gill net catches also indicated an increase in yelloweye mullet in the North Lagoon and Estuary subregions in 2011/12 (Figure 17b).

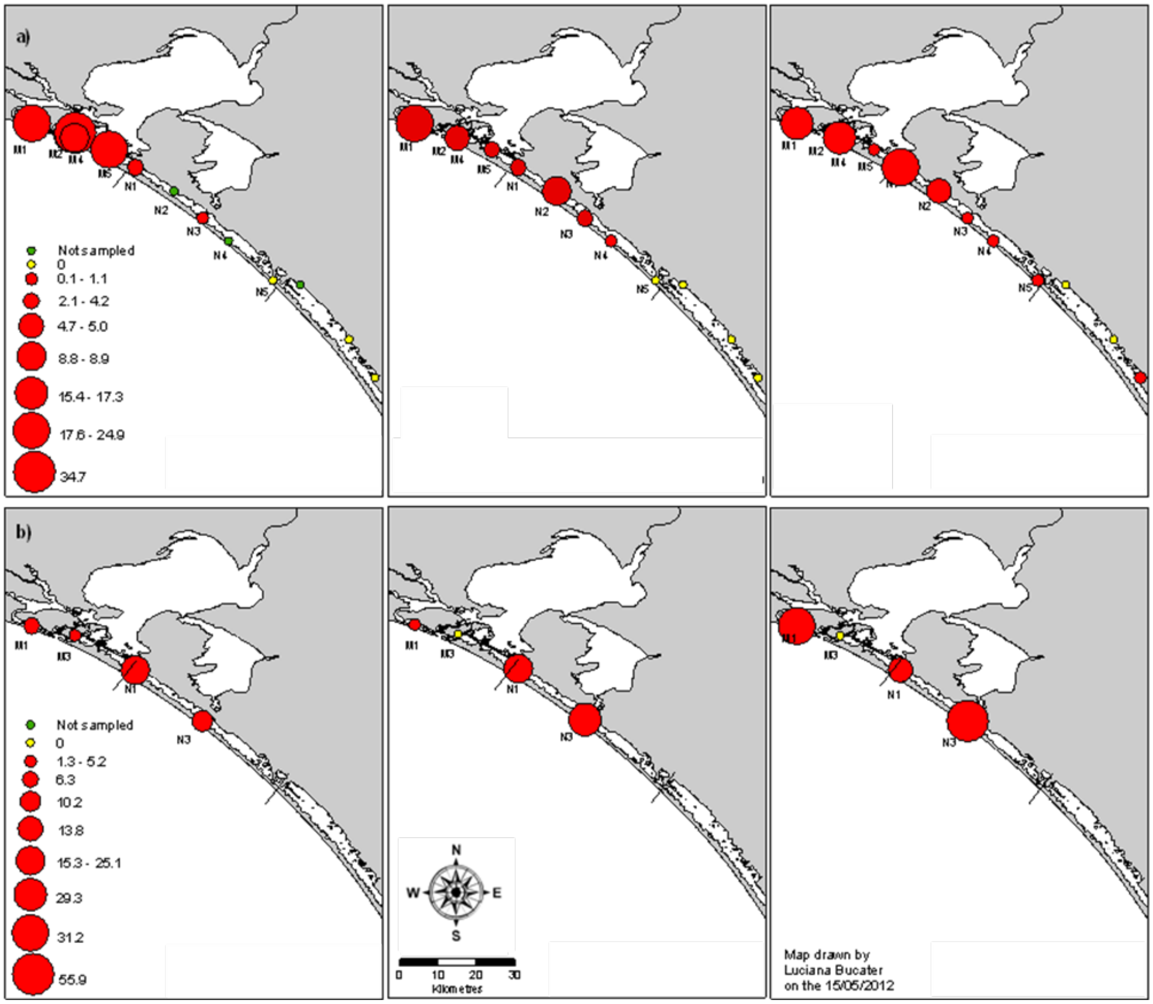

Figure 17. Yelloweye mullet relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

The data indicated a low abundance of black bream in the Coorong in all three years. In 2006/07, both seine net and gill net catches were restricted to the Estuary subregion (Figure 18). In 2010/11, no juvenile fish were sampled by seine net, however, there was an increase in gill net catch of adults, with their range extending into the North Lagoon. In 2011/12, two black bream were collected by seine net (one juvenile in the Estuary and one adult in the South Lagoon); no black bream were caught by gill net.

Mulloway catch by seine net was restricted to the Estuary and only occurred in 2006/07 (Figure 19a). Gill net catch in 2006/07 to 2010/11 indicated a general decline in mulloway abundance, followed by a considerable increase in 2011/12, particularly in the North Lagoon (Figure 19b).

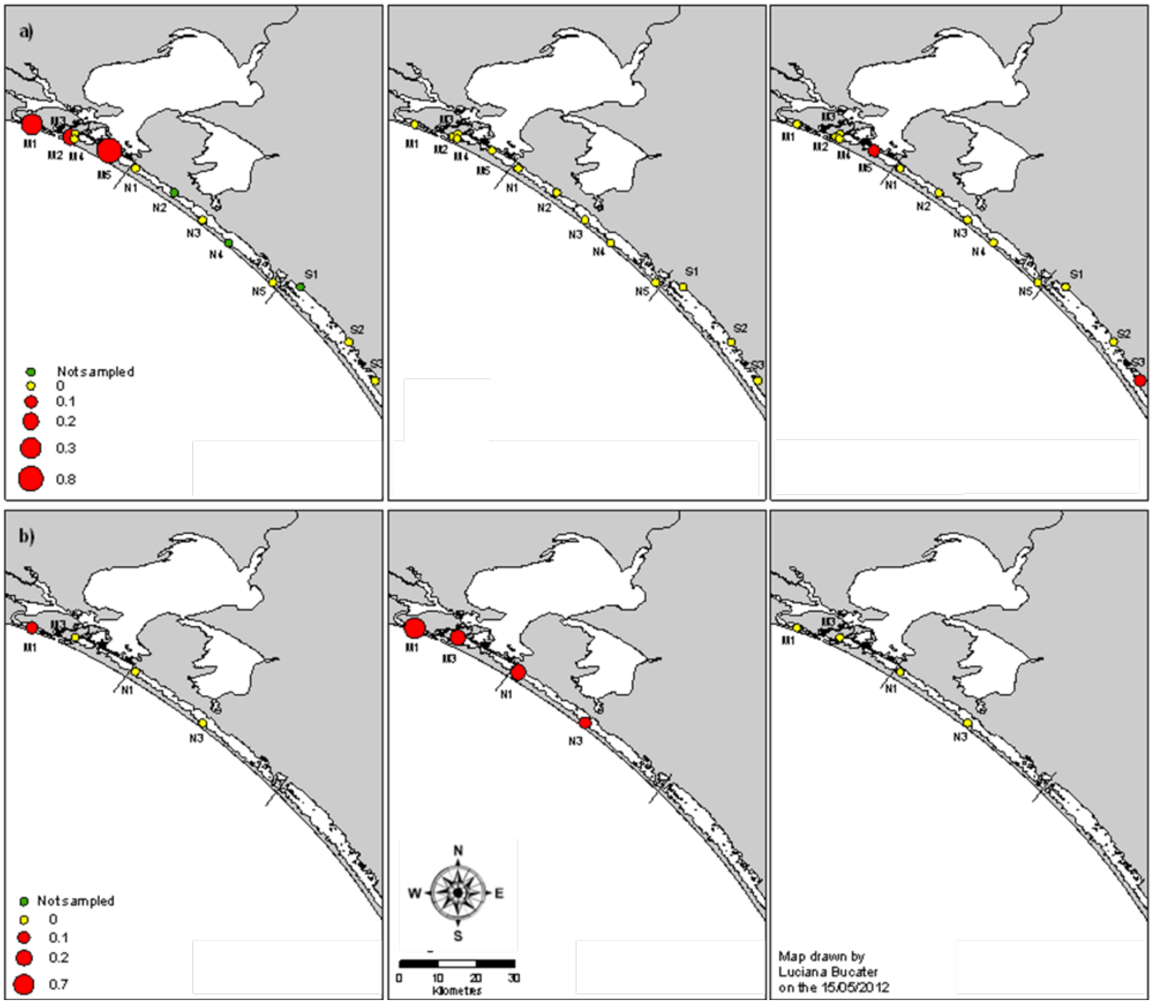

Figure 18. Black bream relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

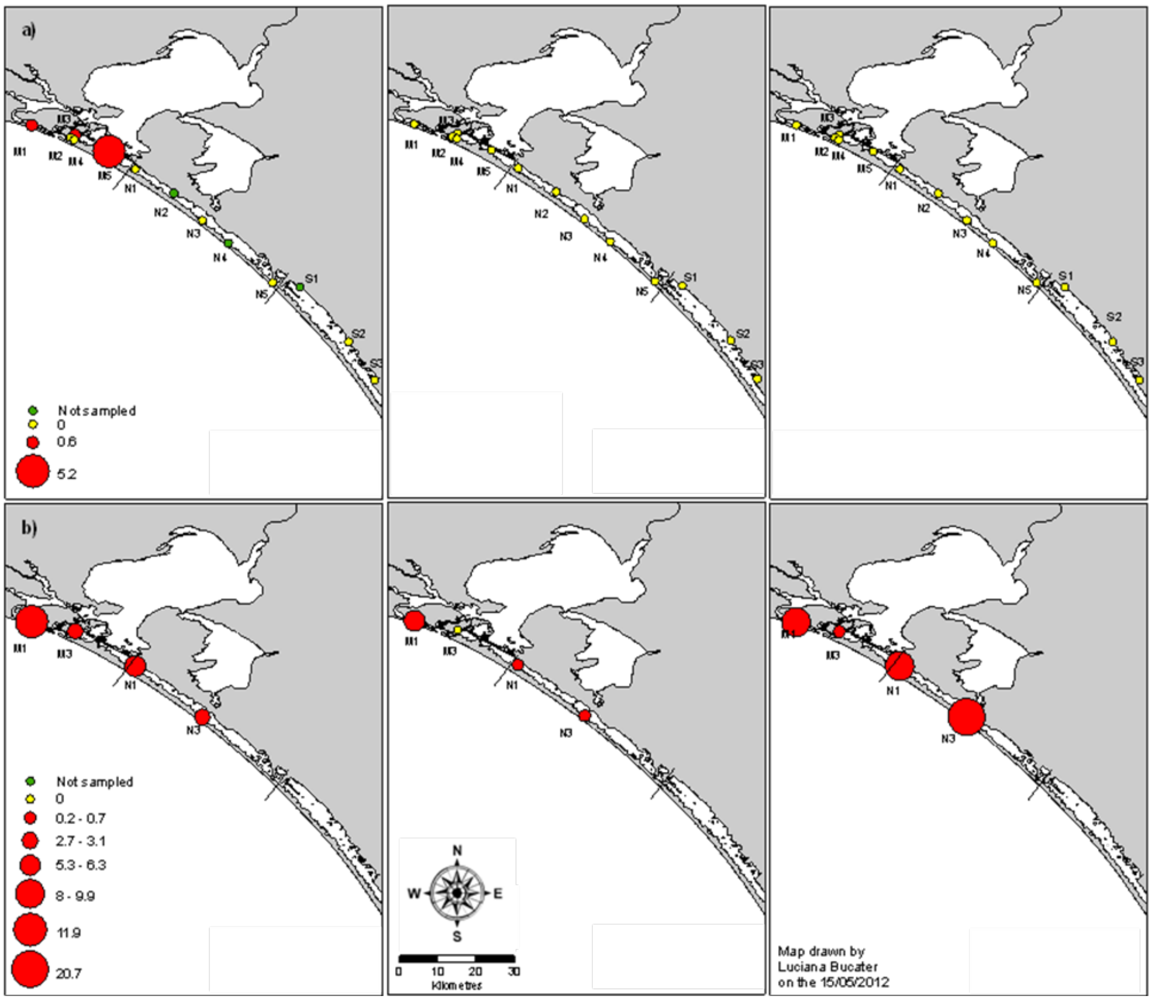

Figure 19. Mulloway relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

3.5.4. Freshwater native species

Bony herring had a substantial increase in both abundance and distribution throughout the Estuary and North Lagoon following barrage releases in 2010/11 (Figure 20). In 2011/12, seine net catches declined in both subregions (Figure 20a), whilst gill net catches continued to increase in the Estuary but decreased slightly in the North Lagoon (Figure 20b).

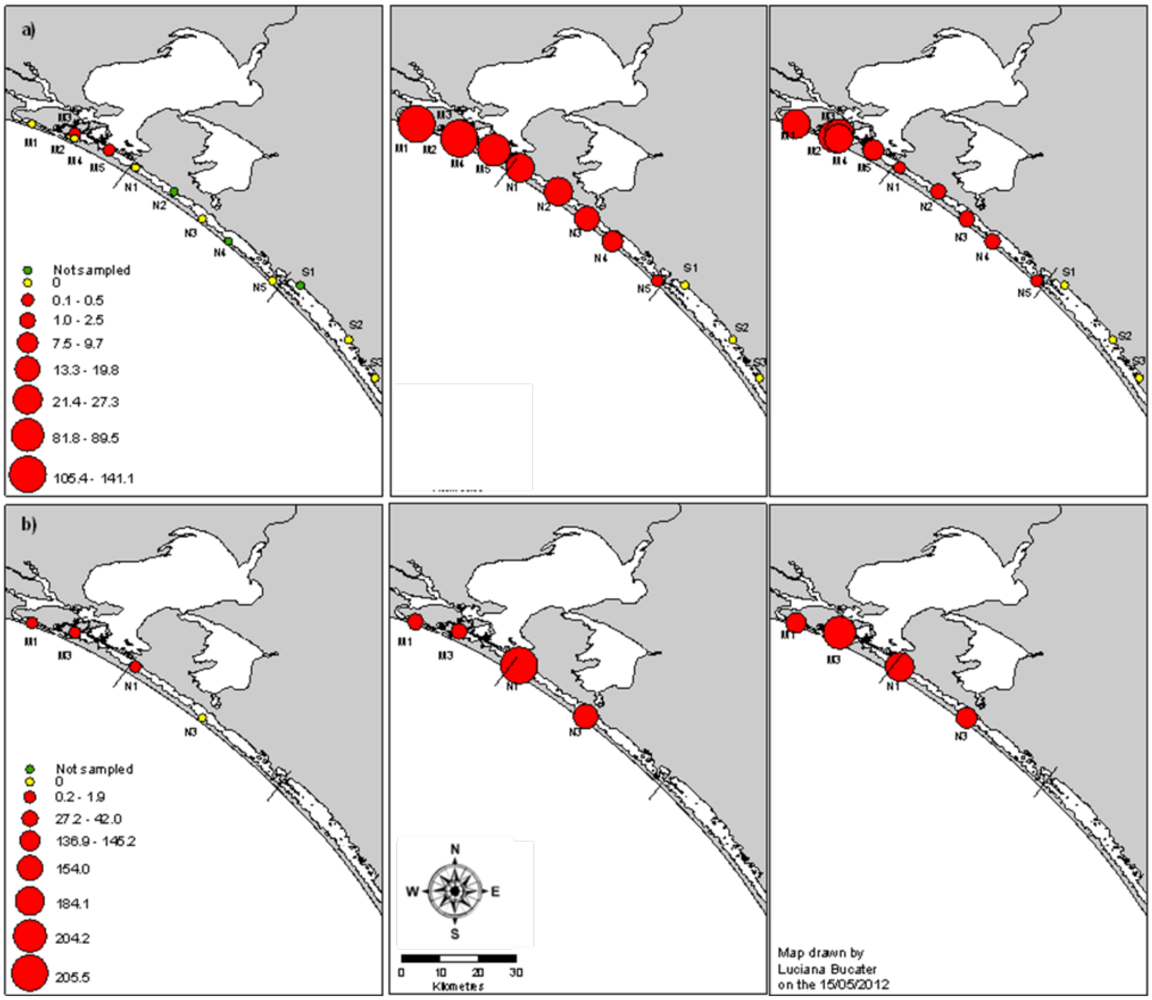

Figure 20. Bony herring relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

3.5.5. Freshwater exotic species

Carp and redfin perch, previously absent in the Coorong in the drought years (Noell *et al.* 2009), were sampled in large numbers by both gear types in 2010/11, particularly in the Estuary and the northern part of the North Lagoon (Figures 21 and 22). In 2011/12, seine net samples showed a decline in both abundance and distribution in carp with catches restricted to the Estuary (Figure 21a), whilst gill net data indicated variable abundance in adult carp between sites with a similar range to the previous years (Figure 21b).

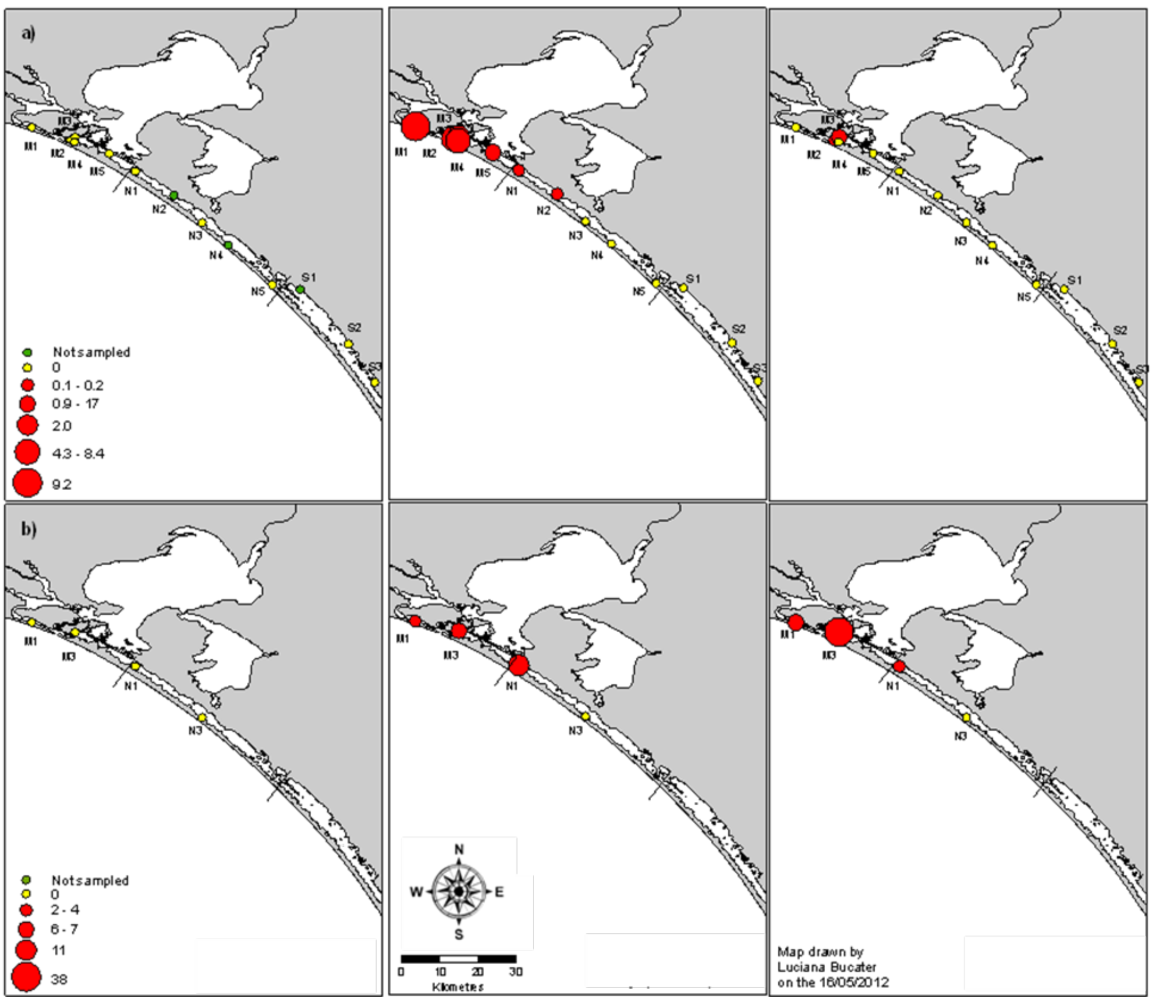

Figure 21. Carp relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

Similarly, for redfin perch, seine net samples showed a decline in both abundance and distribution from 2010/11 to 2011/12. In the later year, redfin perch was only found in the Estuary (Figure 22a). Gill net catches of redfin perch were similar between 2010/11 and 2011/12, although numbers were low in both years (Figure 22b).

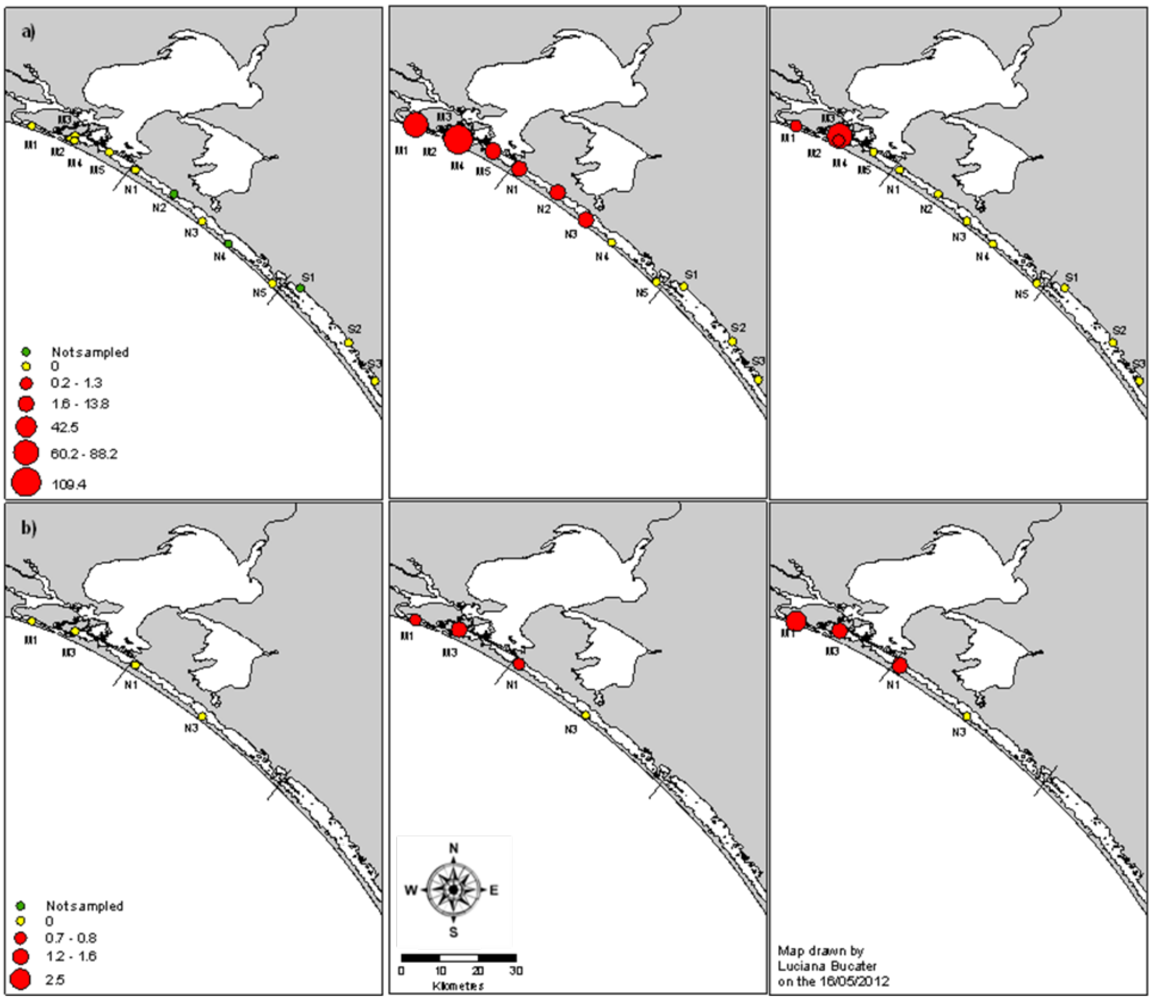

Figure 22. Redfin perch relative abundance and distribution in 2006/07 (left), 2010/11 (middle) and 2011/12 (right) for Coorong, a) fish collected by seine net and b) fish collected by gill net.

3.6. Length frequency distributions of key species

Length measurement data were obtained from fish collected using both seine nets and gill nets. Seine netting from the shore was most effective for sampling small-bodied species and juveniles of large-bodied species, whilst 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 populations. Length frequency data can enable the identification of cohorts that can sometimes be inferred as year classes, to identify recruitment events for key species. The modal progression of these cohorts can be traced with successive samples to analyse fish growth. It should be noted that length frequency distributions were established based on sub-sample data (a fixed number sampling regime); the number of fish is not a measure of abundance.

3.6.1. Small-bodied estuarine species

The length frequency distributions for smallmouthed hardyhead and Tamar goby generally showed broad ranges in size distribution. Several size classes were also present for sandy sprat. These size structures, in conjunction with occasional samples of very small fish, indicated successful recruitment in these species (Figures 23-25). Most significantly for smallmouthed hardyhead, many new recruits were collected in the South Lagoon in 2010/11 and 2011/12 (Figure 23). For sandy sprat, the proportional catch from the North Lagoon increased in 2011/12 compared to 2010/11, with many new recruits evident in this subregion (Figure 24). In contrast, the recruitment of Tamar goby seemed to be enhanced in the Estuary in 2010/11, but not in 2011/12 (Figure 25).

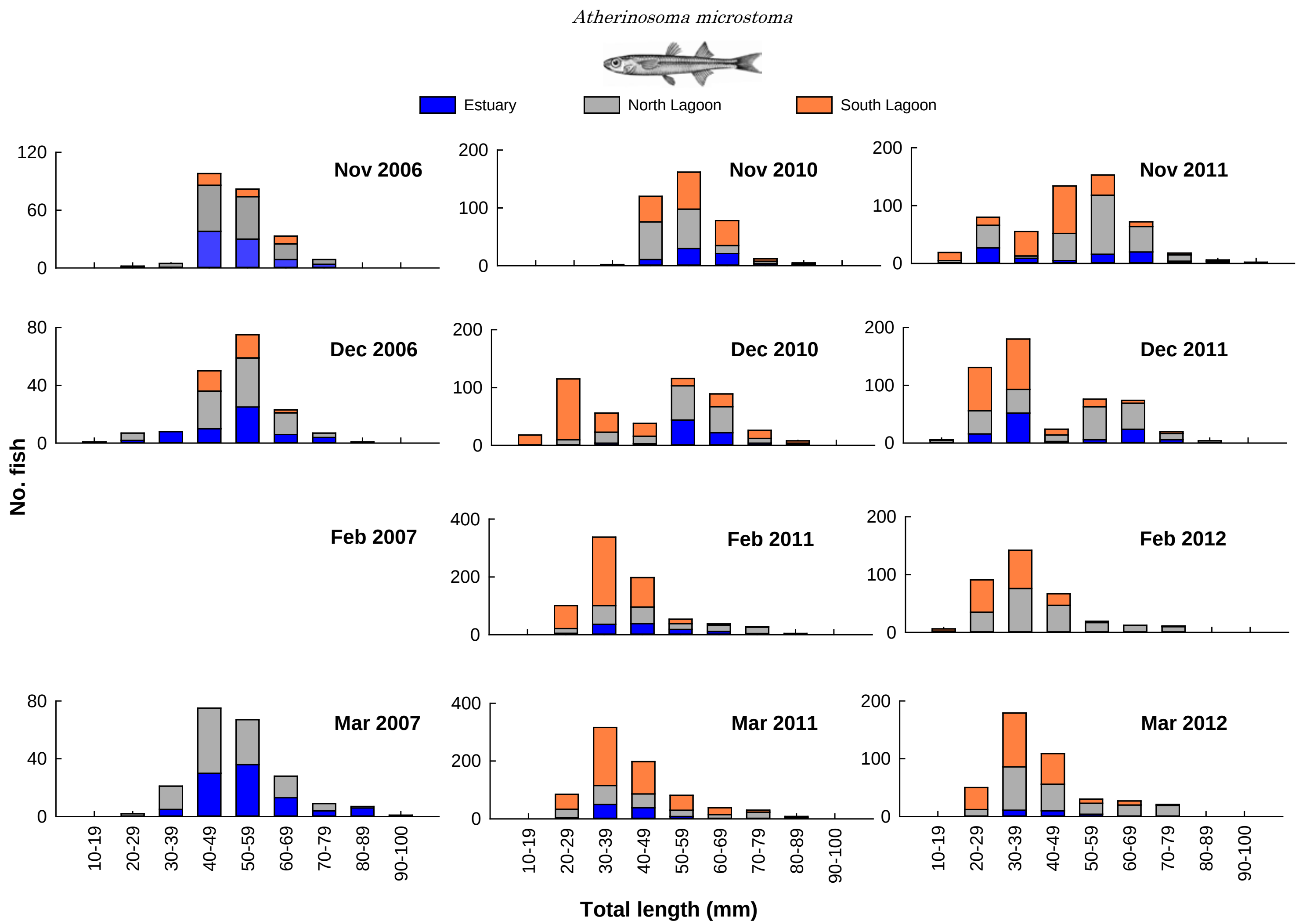

Figure 23. Length frequency distributions of smallmouthed hardyhead from seine net samples in the Estuary, North Lagoon and South Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

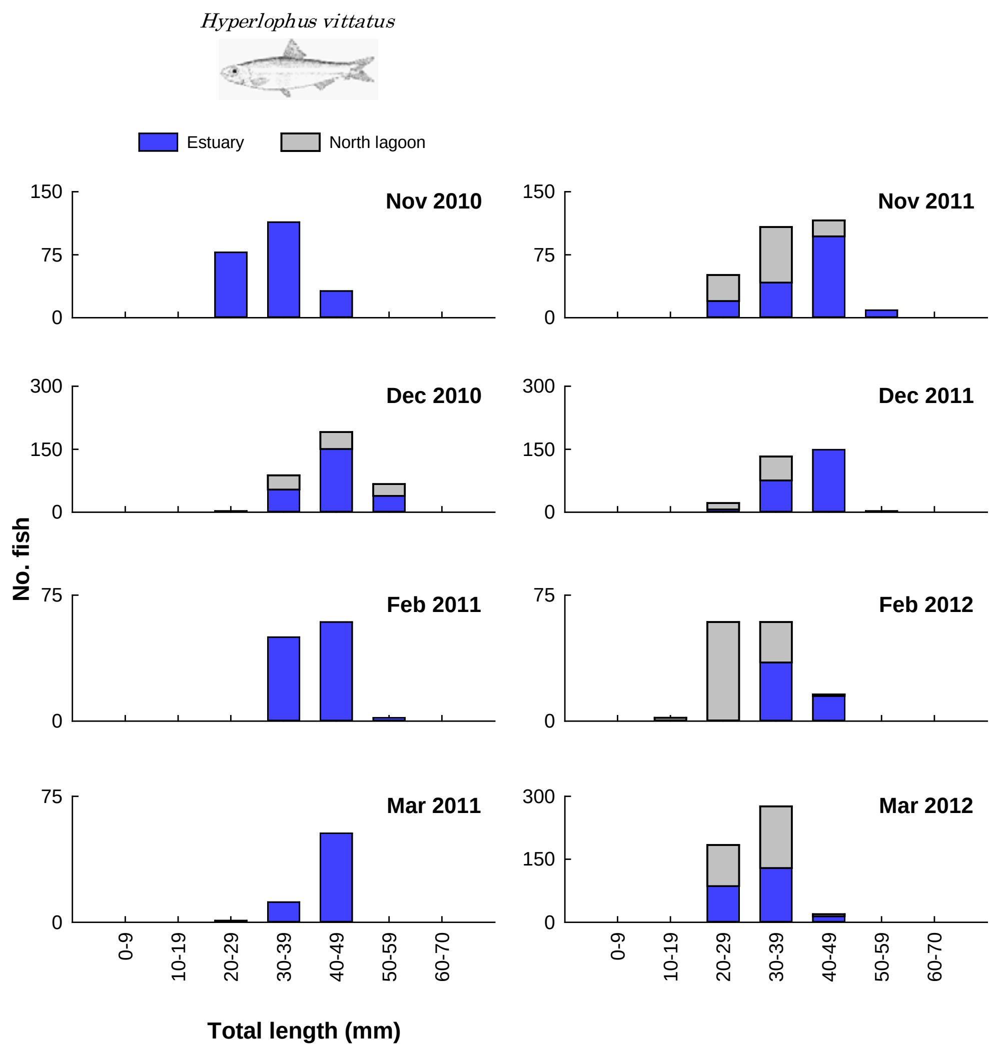

Figure 24. Length frequency distributions of sandy sprat from seine net samples in the Estuary and North Lagoon subregions of the Coorong in 2010/11 and 2011/12. Note the scale differences on the y-axis.

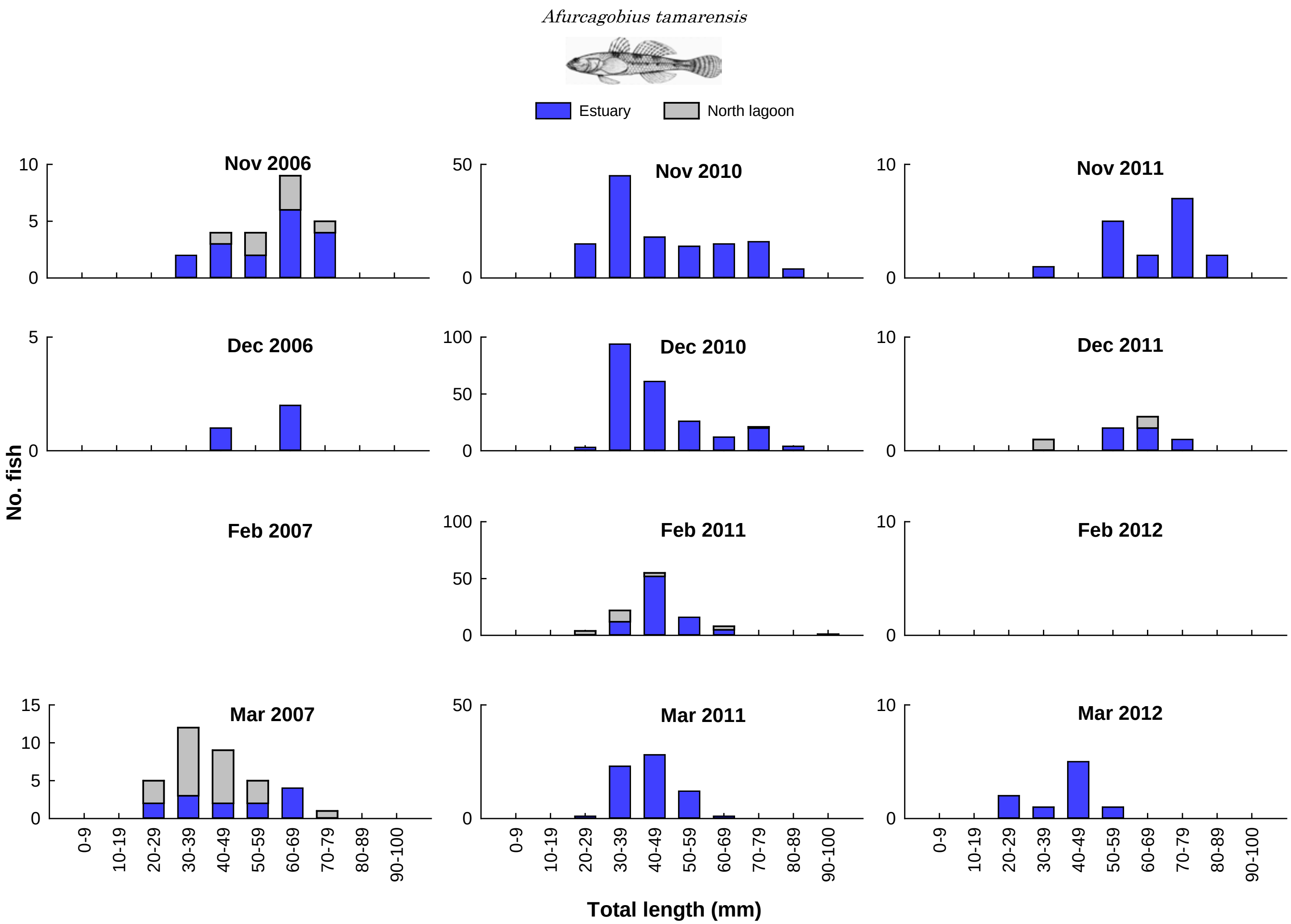

Figure 25. Length frequency distributions of Tamar goby from seine net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

3.6.2. Catadromous species

Congolli, as a medium-bodied species, were successfully collected by both gear types in all years. The length frequency distributions indicated size structures differed greatly among the three years (Figure 26). In 2006/07, low numbers of congolli were sampled with patchy size distributions. In 2010/11, fish numbers increased remarkably, and the population was dominated by new recruits <100 mm TL. In 2011/12, size distributions showed a much broader range, with two distinct size modes. Notably, a considerable proportion of the congolli catch was from the North Lagoon, particularly during 2011/12.

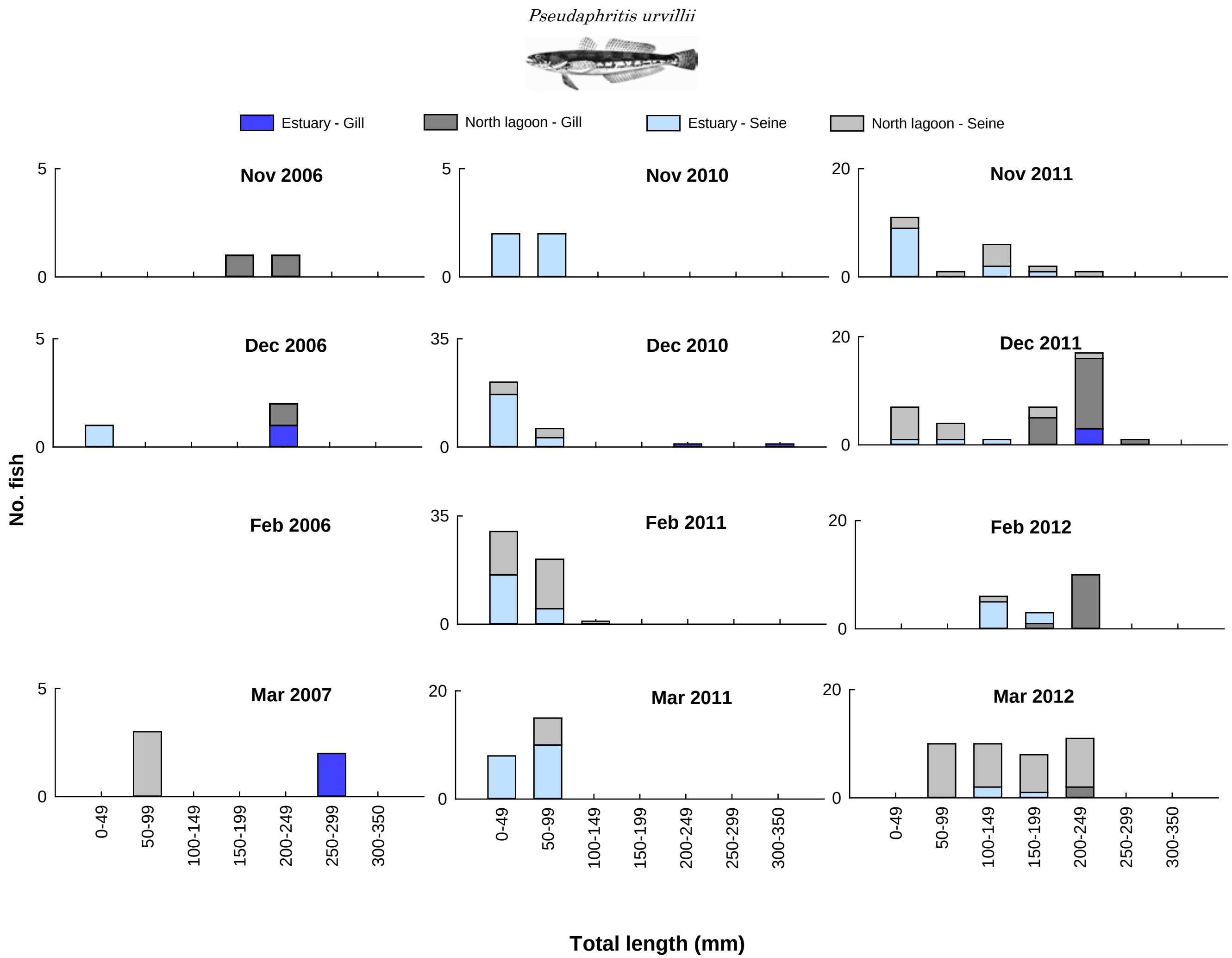

Figure 26. Length frequency distributions of juvenile and adult congolli from seine and gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

3.6.3. Large-bodied estuarine species

The length frequency distribution of greenback flounder was unimodal in all years, with only one distinct modal progression from December 2010 to February 2011, coinciding with a spatial shift of juvenile greenback flounder from the Estuary to the North Lagoon (Figure 27). Seine netting appeared to be effective for sampling greenback flounder, particularly for juveniles. Length frequency distributions indicated the presence of new recruits in all years, in both the Estuary and North Lagoon. Although there were low numbers of fish >150 mm TL collected in this study, commercial fishery catches by gill nets indicated the presence of larger individuals of greenback flounder during 2011/12 in the Coorong (Figure 31b).

Yelloweye mullet length frequency data showed a broad size distribution. The presence of a cohort of small fish (<80 mm) on most sampling occasions suggested recruitment success for this species in both the Estuary and North Lagoon in each of the three years (Figure 28).

Mulloway were present in both the Estuary and North Lagoon in all years, however seine net catches occurred only in 2006/07. In December 2006/07 and 2011/12, a distinct mode of fish between 160–239 mm TL appeared, followed by modal progressions for these cohorts in the following months (Figure 29), suggesting that new recruits enter the Coorong at this size around December.

Black bream were collected in very low numbers throughout the study period. Length frequency data were patchy; hence it was not clear whether recruitment success occurred in 2010/11 and 2011/12 (Figure 30). Length data from commercial fishery catches by gill nets indicated the presence of larger individuals of black bream during 2011/12 in the Coorong with a broad size range (Figure 31a).

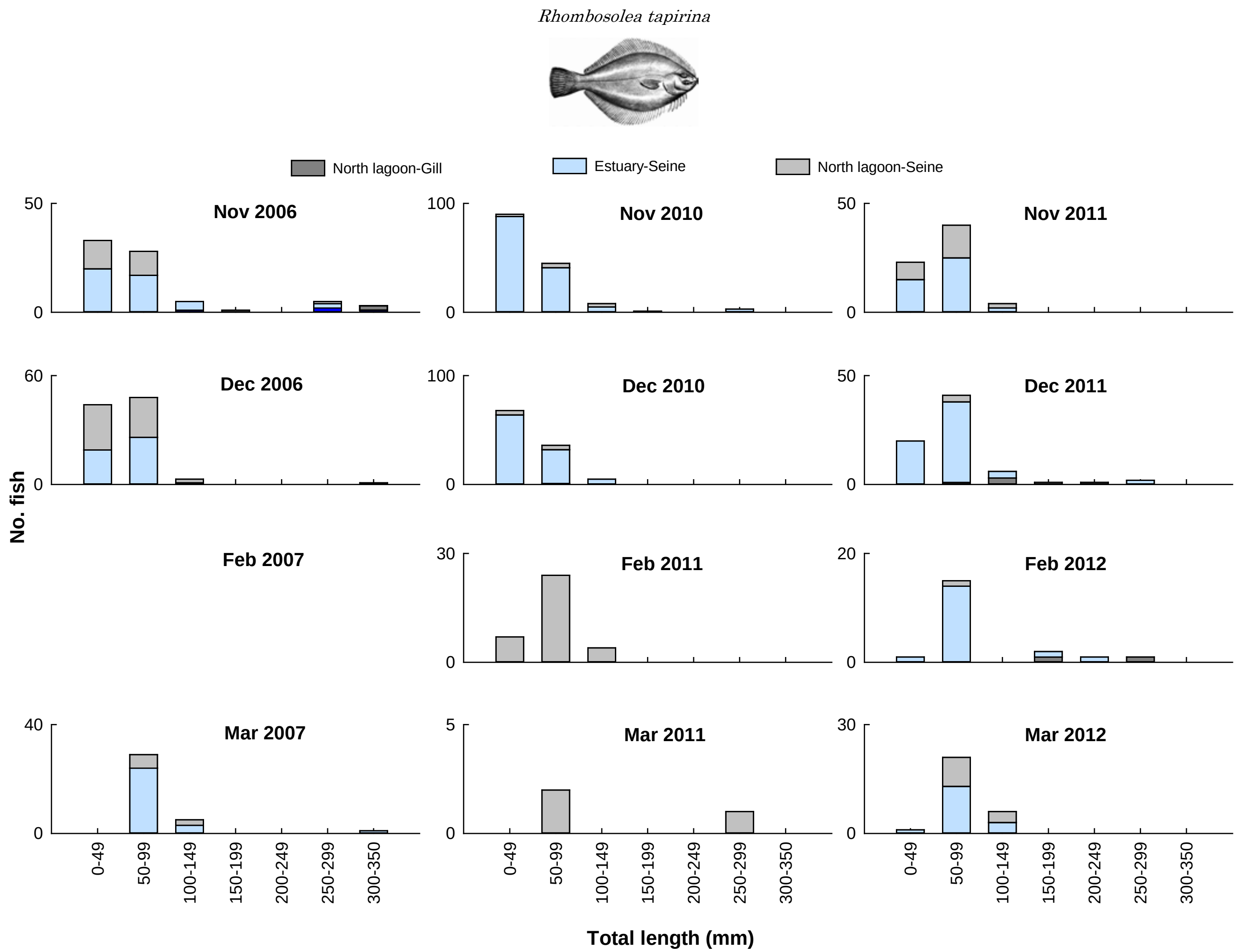

Figure 27. Length frequency distributions of juvenile and adult greenback flounder from seine and multipanel gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

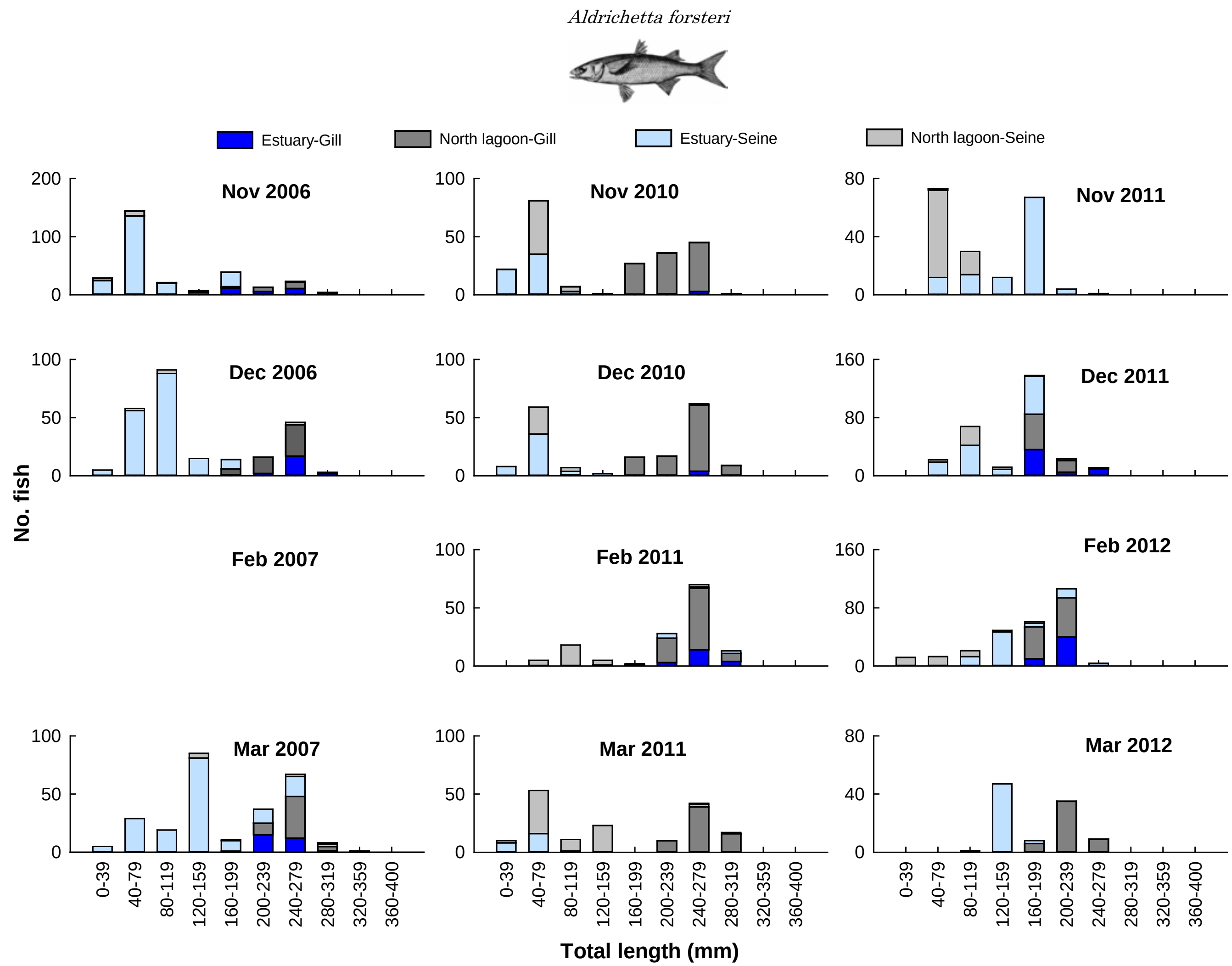

Figure 28. Length frequency distributions of juvenile and adult yelloweye mullet from seine and multipanel gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

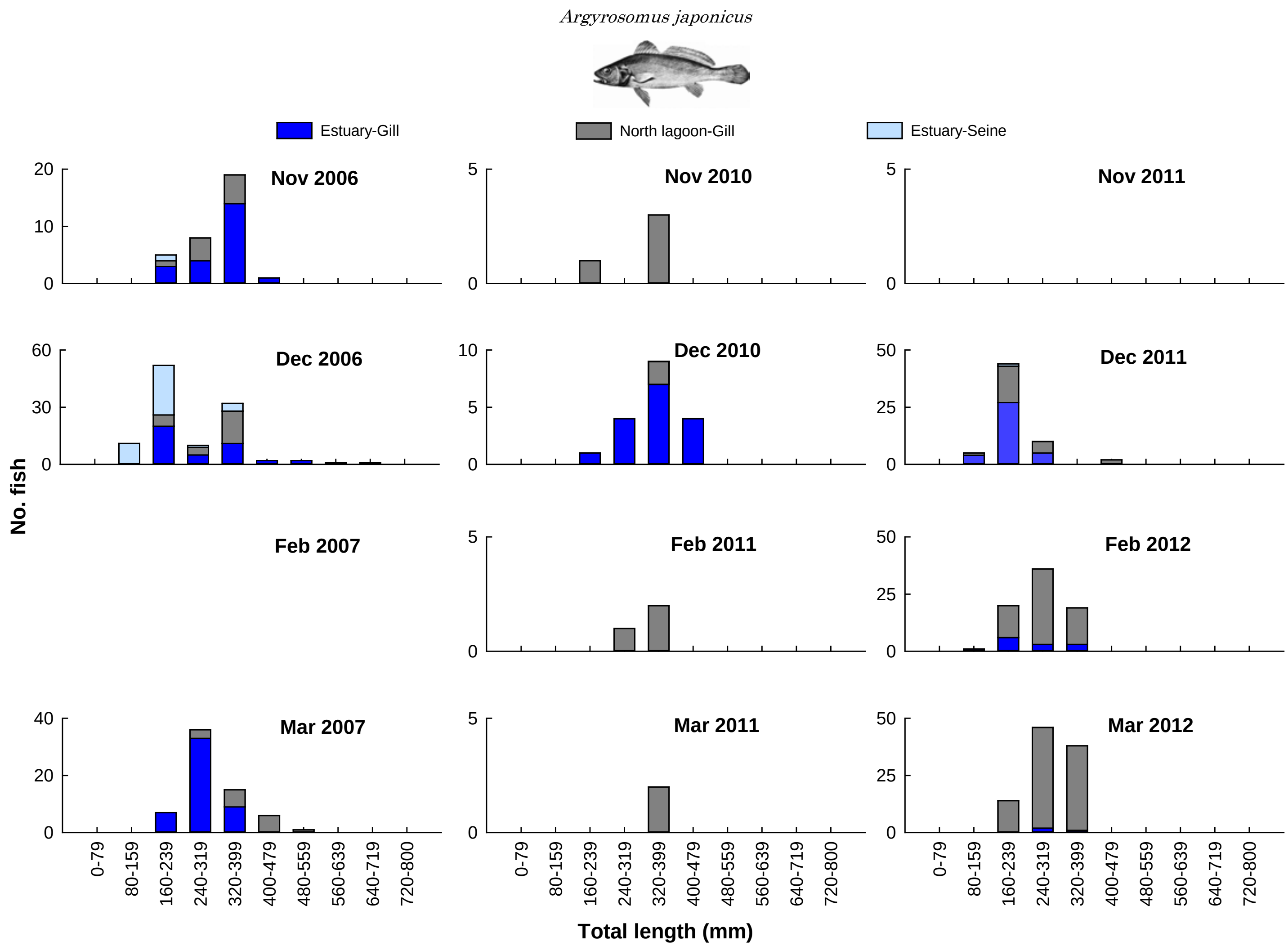

Figure 29. Length frequency distributions of juvenile and adult mulloway from seine and multipanel gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

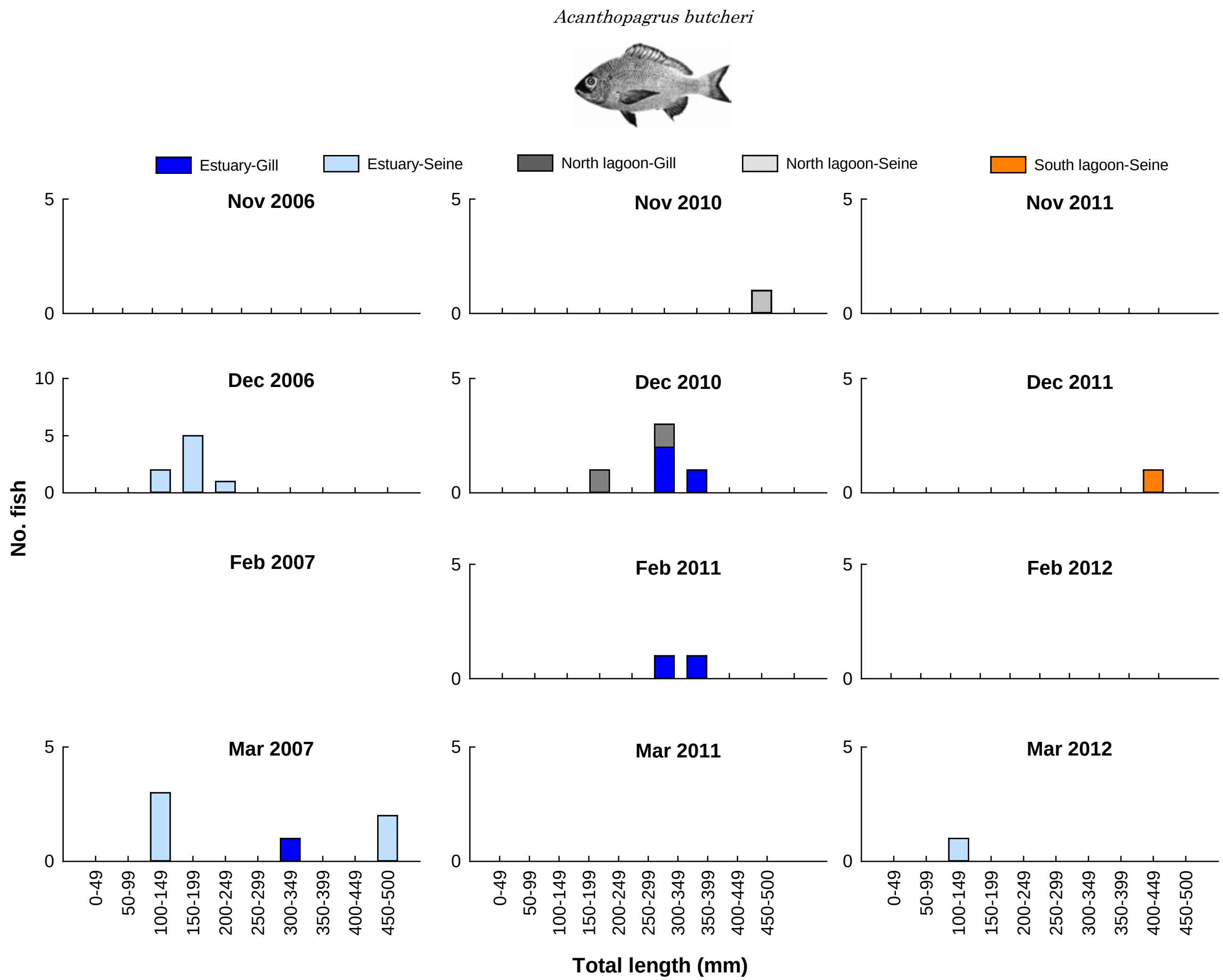

Figure 30. Length frequency distributions of juvenile and adult black bream from seine and multipanel gill net samples in the Estuary, North Lagoon and South Lagoon subregions of the Coorong in 2006/07, 2010/11 and 2011/12. Note the scale differences on the y-axis.

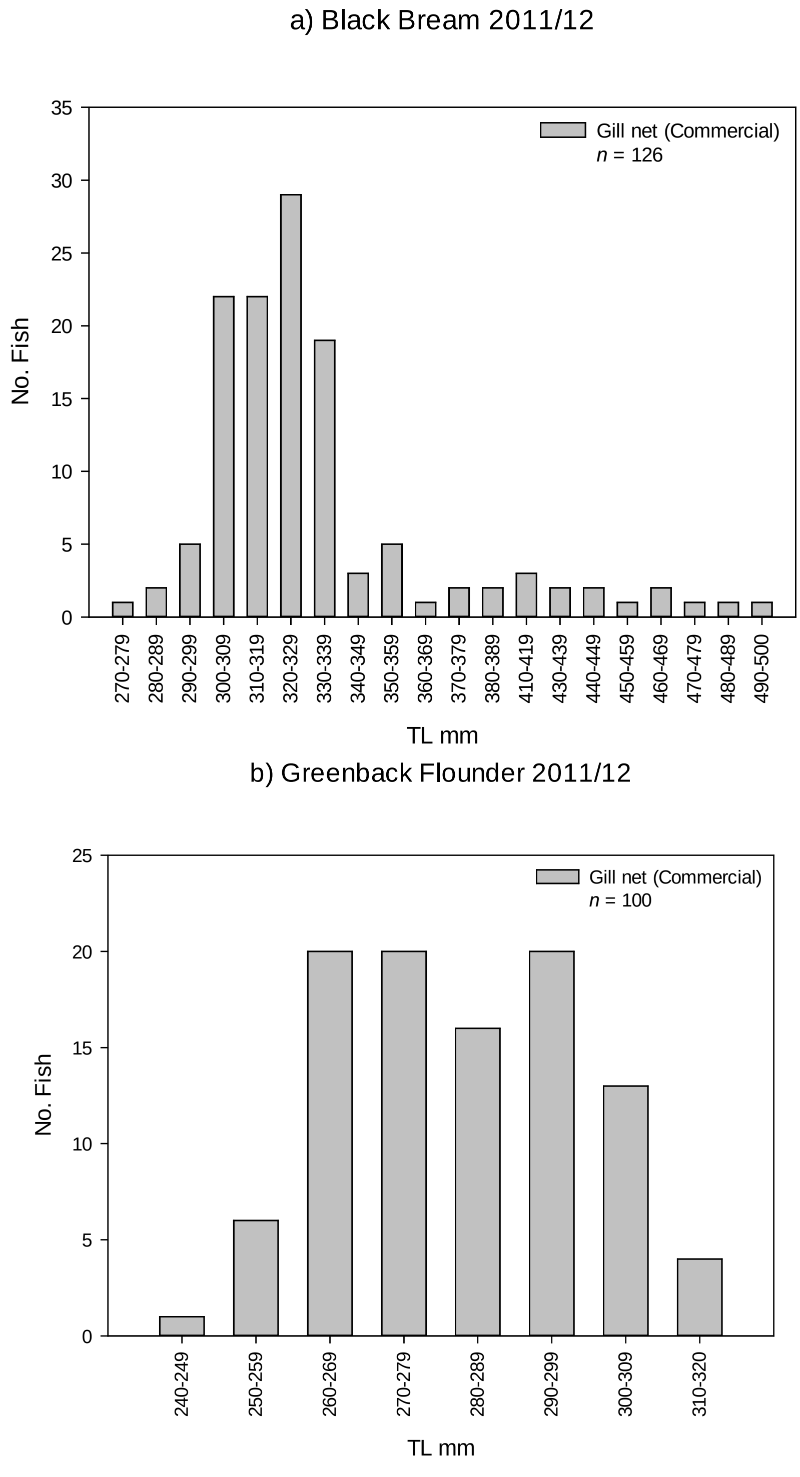

Figure 31. Length frequency distributions of black bream (a) and greenback flounder (b) sampled from commercial fishery catches by gill nets in the Murray Estuary and Coorong during 2011/12.

3.7. Age structures of selected key species

Very low numbers of black bream were sampled using fishery-independent methods (only 2 out of 120 fish) in 2011/12. Commercial fishery catches from the Coorong fish condition monitoring project (Ye *et al.* 2012b) were included for age structure assessment. Overall, black bream age ranged from 1 to 31 years, with a dominant cohort at 4 years (Figure 32). This strong cohort was recruited in 2006/07, coinciding with the last pulse of barrage discharge prior to the 3-year closure.

A combination of commercial fishery and fishery-independent samples was also used for greenback flounder age structure assessment. Fish ranged from 0 to 2 year olds, with seine net samples mostly being young of year (YOY) while fishery samples were dominated by 1 and 2 year old fish (Figure 33).

Mulloway and congolli were collected exclusively from fishery-independent sampling. For mulloway, age structure showed a unimodal distribution (Figure 34). The structure was dominated by 0 and 1 year olds, with 2 and 3 year olds also present.

Similarly, the congolli age structure was dominated by fish that recruited in the last two years, with >95% of the fish collected being 0 and 1 year olds (Figure 35). The timing of ring formation in the otoliths of congolli has not been validated to date. However, interpretations of this species' age structure were made based on the assumption that ring formation occurs annually.

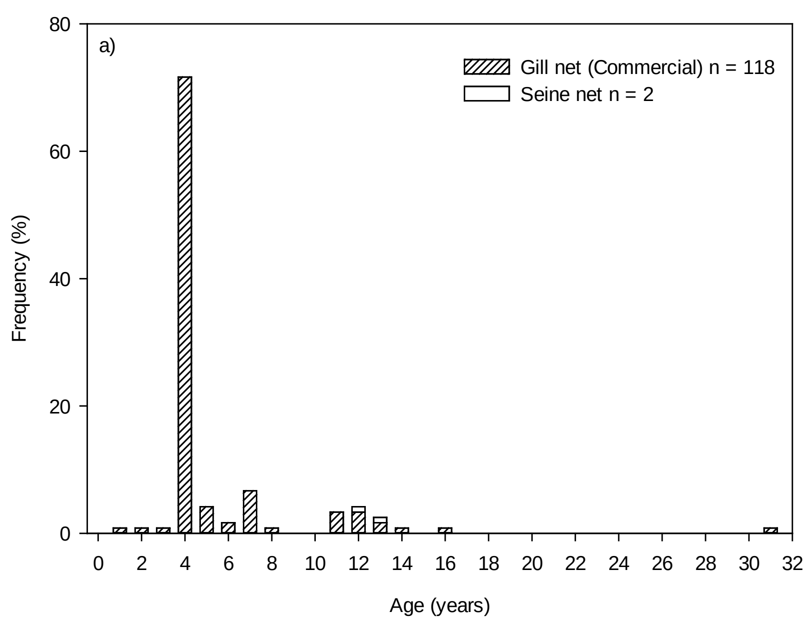

Figure 32. Age structure of black bream from the Murray Estuary and Coorong in 2011/12.

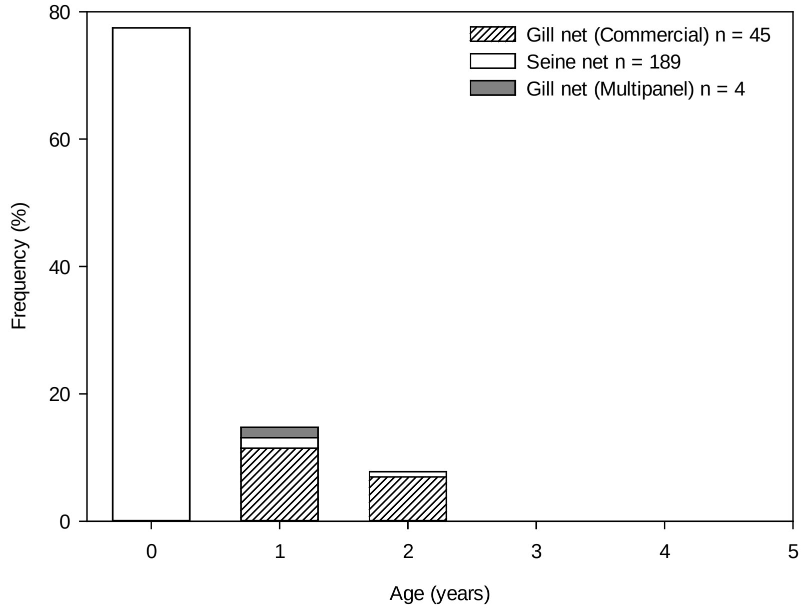

Figure 33. Age structure of greenback flounder from the Murray Estuary and Coorong in 2011.

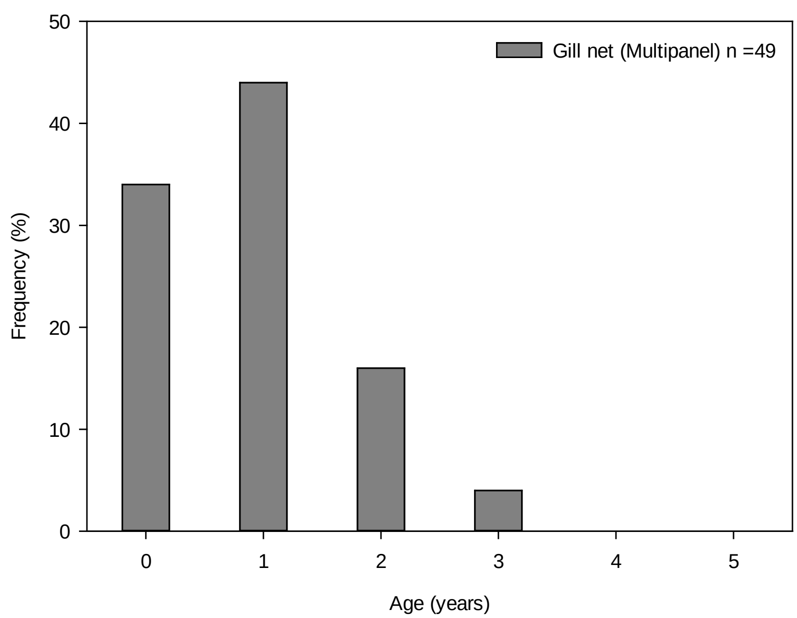

Figure 34. Age structure of mulloway from the Murray Estuary and Coorong in 2011/12.

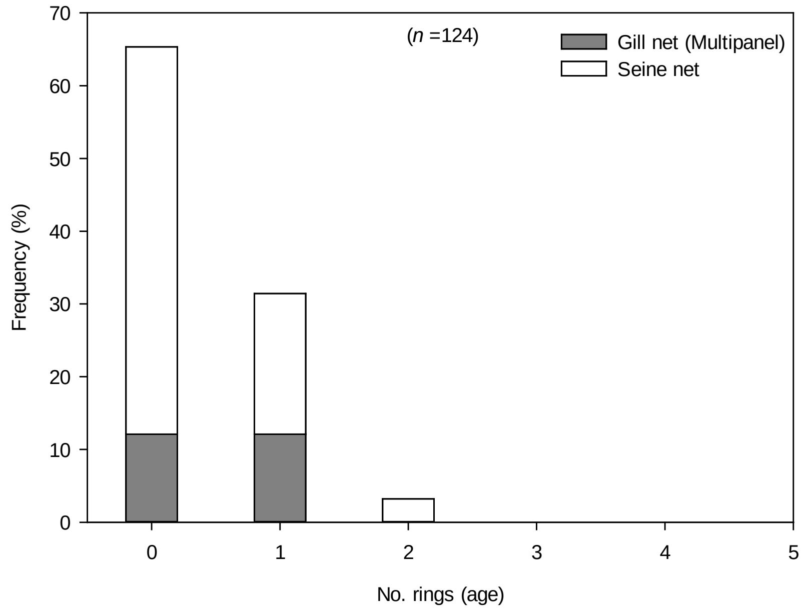

Figure 35. Age structure of congolli from the Murray Estuary and Coorong in 2011/12.

4. DISCUSSION

4.1. Barrage flow and salinity

During the first decade of this century (2001-2010), extensive drought in the Murray–Darling Basin, combined with river regulation and water abstraction, resulted in a significant reduction in annual freshwater flow to the Coorong, with annual discharge <1000 GL y^{-1} and a period of zero discharge between 2007/08 and 2009/10. Following increased rainfall in the MDB and significantly increased flow in the River Murray, the Lower Lakes refilled and freshwater releases to the Coorong in 2010/11 were among the highest (~13,000 GL y^{-1}) in the last 28 years, with high continued flows to the Coorong in 2011/12.

Salinities in the Coorong are highly variable, and are driven mainly by freshwater flows from the River Murray and tidal seawater exchange through the Murray Mouth (Geddes and Butler 1984). Typically, there is a strong north to south gradient with increasing salinities. During a previous fish assemblage study in the Coorong (2006-2008) (Noell *et al.* 2009) and the first two years' fish condition monitoring (2008/09 and 2009/10) when no barrage releases were made (Ye *et al.* 2011b), the Coorong essentially became a marine/hypersaline environment. Salinities in the southern part of the North Lagoon exceeded 100 psu and South Lagoon salinities were about 4-5 times greater than seawater (~170 psu). These salinities are among the highest ever recorded in the Coorong. For example, during the 1982 drought, average salinities were 80 psu in the North Lagoon and 90-100 psu in the South Lagoon (Geddes and Butler 1984). Increased salinities throughout the Murray Mouth and Coorong during the drought had a profound impact on fish assemblages in the region, with negative implications for several estuarine and diadromous species (e.g. black bream, greenback flounder, mulloway, smallmouthed hardyhead, congolli) (Noell *et al.* 2009; Zampatti *et al.* 2010; Ye *et al.* 2011b).

Following substantial freshwater inflows commencing in September 2010, salinities declined throughout the Coorong in 2010/11 and 2011/12, restoring fresh to brackish conditions in the Murray Estuary and an extended area of the North Lagoon, and salinities in the South Lagoon were reduced to <100 psu. Similarly, Geddes (1987) recorded a refreshing of the Coorong in 1983/84 after drought, following a period of substantial flows from the River Murray; the North Lagoon became brackish (<30 psu) and the South Lagoon moderately hypersaline (55-70 psu). Intervention monitoring in 2010/11 indicated several positive responses in fish assemblages in the Coorong, including an overall increase in species diversity and abundance; enhanced recruitment for small-bodied estuarine species and catadromous congolli; and a southward distributional range expansion into the North Lagoon for a number of estuarine species (Ye *et al.* 2011a).

4.2. Fish assemblages, species richness and abundance

4.2.1. Total species

Overall, 28 species were recorded from both seine and gill net samples during the monitoring for barrage releases in 2010-2012. The total number of species increased slightly compared to 2006/07 (26 species) under drought conditions. In particular, there was a substantial increase in the number of freshwater species (from two to seven species) and a decline in the number of marine estuarine opportunistic species (from twelve to nine) in this study. The two catadromous species, common galaxias and congolli, and six estuarine resident species, were sampled in both studies, however, the number of estuarine/marine fish species showed a reduction (from five to three). 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 2010-2012, 27 species were sampled by seine netting across a total area of ~78,144 m^2 in each year. The overall species richness is comparable to that in a previous study conducted during 2006-2008 (26 species) in the Murray Mouth and Coorong, when the total area sampled was 150,000 m^2 (Noell *et al.* 2009), however, the total number of fish collected was 4-5 times higher during the post flow study in 2010-2012. Primary contributors to the substantial increases in flow years were smallmouthed hardyhead, an estuarine resident species, and sandy sprat, a marine estuarine opportunistic species. In addition, there was an overall increase in the number of freshwater species (e.g. bony herring, redfin perch, Australian smelt) in flow years, particularly in 2010/11. The greater species richness at several sites following barrage releases in 2010-2012 was due to the presence of freshwater fish that were not collected during 2006/07 (i.e. redfin perch, flatheaded gudgeon, carp, golden perch, goldfish).

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. Certain fish taxa were probably forced out of the more saline areas due to the increasing osmoregulatory stress and/or diminishing food resources (Whitfield 1999). This allows a low number of species that are able to tolerate such environmental conditions to have a broader access to food resources, habitat and space, and to expand their ecological niche (Colburn 1988). Our study found that most of the decrease in species richness in 2006/07 occurred in the northern part of the North Lagoon, whilst in 2010-2012 the sharp decline shifted southward to the southern part of the North Lagoon, with both corresponding to salinity increases from ~38 psu to ~80 psu.

Smallmouthed hardyhead, an estuarine species that is tolerant of hypersaline and highly variable salinities (Lui 1969; Noell *et al.* 2009), was the most abundant fish in seine net samples in this study. It comprised ~60% of the total number of fish collected in 2010-2012, and continued to be the dominant species (almost 100% by number) in the South Lagoon after salinities reduced to 54-98 psu. 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 enters estuaries in large numbers (Potter and Hyndes 1999; Whitfield 1999). Sandy sprat constituted 20% and 38% of the total catch in 2010/11 and 2011/12, respectively. This species spawns 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 substantial increase in sandy sprat abundances in 2010-2012 was probably due to the barrage flows and subsequent enhanced productivity in the Coorong.

The next two most abundant species, bony herring and redfin perch, are freshwater fish, which entered or were displaced into the Murray Estuary and Coorong during the extended barrage releases in 2010-2012. Two other small-bodied freshwater species (Australian smelt and flatheaded gudgeon), were also abundant in the Estuary following the very high flows in 2010/11. 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 bony herring and Australian smelt were caught downstream of the barrages, and no other freshwater fish were 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 (e.g. redfin perch) in this study is of some concern. In freshwater environments such as the Lower Lakes and the River Murray, this species poses a biological threat to native fish communities. Redfin perch is a predator species that can prey on small native fish (Morgan *et al.* 2002), and it also carries a virus (Epizootic haematopoietic necrosis) that is potentially damaging to native species (Langdon and Humphrey 1987). In addition to redfin perch, there was an increase in carp numbers in the Coorong, but not to the same extent. Whilst exotic species reacted to environmental changes through increases in their population sizes, native freshwater species also showed a response. For example, the presence of juvenile golden perch, indicating spawning success of this iconic native flow-cued species (Cheshire *et al.* 2012), is a significant positive environmental outcome of the 2010/11 flood/high flow events.

4.2.3. Gill net samples

Total catches from gill net sampling, which targeted medium-large bodied species, were much lower than seine net catches, as gill netting was only conducted at four of thirteen sampling sites. Of the 15 species caught using gill nets during 2010-2012, 14 were adult representatives of species that were also collected using seine netting. Mulloway was the only species collected by gill net but not the seine nets.

The most abundant species in gill net samples was the freshwater bony herring, numerically accounting for 82% and 72% of the total catch in 2010/11 and 2011/12, respectively. More than 90% of bony herring were collected from the North Lagoon following the barrage releases in 2010/11, likely due to the very high inflows to the Coorong and broadly reduced salinities throughout the North Lagoon. Although being a common freshwater species, bony herring are known to tolerate high salinities (as well as high temperatures, high turbidities and low dissolved oxygen) (Briggs and McDowall 1996; Lintermans 2007). Nevertheless, their occurrence in the North Lagoon in this study at salinities as high as 72 psu probably represents the upper salinity tolerance for this species, which has been suggested to be at least 39 psu (Lintermans 2007).

The second and third most abundant species were the marine estuarine opportunists yelloweye mullet and Australian salmon. These species are also common in several south-western Australian estuaries (Potter and Hyndes 1999). For yelloweye mullet, despite an overall increased gill net catch (adult and sub-adult representatives) in 2010/11, a reduction was observed in the Estuary, with 96% of the catch taken from the North Lagoon. This may reflect the short-term disturbance in the Estuary during a period of substantial barrage releases which led to broad-scale reductions in salinity along the Coorong and a subsequent southward movement of this species into the North Lagoon. During the second flow year (2011/12), yelloweye mullet numbers increased in the Estuary, and their abundance was maintained in the North Lagoon. Yelloweye mullet is able to tolerate high salinities; the maximum salinity where this species was collected was 74 psu in the Coorong (Noell *et al.* 2009) and 81 psu in a coastal lagoon system (Lake George) in the south east of South Australia (Ye unpublished data). A similar pattern was observed for Australian salmon, with a shift of catch from the Estuary to the North Lagoon in the first high flow year (2010/11) followed by an increase in numbers in the Estuary during the second flow year (2011/12). Freshwater inflows to the Coorong have likely benefited these marine estuarine opportunistic species, which spawn in marine conditions but regularly enter and use estuaries as juveniles and/or adults when conditions are favorable. Fish would potentially take advantage of any enhanced biological productivity (i.e. food availability) related to freshwater inflows which can facilitate increased growth rates (and therefore survival rates) and enhance recruitment success.

For gill net samples, the increase in species richness from drought to flow years was most apparent at Noonameena (middle of the North Lagoon), and was probably driven by salinity reductions (73 psu in 2006/07 to ~37 psu in 2010-2012). Freshwater species (i.e. bony herring and golden perch), estuarine residents (i.e. black bream and river garfish) and opportunistic species (i.e. Australian salmon), were sampled during years of high flow, however, they were absent at this site during drought years (Noell *et al.* 2009). The total abundance of fish, as shown in gill net catches, increased in the North Lagoon during 2010/11 and throughout the three subregions during 2011/12. Not surprisingly, the primary contributors to these changes were the most abundant freshwater (bony herring) and marine/estuarine opportunistic species (yelloweye mullet and Australian salmon).

4.3. Spatio-temporal variation in fish assemblage structure and link to salinity

Following barrage releases in 2010-2012, fish assemblages changed significantly compared to the drought year (i.e. 2006/07), as reflected by seine net and gill net samples from the Coorong. Although the shift in assemblage structure was mainly driven by increased abundances in several freshwater species (bony herring, redfin perch, Australian smelt, flatheaded gudgeon, carp), particularly in the Estuary during 2010/11, enhanced abundances of several small-bodied estuarine species (i.e. smallmouthed hardyhead, Tamar goby, bridled goby), estuarine opportunists (i.e. sandy sprat) and catadromous species (i.e. congolli) also contributed. This suggests a positive response to the barrage flow releases in 2010-2012. Notably, in the North Lagoon, the change in fish assemblage (seine net data) during the first flow year (2010/11) was primary attributed to a substantial increase in smallmouthed hardyhead, whilst greater abundances in estuarine/opportunistic species and congolli have contributed to the further shift in assemblage structure in the second flow year (2011/12). This may suggest a time lag in biological response in some species following salinity reductions (e.g.

recruitment and recolonisation into the North Lagoon). For several large-bodied marine/estuarine opportunistic species (i.e. mulloway, yelloweye mullet and Australian salmon), abundances in the Estuary subregion declined in 2010/11, but then recovered in 2011/12, suggesting that very high freshwater inflows may represent a short-term disturbance for these species. However, in the long term, freshwater flows and the maintenance of typical estuarine conditions ultimately benefit these species, as they enter estuaries regularly, often in large numbers, seeking refuge, food resources and/or favourable nursery ground (Potter and Hyndes 1999; Whitfield *et al.* 2006). Evidence of this was the increased numbers of these large-bodied marine/estuarine opportunists in the second flow year.

Overall, the study demonstrated a clear shift in fish assemblage composition in the Coorong from assemblages dominated by marine/estuarine species in 2006/07 during the drought (Noell *et al.* 2009), to assemblages dominated primarily by freshwater/estuarine species during years of high flow (2010-2012). With the barrage opening and extensive reductions in salinity, the Murray Estuary and a large part of the North Lagoon became brackish (<35 psu). Typically, in estuaries with a strong freshwater influence, fish communities consist of estuarine residents along with freshwater and marine species that penetrate into the brackish reaches of systems, often resulting in high species diversity (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 attributed to the restoration and/or extension of estuarine habitats as a result of freshwater inflows and reduced salinities in the Coorong. Such biological responses, in addition to the enhanced recruitment in congolli (catadromous species), may suggest an initial recovery in estuarine fish assemblages in the region.

The importance of freshwater inflow and the responses of estuarine communities to variable inflows have been well 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; Ye *et al.* 2011a). 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 modifying 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 and transparency were identified as the main drivers influencing spatio-temporal patterns of fish assemblage structure in the Coorong with temeperature and pH also having a small influence for seine net samples. The effects of a large salinity gradient, ranging from saline (~30 psu) in the Estuary to extreme hypersaline (168 psu) in the South Lagoon, on the fish assemblages along the length of the Coorong were also described by Noell *et al.* (2009) during an extended drought period in the region and indicated the influence of this spatial gradient under varying flow conditions. It has been recognised 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).

As well as salinity, water transparency was another water quality variable that showed a significant effect on fish assemblages in the present study. Greater transparency in the Murray Estuary and North Lagoon regions during drought periods may be attributed to the lack of sediment loaded freshwater entering the system. Water transparency can affect behavioural as well as physiological aspects of fish that may determine distribution and abundance in different environments. Some small-bodied fish species have been shown to reduce general activity and intensify reproductive behaviours with reduced water transparency (Gray *et al.* 2012). Indirect effects of low water transparency may also occur by altering visual perception due to low levels of light (Utne-Palm 2002). This can have several consequences including alteration of predator-prey interactions (Abrahams & Kattenfeld 1997), disruption of species recognition signals (Seehausen *et al.* 1997) and change in reproductive behavior (Wong *et al.* 2007; Sundin *et al.* 2010). Variation in water transparency may also affect primary productivity, which ultimately impacts fish populations. Many studies suggested that the protection against predators afforded by turbid water, in addition to enhanced food resources, may explain why estuaries are productive nursery grounds for many fish species (Cyrus and Blaber 1987; Marais 1988; Griffiths 1996).

Accurate field records of dissolved oxygen (DO) were not possible due to the extreme salinities in which the available measuring instruments are not reliable. Therefore, DO was not included in the multivariate analysis as values were derived from a theoretical saturation formula dependent on salinity and temperature. However, it is widely accepted that oxygen concentration in the water column may also affect fish abundance and distribution. Early life stages, which can determine recruitment success, are particularly vulnerable to low oxygen availability (Levin *et al.* 2009). Laboratory experiments on black bream showed that low oxygen led to delayed hatching, reduced survival and increased deformities in moderately hypoxic conditions (Hassell *et al.* 2008a, b). However, interpretation of the influence of DO on distribution and abundance of fish in the Coorong should be undertaken cautiously, as many other factors can co-vary with DO and hinder or intensify the effects of oxygen depletion (Rose *et al.* 2009).

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

Following the barrage releases and substantial salinity reductions in the Coorong, all the key estuarine, opportunistic and catadromous species had a southward range extension, with several species also expanding their distribution further south from 2010/11 to 2011/12 (sandy sprat, Tamar goby, yelloweye mullet and black bream). It is worth highlighting that black bream and yelloweye mullet were sampled, although in low numbers, in the South Lagoon in 2011/12; whilst previous studies during the drought found no fish or only a single species, smallmouthed hardyhead, in low numbers in this subregion (Noell *et al.* 2009; Ye *et al.* 2011c, d). Our findings support the hypothesis that fish populations would at least maintain the ranges observed in the Coorong in 2010/11 for key estuarine and catadromous species under continued flow. Black bream, yelloweye mullet and congolli occured in the northern part of the South Lagoon during 1983/84, when salinities reduced to 55 psu following above average barrage flows (Geddes 1987).

In terms of freshwater species, bony herring (native fish) had a substantial increase in abundance and extended its distribution into the southern end of the North Lagoon 2010/11 following the very high barrage releases, which likely displaced many freshwater fish from the Lower Lakes downstream into the Coorong. With slightly reduced flows in 2011/12, abundance of bony herring declined but its distributional ranged was maintained (Goolwa to Hells Gate). Bony herring, although a freshwater species, can tolerate higher salinities and is often caught in brackish water (SARDI unpublished data). The findings of this study also support the hypothesis that fish populations would at least maintain the ranges observed in the Coorong in 2010/11. On the other hand, a large number of redfin perch and carp (exotic species) were also displaced into the Coorong during the high flows in 2010/11, distributing throughout the Estuary and the northern part of the North Lagoon. In the following year with less flow, both species had reduced abundances and their ranges contracted to the Estuary subregion. Exotic freshwater species are less tolerant of high salinities compared to Australian native species of marine origin. This range contraction for freshwater exotic species therefore does not support the hypothesis regarding fish maintaining ranges of 2010/11.

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 high flows in 2010-2012 and subsequently their abundances increased in the Coorong, with many new recruits occurring in the North Lagoon, where they were formerly absent or less abundant during the drought years (Noell *et al.* 2009). These results support the hypotheses that diadromous and estuarine fish would continue to recruit in 2011/12, and estuarine fish habitat would maintain in the North Lagoon and serve as a nursery ground for several species. An exponential increase in smallmouthed hardyhead abundance occurred in the South Lagoon after salinities reduced from 105-168 psu in 2006/07 to the current 54-98 psu. This was likely a combined result of local spawning events, a range extension in this species from the North Lagoon, and dispersion of the remnant population from Salt Creek into the South Lagoon. Importantly, the presence of many fish <30 mm TL in the South Lagoon in both flow years suggested recruitment success in this subregion. Such a response by this keystone species has high ecological significance, as smallmouthed hardyhead provide important ecological services, in particular as a major food item for various piscivorous fish and water birds in this Ramsar site (Paton 1982; Rogers and Paton 2009; Deegan *et al.* 2010). Length frequency distribution and age structure analysis for congolli indicated that strong cohorts of 0+ and 1+ year old fish recruited to the Estuary following the barrage opening and increased freshwater inflows to the Coorong during 2010-2012. As an obligate migratory species (catadromy), recruitment success in congolli is strongly dependent upon the connectivity between marine, estuarine and freshwater habitats, and river inflows to the Coorong which likely produce favourable environmental conditions (Zampatti *et al.* 2010). The importance of freshwater flows for the recruitment of congolli and other catadromous species (common galaxias) has been previously documented in the Murray Estuary (Bice *et al.* 2007; Jennings *et al.* 2008; Zampatti *et al.* 2010).

In terms of the large-bodied estuarine opportunistic species, yelloweye mullet showed a general decline in abundance (both juveniles and adults) in the Estuary but an increase in the North Lagoon following the barrage releases during 2010-2011; although there appeared to be a slight recovery in abundance in the Estuary during the second flow year. This suggests that high freshwater inflows may represent a short-term disturbance in the Estuary for this opportunistic species. Given yelloweye mullet have a relatively high salinity tolerance (i.e. laboratory estimates of 50% lethal concentration (LC_{50}) range between 82-91 psu; Ye *et al.* 2012a), this species may have moved southward to explore more saline environments, particularly in the North Lagoon (8-76 psu). This was supported by their southward range expansion in both flow years (although only one individual was caught in the South Lagoon). For mulloway, gill net samples indicated a reduction in catch throughout the Coorong in 2010/11 compared to previous years; this was not unexpected given the very low salinities in the Murray Estuary following substantial freshwater inflows over a long period. Freshwater flows are believed to be important for the recruitment of mulloway (Ferguson *et al.* 2008). Freshwater attracts spawning aggregations of reproductively mature adults and sub adults at the interface of the River Murray plume with the Southern Ocean 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 Estuary several months later at 100-150 mm total length (Hall 1986). Therefore, sampling might have occurred too early to detect a flow related recruitment response in mulloway during the 2010/11 season, or the very high flows might have reduced their catchability. However, gill net sampling in 2011/12 identified the presence of a cohort of juvenile mulloway in the 1+ year class that originated from successful recruitment in 2010/11. In addition, the 2011/12 year class also appeared as a strong pulse of 0+ year old fish in the age composition. These two cohorts were the primary contributors (~80%) to the improved catch of mulloway in 2011/12. These results support the critical role of freshwater inflows in facilitating the recruitment of mulloway and the Coorong being an important nursery ground for mulloway (Ferguson *et al.* 2008).

Greenback flounder, an estuarine and marine species, responded positively to the barrage releases during 2010-2012 by extending their nursery grounds into the southern part of the North Lagoon (to Hells Gate in 2011/12), as evidenced by the increased range of juveniles. In contrast, juvenile abundance showed a general decline in the Coorong, which might partially relate to their dispersion throughout a much broader habitat. Targeted investigation on this species during fish condition monitoring indicated increased numbers of juveniles at specific sites (e.g. Mark Point) in the North Lagoon following the 2010-2012 barrage releases (Ye *et al* 2012b). Greenback flounder recruitment is likely influenced by freshwater flows to estuaries (Robins and Ye 2007); as this species spawns during winter (Crawford 1984), before the typical high flow season, larval and juvenile growth may be enhanced by increased biological productivity (i.e. food availability) related to freshwater flows to estuaries, resulting in higher levels of recruitment success (Robins and Ye 2007). In addition, freshwater inflow is a key driver of the Coorong salinity regime (Geddes and Butler 1984; Geddes 1987; Brookes *et al.* 2009; Ye *et al.* 2011a). Salinity is known to play a key role in the reproductive biology of greenback flounder, with optimum fertilisation rates occurring between 35-45 psu and egg tolerance range of 14-45 psu after fertilisation (Hart and Purser 1995). Increased salinities during years of no barrage discharge (2007-2010) likely excluded a large area of the Coorong (the North and South Lagoons where average salinities were ~55-150 psu) as a favorable spawning ground, potentially impacting recruitment success of greenback flounder. Fisheries data also suggest a contraction of the adult population to a reduced habitat in the Murray Estuary during recent drought years (Ye *et al.* 2011b). The significant flows in 2010-2012 restored a more favorable salinity gradient, and probably increased habitat quality and availability for greenback flounder throughout most of the North Lagoon (salinities 8-76 psu), which likely benefited spawning and recruitment. Furthermore, juvenile greenback flounder are more tolerant of hypersaline conditions than eggs, with the laboratory estimates of LC_{50} for juveniles ranging from 79-88 psu (Ye *et al.* 2012a). Tolerance data therefore agree with the collection of juvenile greenback flounder in the northern to mid part of the North Lagoon during recent drought years (Noell *et al.* 2009; Ye *et al.* 2011b), as well as its distribution expansion to the southern end of the North Lagoon (Hells Gate) in 2011/12.

Many estuarine associated species, particularly small-bodied fish, have shown signs of a positive response to the barrage releases in 2010-2012; however black bream, an iconic estuarine resident species showed no signs of a population recovery. Black bream relative abundance remained low in the Coorong for both adults and juveniles. Whilst salinity reductions throughout the Coorong have allowed adults to recolonise the North Lagoon (i.e. slight increase in gill net catch 2010/11,) and possibly expand their range to the South Lagoon (i.e. one individual caught in the South Lagoon in 2011/12), no YOY were collected in 2010/11 and only one juvenile fish was caught in 2011/12. The lack of juvenile black bream may suggest either recruitment failure or an artifact of reduced sampling efficiency during the high flow years (e.g. reduced fish density, dispersion or re-distribution, shifted location of favorable estuarine habitats). 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). Ye *et al.* (2012b) found that the three strong cohorts (i.e. 1997/98, 2003/04, 2006/07) of the Coorong population were associated with below-average inflows from the River Murray; indeed the volume of barrage releases was only 78 GL y^{-1} in 2006/07. Another study in Western Australia also indicated that recruitment of juveniles was greatest in moderate flow years (Hoeksema *et al.* 2006). Newton (1996) reported that aligning the timing of spawning with inflows was likely an important part of the spawning strategy of black bream and may be a critical factor for recruitment success as the inflows provide increased food supply for the larval fish. This suggests that the influence of flow on the population dynamics of black bream in the Coorong is more complex than just flow volumes. Therefore, environmental flow management should consider the importance of flow regimes (i.e. timing, frequency, duration, etc) in concert with water allocation when considering appropriate management strategies for black bream.

Many large-bodied fish (e.g. black bream, greenback flounder, mulloway, yelloweye mullet) that inhabit the Murray Estuary and Coorong are important species for the Lakes and Coorong fisheries (both commercial and recreational). Recent fish condition monitoring in the Coorong reported that population abundance of black bream and greenback flounder had declined significantly, particularly over the last ten years (Ye *et al.* 2012b). Their relative abundances were at historical lows in 2008-2011. In addition, the truncated population age structures for both species may imply a high exploitation rate by the fishery. Although for greenback flounder, this may partially be attributed to movement between the Coorong and marine system (Ye *et al.* 2012b). A recent stock assessment for mulloway also documented a population under stress in the Coorong, likely due to the combined impacts of habitat degradation and fishing (Ferguson and Ward 2011). However, the current study suggests a positive recruitment response in this species to the flows in 2010-2012. Given the uncertainty in population trajectory for some of these large-bodied long-lived species, monitoring will be required in subsequent years to continue to investigate the recruitment response and population recovery in these commercially important species and evaluate potential benefits of freshwater inflows to the Coorong on these species. Environmental water management should also consider small to moderate freshwater releases, which could potentially lead to recruitment success in black bream, as suggested by the presence of strong cohorts of 1997/98, 2003/04 and 2006/07 in the Coorong. In addition, conservation management should seek to protect the remnant populations of these species and rebuild the age structures to improve capacity for egg production and therefore enhance population resilience. Further investigation is required into the dynamic movement patterns of the estuarine and marine estuarine opportunistic species in the Murray Estuary and Coorong, as well as between the Coorong, freshwater and marine environments under different flow conditions. Additional research is also required to determine the environmental factors and/or mechanisms, including flow regimes, critical habitat requirements and food resources, that contribute to recruitment success of key estuarine species. Such knowledge will facilitate the development of well informed ecologically sustainable management strategies for estuarine fish populations in the dynamic ecosystem in the Coorong.

5. CONCLUSIONS

Freshwater inflows play an important role in structuring fish assemblages in the Murray Estuary and Coorong, maintaining estuarine conditions and facilitating the recruitment of estuarine and catadromous species. Following the barrage releases in 2010/11 and 2011/12, salinities fell significantly from marine–extremely hypersaline (up to ~170 psu) to the current levels of 0-14 psu in the Estuary, 8-76 psu in the North Lagoon, and 54-98 psu in the South Lagoon. Broadly decreased salinities, coupled with other freshwater induced environmental changes (e.g. dissolved oxygen, transparency), elicited significant ecological responses in fish assemblages in the region. The fish assemblage composition has changed significantly compared to that of the drought years, predominantly due to an increase in the diversity and abundance of freshwater species and increased abundances of small-bodied estuarine resident and opportunistic species (i.e. smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (i.e. congolli) following enhanced recruitment. Although large-bodied estuarine opportunistic species (yelloweye mullet and Australian salmon) declined in the first flow year in the Estuary, they recovered in 2011/12. The freshening of the Coorong also resulted in a southward range expansion for all key species, including black bream (adult), yelloweye mullet, congolli, greenback flounder, Tamar goby, sandy sprat and probably mulloway given its increased abundance in the middle of the North Lagoon (Noonameena) in 2011/12. Length frequency distributions and/or age structures indicate recruitment success at different levels in all key species (except for black bream) during the 2010-2012 flow events, and many new recruits occurred in the North Lagoon where they were absent or less abundant during the drought period. The substantial increase in smallmouthed hardyhead abundance in the South Lagoon following salinity reductions (to <100 psu), with many fish <30 mm TL sampled, indicates their spawning and recruitment success in this subregion. This is of particular ecological significance, given the important role of this keystone species in the trophic ecology of the ecosystem in the Coorong. In spite of multiple positive fish responses to the 2010-2012 flow events, it is of concern that black bream, an iconic estuarine resident species, showed no signs of population recovery in the Coorong; overall population trajectories for these large-bodied species, including black bream, greenback flounder and mulloway, remain uncertain and their status should be assessed in future years.

The following points are provided to address the specific questions and hypotheses outlined in Section 1.2, which align with DEWNR's fish response monitoring objectives (Appendix I), with regard to the changes in fish assemblages from 2010/11 to 2011/12,

- Further barrage flows in 2011/12 maintained the presence of freshwater fish in the Murray Mouth and Coorong region, although total abundance declined. Fish assemblage structure changed, in the Estuary due to increased numbers of estuarine opportunistic (sandy sprat, yelloweye mullet, Australian salmon) and in the North Lagoon due to the dominance of sandy sprat, estuarine resident species (Tamar goby, river garfish) and catadromous congolli. The assemblage structure for large-bodied species also differed in 2011/12 in the Estuary due to an increased abundance of Australian salmon; whilst the change was not as distinct in the North Lagoon.
- Fish populations maintained the ranges observed in the Coorong in 2010/11 for all key species including native freshwater fish (bony herring). Some species extended their distribution further southward (black bream, yelloweye mullet, sandy sprat, Tamar goby) in 2011/12. In contrast, freshwater exotic species (redfin perch, carp) had a range contraction to the Estuary in 2011/12.
- Diadromous and estuarine fish continued to recruit in 2011/12; importantly the recruitment success of congolli and mulloway was confirmed by analysis of their age structures, showing potential strong year classes for 2010/11 and 2011/12.
- Estuarine condition was maintained in the North Lagoon, which served as a nursery ground for many species (catadromous, small-bodied and large-bodied estuarine resident and opportunistic species).
- Smallmouthed hardyhead maintained their presence and further increased in abundance in the South Lagoon, where they spawned and successfully recruited.
- The positive responses in fish assemblages following the significant flows of 2010/11 and further flows in 2011/12 indicated some early signs of recovery for most species; however, for long-lived large-bodied species, population recovery could take a longer period of time. Consequently, a long-term management approach is required for the restoration and recovery of this ecosystem in the Coorong.

Overall, the intervention monitoring for barrage releases in 2010-2012 following years of minimal freshwater inflows into the Murray Estuary and Coorong demonstrated the changes in estuarine fish assemblages; the dynamic response of species that exhibit different life history strategies and the importance of freshwater flows to fish assemblages in estuarine environments. Further research is required to determine the environmental factors and/or mechanisms, including flow regimes, critical habitat requirements and food resources that contribute to recruitment success for key estuarine species. Given the uncertainty in population trajectory for some large-bodied estuarine species (black bream, greenback flounder and mulloway), long-term monitoring will be required to continue to investigate the biological performance of these commercially important species and evaluate potential benefits of freshwater inflows to the Coorong for these fish. This study suggests that environmental water management should also consider small to moderate freshwater releases, which could be linked to strong recruitment in some species (as implied by strong cohorts of black bream produced in low-moderate flow years). In addition, conservation management should seek to protect the remnant populations of these species and rebuild the age structures to improve population resilience. Additional research is needed to improve our understanding of the dynamic movement patterns of the estuarine and marine estuarine opportunistic species within the Coorong, and between the Coorong, freshwater and marine environments under different flow conditions. Such information and knowledge will inform ecologically sustainable management of estuarine fish populations in the dynamic Coorong ecosystem. Furthermore, it should be emphasised that long-term monitoring data and robust science are important to underpin adaptive management, including the use of environmental flows, 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.

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. J. (2005). Using otolith chemistry to track the movements of a diadromous fish: the congolli *Pseudaphritis urvilli* (Teleostei: Pseudaphritidae). Honours Thesis. The University of Adelaide, Australia.

Cheshire, K. J. M., Ye, Q., Wilson, P. and Bucater, L. (2012). *From drought to flood: annual variation in larval fish assemblages in larval fish assemblages in a heavily regulated lowland temperate river*. Goyder Institute for Water Research Technical Report Series No.12/6.

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.

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

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

Cyrus, D. P. and Blaber, S. J. M. (1987). The influence of turbidity on juvenile marine fishes in estuaries. Part 1. Field studies at Lake St. Lucia on the southeastern coast of Africa. *Journal of Experimantal Marine Biology and Ecology* **109**, 53-70.

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, and Ward, T. M. (2011). Mulloway Fishery. Fishery Stock Assessment Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000898-2. SARDI Research Report Series No. 573.

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, M. H. (1996). Life history of the Dusky kob Argyrosomus japonicus (Sciaenidae) off the east coast of South Africa. *South African Journal of Marine Science* **17**,135-154.

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.

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

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).

Marais, J. F. K. (1988). Some factors which influence fish abundance in South African estuaries. *South African Journal of Marine Science* **6**, 67-77.

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

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.

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

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

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

Ye, Q., Bucater, L., Ferguson, G. and Short, D. (2011b). *Coorong fish condition monitoring 2008–2010: population and recruitment status of the black bream (Acanthopagrus butcheri) and greenback flounder (Rhombosolea tapirina)*. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Ye, Q., Bucater, L. and Short, D. (2011c). *Coorong fish condition monitoring 2008/09–2009/10: population and recruitment status of the smallmouthed hardyhead (Atherinosoma microstoma*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication Number F2010/000980-1. SARDI Research Report Series Number 594.

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

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

Ye, Q., Bucater, L., Short, D. and Earl, J. (2012b). *Coorong fish condition monitoring 2008–2012: the black bream (Acanthopagrus butcheri), greenback flounder (Rhombosolea tapirina) and smallmouthed hardyhead (Atherinosoma microstoma) populations*. 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.

7. APPENDIX I. OBJECTIVES, HYPOTHESES AND KEY QUESTIONS FOR FISH RESPONSE MONITORING IN THE COORONG

Monitoring Objective	**Hypotheses**	**Key Questions**	**Addressing Hypotheses (H) and Questions (Q)**
To assess the response of fish to: A) A minimum of 1,000GL being released over the barrages in 2011-2012; B) The continued water availability following the recent drought	1. Salinity in the Murray Mouth in 2011-2012 will not be reduced as significantly as observed in 2010-2011; 2. Salinity in the North and South Lagoons will be maintained at levels lower than measured from 2008-2010; 3. Fish populations will maintain the ranges observed in the Coorong in 2010-2011; 4. Diadromous and estuarine fish will continue to recruit in 2011-2012; 5. Estuarine fish habitat will extend to the North Lagoon and serve as a nursery ground for several species.	1. Are there indications of system recovery in 2011-2012 following the significant flows of 2010-2011 and further flows in 2011-2012? 2. Will species be able to maintain any range increases observed in 2011-2012 3. Will further barrage flows in 2011-2012 maintain the presence of freshwater fish species in the Murray Mouth and Coorong region, or will fish assemblage structure change and be dominated by more estuarine species? 4. Will smallmouthed hardyhead maintain their presence and abundance in the South Lagoon; will they spawn and recruit in the South Lagoon?	**H1**: Salinity in the Murray Mouth in 2011-2012 was not reduced as significantly as observed in 2010-2011; **H2**: Salinity in the North and South Lagoons was maintained at levels lower than measured from 2008-2010; **H3 & Q2**: Fish populations did maintain the ranges observed in the Coorong in 2010-11 for all key species including native freshwater fish (bony herring). Some species extended their distribution further southward (black bream, yelloweye mullet, sandy sprat, Tamar goby) in 2011-12. In contrast, freshwater exotic species (redfin perch, carp) had a range contraction to the Estuary in 2011-12. **H4**: Diadromous and estuarine fish continued to recruit in 2011-12; importantly the recruitment success of congolli and mulloway was confirmed by analysis of their age structures, showing strong year classes of 2010-11 and 2011-12. **H5**: Estuarine conditions were maintained in the North Lagoon, which served as a nursery ground for many species (catadromous, small-bodied and large-bodied estuarine resident and opportunistic species). **Q1**: The positive responses in fish assemblages following the significant flows of 2010-11 and further flows in 2011-12 indicated

			some early signs of recovery for most species; however, for long-lived large-bodied species, population recovery could take a longer period of time. Consequently, a long-term management approach is required for the restoration and recovery of this ecosystem in the Coorong. **Q3**: Further barrage flows in 2011-12 did maintain the presence of freshwater fish in the Murray Mouth and Coorong region although total abundance declined. Fish assemblage structure changed, in the Estuary due to increased numbers of estuarine opportunists (sandy sprat, yelloweye mullet, Australian salmon) and in the North Lagoon due to the dominance of sandy sprat, estuarine resident species (Tamar goby, river garfish) and catadromous congolli. The assemblage structure for large-bodied species also differed in 2011-12, in the Estuary due to an increased abundance of Australian salmon; whilst the change was not as distinct in the North Lagoon. **Q4**: Smallmouthed hardyhead maintained their presence and further increased in abundance in the South Lagoon where they spawned and successfully recruited.