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Fish response to flows in the Murray Estuary and Coorong during 2013/14

Qifeng Ye, Luciana Bucater and David Short

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EXECUTIVE SUMMARY

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region is a wetland of international importance under the Ramsar convention and an 'Icon Site' under the Murray–Darling Basin (MDB) Authority's *Living Murray* program. Between 2001 and 2010, the Coorong ecosystem became increasingly degraded due to the impact of protracted drought in the MDB, and subsequent reduced freshwater flows through barrages, increased salinities, and loss of connectivity between the freshwater and estuarine/marine environments. Many native fish species that are found in the Murray Estuary and Coorong and depend upon its habitat as a breeding, nursery and feeding ground were severely affected by the changes associated with the drought, showing reduced distribution, abundance and recruitment.

In 2010/11, increased water discharge in the River Murray led to significant flows (~13,000 GL y^{-1}) into the Coorong. Flow releases continued in 2011/12–2012/13 supported by the provision of environmental water. These removed constraints on the connectivity and water quality, improving conditions for native fish. The broadly decreased salinities in the Coorong, coupled with other freshwater-induced environmental changes, led to significant ecological responses in the fish assemblages. The responses included: increased diversity and abundance of freshwater species; enhanced recruitment and subsequent abundances of small-bodied estuarine and opportunistic species and catadromous species (congolli), and a southward range expansion for many species. Continued flows and connectivity during 2013/14 provided the opportunity to investigate whether further responses of fish assemblages in the estuary and their recovery were evident. The monitoring undertaken in this study augments the data collected during 2010/11–2012/13 and was compared against fish baseline information collected during the severe drought in 2006/07 (Noell *et al.* 2009).

The total barrage discharge in 2013/14 was lower than that for the previous three years (2010/11–2012/13) and was approximately 1,000 GL. The salinity ranges at sampling sites were 9–30 psu and 31–69 psu in the Estuary and North Lagoon, respectively, compared to 2012/13, when values were 7–21 psu and 23–66 psu in respective subregions. Contrastingly, in the South Lagoon, the salinity band was lower, with a range of 61–77 psu in 2013/14, as compared to 76–79 psu in 2012/13.

Over the four year study period (2010/11–2013/14), fish assemblage composition changed significantly from that of the drought years, displaying increased diversity and abundances of freshwater species, as well as small-bodied estuarine resident and opportunistic species (smallmouthed hardyhead, Tamar goby and sandy sprat), catadromous species (congolli) and some large-bodied estuarine opportunists (yelloweye mullet) through enhanced recruitment. In 2013/14, fish assemblages continued to remain distinctly different from that of the drought period. The abundance of freshwater fish species (e.g. bony herring) continued to decline throughout the region. In the Estuary, there was a general increase in estuarine and opportunistic species (e.g. smallmouthed hardyhead, Tamar goby, sandy sprat, yelloweye mullet, mulloway) but in the North Lagoon, abundances decreased for some of these species (e.g. sandy sprat, yelloweye mullet) and for catadromous congolli. This was attributed to the elevated salinities in the Estuary and North Lagoon as a result of lower freshwater inflows in 2013/14.

The southerly-extended range observed in 2012/13 for many species after the freshening of the Coorong, was generally maintained in 2013/14 although some species (Tamar goby and congolli) started to show a northward contraction, probably due to reduced flow and elevated salinities in the Coorong. Remarkably, a relatively diverse group of species were still utilizing the South Lagoon - including yelloweye mullet, congolli, black bream, bony herring, smallmouthed hardyhead, and goldspot mullet. Goldspot mullet was caught for the first time since the drought of 2001–2010.

Length frequency distributions indicated recruitment success at different levels among key species during 2010–2014; the exception was black bream with little recruitment evident during this period. Some species, such as catadromous congolli and the large-bodied opportunistic yelloweye mullet, showed significantly improved recruitment success in 2012/13 and 2013/14 compared to the first two flow years (2010/11–2011/12). This highlights the importance of sustained estuarine conditions and maintenance of connectivity between freshwater, estuarine and marine systems. Most recently, many of these 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. Sandy sprat also showed a consistent increase in abundance since connectivity was re-established, demonstrating a 10 fold increase in 2012/13 and 25 times in 2013/14 compared to the drought year. Such responses are of ecological significance, given the important role of these prey species in the trophic ecology of the Coorong.

The positive responses in fish assemblages following the significant flows of 2010/11, and further flows in 2011/12–2013/14 indicate some signs of recovery in the Coorong ecosystem. Many small-bodied estuarine species showed an ‘instantaneous’ response within a year after the commencement of freshwater inflows, particularly in the Estuary; whereas diadromous species and some large-bodied long-lived estuarine-associated species only showed a recruitment response after multiple years with continued freshwater releases, as evidenced in 2012/13 and 2013/14. However, it is of concern that black bream, an iconic estuarine resident species, showed little signs of population recovery after three years of flows. Further monitoring will be required in subsequent years to continue to investigate the biological performance of this commercially and ecologically important species to evaluate the effects and potential benefits of prolonged freshwater releases. The current study suggests that the maintenance of estuarine conditions for extended periods of time (i.e. several years) is required to enhance recruitment for some species (as implied by strong cohorts of congolli, yelloweye mullet and mulloway).

Further research is required to determine the environmental factors and/or mechanisms that contribute to recruitment success for key estuarine fish species. These include, flow regimes, critical habitat and food resources. In addition, the dynamic movement patterns of estuarine resident and marine estuarine opportunistic species within the Coorong and between the Coorong, freshwater and marine environments under different flow conditions need to be investigated. Such knowledge will improve the conceptual understanding of the population dynamics of key species and facilitate the development of well-informed ecologically sustainable management strategies for estuarine fish populations in this region. Long-term monitoring data and robust science are essential 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 represents a temperate estuarine-lagoonal system of a large regulated river. The region is recognised internationally as a Ramsar-listed wetland, providing an important breeding and feeding ground for waterbirds, and supporting significant populations of several species of fish and invertebrates (Phillips and Muller 2006). The region is classified as an 'icon site' under the Murray–Darling Basin Authority's The Living Murray program, based upon its unique ecological qualities, hydrological significance, economic and cultural values (MDBA 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 Butler 1984; Geddes 1987). Nonetheless, salinities are spatiotemporally 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 (up to ~500 GL y^{-1}) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek (Ye *et al.* 2015).

As the terminal system of the Murray–Darling Basin (MDB), the Murray Estuary and Coorong 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} in 1895 to 4,733 GL y^{-1} in 2006; 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. This situation was exacerbated during the decadal drought in the MDB, with very low or no flow releases through barrages between 2002 and 2009 (DFW 2010). Concurrently, the Murray Mouth closed due to siltation, requiring a dredging operation to maintain its opening from 2002 (DWLBC 2008) until December 2010. During the drought period, the Coorong transformed into a marine/hypersaline environment, and extreme hypersaline conditions in the South Lagoon caused severe degradation of critical habitats for Ramsar listed bird species - which compromised the ecological character of the system (Rogers and Paton

2009). Such changes have severely impacted on the regional ecology (Brookes *et al.* 2009). Many native fish species that are found in the Coorong estuary and depend on its habitat for breeding, nursery and feeding grounds were also negatively affected (Noell *et al.* 2009), and recruitment of catadromous fish failed due to lack of connectivity between freshwater and estuarine/sea (Zampatti *et al.* 2010).

In late 2010, the drought was broken by an extensive flood in the MDB. Since then, continued high flows in the River Murray have led to substantial barrage releases to the Coorong and the restoration of connectivity between freshwater, estuarine and marine environments (with barrages and fishways opening). Intervention monitoring in response to post-drought flows detected significant changes in fish assemblages in the Coorong in association with increased freshwater inflows and the improved environmental conditions, with a general increase in species richness, diversity and abundance, and enhanced recruitment for a number of estuarine and diadromous species (Livore *et al.* 2013; Bice and Zampatti 2014). Despite the positive responses in fish assemblages following increased flows during 2010/11–2012/13, not all fish species have shown signs of recovery (e.g. black bream, *Acanthopagrus butcheri*) (Ye *et al.* 2015).

With the continued freshwater releases in 2013/14, further changes were expected in the Coorong, including variations in salinity gradient, water quality conditions, productivity, water level and connectivity. Intervention monitoring continued in the Murray Estuary and Coorong (North and South lagoons) during 2013/14, as part of the CLLMM Fish Monitoring Program, to assess whether there was evidence of fish responses to the previous or existing environmental conditions. This monitoring has built on previous investigations of flow-related fish responses in the region since 2006/07 (Noell *et al.* 2009; Ye *et al.* 2011; 2012a; Livore *et al.* 2013). The findings from this work will improve our understanding of flow-related ecology and resilience of fish species to drought and flood events. The information and knowledge generated will underpin adaptive management, including environmental water allocation, to ensure the long-term ecological sustainability of the CLLMM region.

1.2. Objectives

The aim of this project is to conduct intervention monitoring in the Murray Estuary and Coorong during 2013/14 to assess fish responses to the continued water availability (and associated environmental variables) following the recent drought. Specific objectives are:

1) To determine 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 nursery ground for key species*.

*Key species are black bream (*Acanthopagrus butcheri)*, greenback flounder (*Rhombosolea tapirina*), smallmouthed hardyhead (*Atherinosoma microstoma*), congolli (*Pseudphritis urvilli*), yelloweye mullet (*Aldrichetta forsteri*), mulloway (*Argyrosomus japonicus*), Tamar goby (*Afurcagobius tamarensis*) and sandy sprat (*Hyperlophus vittatus*). These species were selected in consultation with DEWNR managers (Ye *et al.* 2013).

The following key questions (with reference to Department of Environment, Water and Natural Resources' 'Request for Proposal', 2014) will be addressed in this report including:

1) Are there indications of continued system recovery in 2013/14 following the significant flows of 2010/11 and further flows in 2011–2013, when a recovery was first documented?
    a) Do environmental conditions within the Murray Mouth reflect true estuarine conditions and have they further improved in the North and South lagoons since flows recommenced in 2010/11?
    b) Have fish species shown signs of recruitment in 2013/14?
2) Are species able to maintain any range increases observed in 2012/13?
3) What are the differences in the community structure of fish between flow scenarios (drought/flood)? How do 2013/14 fish populations compare to previous monitoring?

2. METHODS

2.1. Field Sampling

Fish sampling was conducted at thirteen sites in the Murray Estuary and Coorong on four occasions in 2013/14 (November 2013, December 2013, February 2014 and March 2014), following the same regime used for the 2010/11– 2012/13 fish intervention monitoring (Livore *et al.* 2013). Five sites were located within 15 km of the Murray Mouth within the Estuary subregion, five in the North Lagoon, and three in the South Lagoon (Table 2.1 and Figure 2.1). On each occasion, 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, five of the thirteen sites (two in the Estuary, two in the North Lagoon and one in the South Lagoon, see Table 2.1 for details) 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 overnight for approximately 15 hours. 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.

Both seine nets and gill nets were used in fish sampling. Seine netting from the shore was most effective for sampling small-bodied species and juveniles of large-bodied species, whilst gill nets set near the main channel, effectively targeted adults of large-bodied species. It is assumed that both methods collectively sampled representative fish assemblages and most size classes of the fish populations. All fish collected using seine and gill nets were identified to species, and the total number of individuals of each species recorded. For the key species, total length (TL) measurements were taken to the nearest mm for up to 50 individuals per gear type, on each sampling occasion, at each site. Sub-samples of up to 30 fish per large-bodied species (not smallmouthed hardyhead, Tamar goby and sandy sprat) from the multi-panel gill nets were retained for laboratory processing to extract otoliths for age determination.

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 provided maximum DO at equilibrium and did not account for potential biological consumption of oxygen at the time of sampling. Flow data prior to 2010/11 were monthly modelled flow discharges from the MDBA whereas since 2010/11 data were obtained from SA Water.

Table 2.1. Fish sampling sites and gear type used for barrage release intervention monitoring in the Murray Estuary and Coorong during 2010–2014. Note: Both nets = seine and gill nets.

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

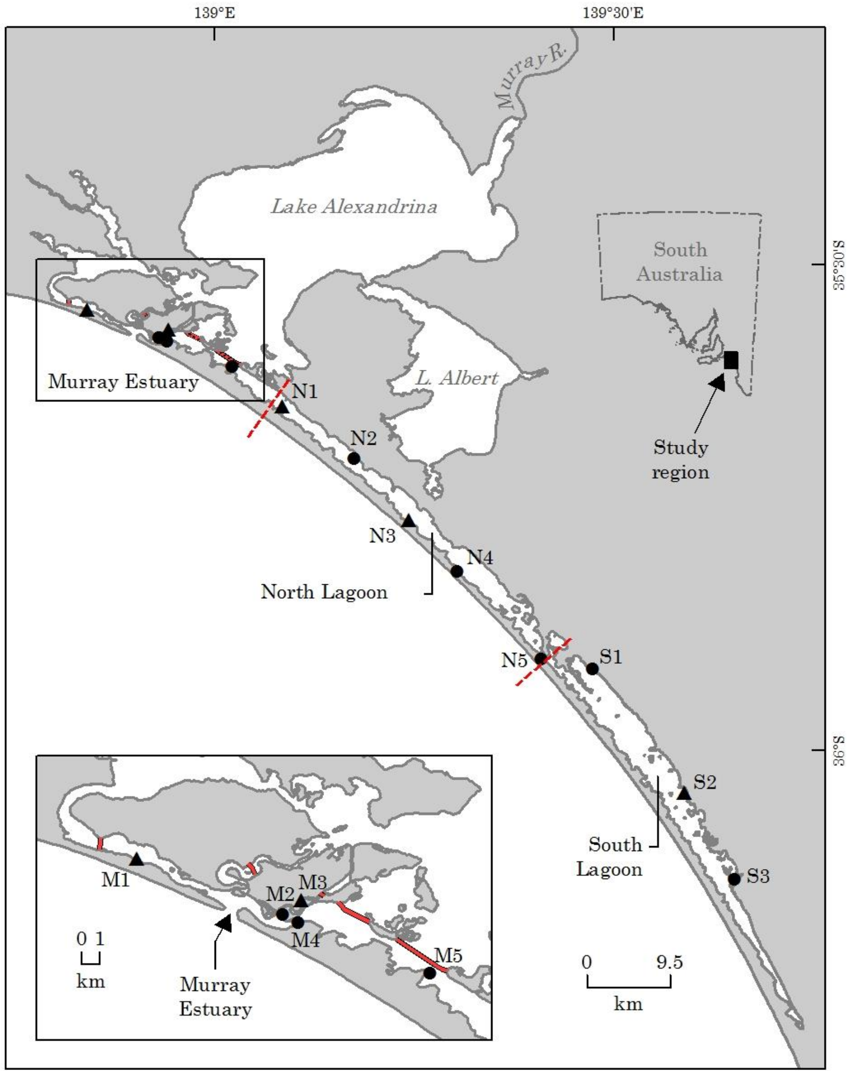

Figure 2.1. Fish sampling sites for barrage release intervention monitoring in the Murray Estuary and Coorong. (▲) both seine and gill netting; (●) seine netting only. Red lines represent the five barrages and red dashed lines show approximate boundaries between the three subregions.

2.2. Life-cycle designations

Each species was categorised using similar criteria to Potter and Hyndes (1999) after Noell *et al.* (2009) (Table 2.2). 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, whereas freshwater species are those whose life-cycle is typically restricted to fresh water. The various species sampled in this study were allocated to one of the above life-cycle categories (Table 2.3).

Table 2.2. Life cycle designation of species collected in the Murray Estuary and Coorong during the drought year (2006/07) and post-flood years (2010/11 – 2013/14).

Life cycle designation	Code
Marine straggler	S
Marine estuarine opportunist	O
Estuarine resident	E
Estuarine and marine	E&M
Catadromous	C
Freshwater native	FW
Freshwater exotic	FE

Table 2.3. Names and life cycle designation of species collected in the Murray Estuary and Coorong during the drought year (2006/07) and post-flood years (2010/11 – 2013/14).

Common Name	Scientific Name	Life Cycle Designation
Common galaxias	*Galaxias maculatus*	C
Congolli	*Pseudaphritis urvilli*	C
Black bream	*Acanthopagrus butcheri*	E
Bluespot goby	*Pseudogobius olorum*	E
River garfish	*Hyporhamphus regularis*	E
Scary's Tasman goby	*Tasmanogobius lasti*	E
Smallmouthed hardyhead	*Atherinosoma microstoma*	E
Tamar goby	*Afurcagobius tamarensis*	E
Bridled goby	*Arenigobius bifrenatus*	E&M
Goldspot mullet	*Liza argentea*	E&M
Prickly toadfish	*Contusus brevicaudus*	E&M
Soldier	*Gymnapistes marmoratus*	E&M
Carp	*Cyprinus carpio*	FE

Goldfish	*Carassius auratus*	FE
Redfin perch	*Perca fluviatilis*	FE
Australian smelt	*Retropinna semoni*	FN
Bony herring	*Nematolosa erebi*	FN
Flat-headed gudgeon	*Philypnodon grandiceps*	FN
Golden perch	*Macquaria ambigua*	FN
Greenback flounder	*Rhombosolea tapirina*	O
Australian herring	*Arripis georgianus*	O
Longsnout flounder	*Ammotretis rostratus*	O
Sandy sprat	*Hyperlophus vittatus*	O
Western Australian salmon	*Arripis truttaceus*	O
Yelloweye mullet	*Aldrichetta forsteri*	O
Mulloway	*Argyrosomus japonicus*	O
Western striped grunter	*Pelates octolineatus*	S
Australian anchovy	*Engraulis australis*	S
Little weed whiting	*Neoodax balteatus*	S
Southern garfish	*Hyporhamphus melanochir*	S
Sea mullet	*Mugil cephalus*	S
Southern eagle ray	*Myliobatis australis*	S
Southern longfin goby	*Favonigobius lateralis*	S

2.3. Multivariate Analysis

Fish assemblage data collected during barrage releases from 2010/11 to 2013/14 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 four 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 the excessive influence of highly abundant species. Log (x+1) transformation was used for the seine net data because a few species dominated the assemblages with extremely high numbers (e.g. >3000); square-root transformation was applied for the gill net data to allow the species of intermediate abundance to play a part in the analyses. 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 to detect differences at *p* level after a modified false discovery rate (FDR) by Benjamin and Yekutieli (B-Y) correction was applied (see Narum 2006). 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 were correlated (Spearman rank correlation, $\rho > 0.5$) with the ordination axes. For significantly different assemblages, one-way similarity percentages (SIMPER) analysis was used to identify the species that 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* stepwise 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 showed similar 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 1984–2014, the Murray Estuary and Coorong experienced substantial fluctuations in freshwater inflows. Annual discharge was consistently high during the late 1980s and early 1990s, ranging between 10,500 and 12,000 GL y^{-1} with the exception of 1991/92 when it was just under 3,000 GL y^{-1} (Figure 3.1). After 1993/94, inflows to the Coorong generally declined until 2007/08. No freshwater was discharged to the Coorong from 2007/08 to 2010/11. Since September 2010, significant flow increases in the MDB led to substantial barrage releases with an annual discharge of ~12,500 GL in 2010/11, ~9,000 GL in 2011/12 and ~5,000 GL in 2012/13. In 2013/14, freshwater inflows to the Coorong decreased substantially to ~1,000 GL y^{-1}. For the last two years prior to sampling, peak monthly inflow occurred during spring with ~1,500 GL m^{-1} recorded in September 2012 and ~400 GL m^{-1} in October 2013 (Table 3.1), just prior to the sampling period (i.e. November 2012–March 2013).

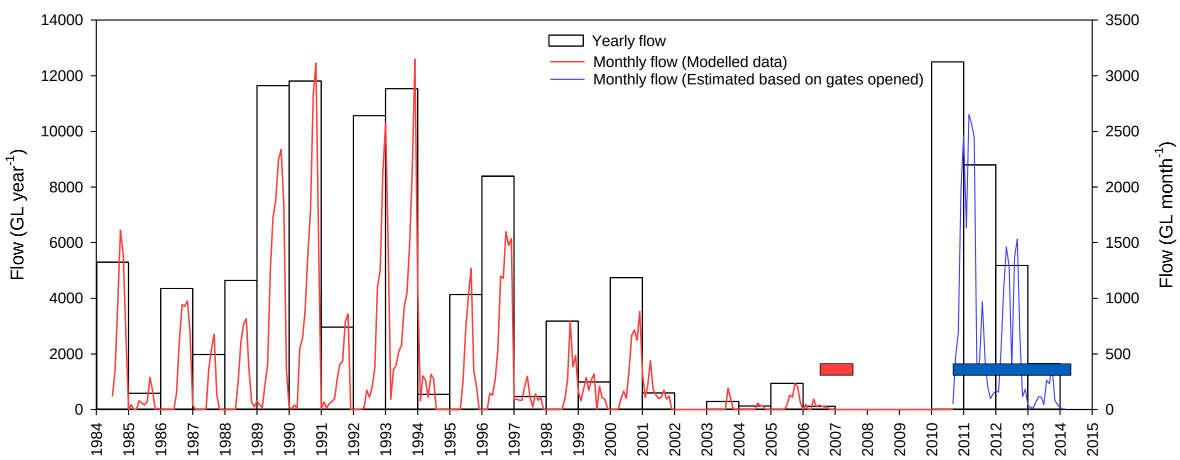

Figure 3.1. Average annual and monthly freshwater inflows across the barrages from July 1984 to March 2014 (Data sources: MDBA and SA Water as indicated in legend). Red bar indicates fish sampling period during the drought period in 2006/07 and blue bars indicate intervention fish monitoring following barrage releases from 2010–2014.

Table 3.1. Annual total discharge and month of maximum discharge across the barrages from 1990 to 2013 and the months when peaked discharge occurred. * Denotes dataset sourced from SA Water.

	Annual Discharge (GL)	Monthly Discharge Peak (GL)	Month
1990	11809	2834	November
1991	2964	984	November
1992	10565	2536	January
1993	11537	2914	December
1994	547	319	July
1995	4131	1330	September
1996	8392	1709	October
1997	466	307	September
1998	3183	746	December
1999	992	290	July
2000	4739	851	December
2001	597	186	September
2002	0	0	
2003	288	127	September
2004	124	46	August
2005	941	195	October
2006	114	29	July
2007	0	0	
2008	0	0	
2009	0	0	
2010	12498	1986*	December
2011	7035*	2654*	March
2012	4605*	1530*	September
2013	1094*	397*	October

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 2006/07 (Noell *et al.* 2009) (Figure 3.2). 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 from 2010/11 to 2013/14 compared to 2006/07. In 2006/07, year with no barrage discharge, mean salinities ranged from 31–41 psu in the Murray Estuary, 46–107 psu in the North Lagoon, and 127–129 psu in the South Lagoon. In contrast, salinities after considerable freshwater inflows in 2010/11 declined to 1–5 psu, 6–74 psu and 61–99 psu and to 1-13 psu (in the Murray Estuary, North and South lagoons, respectively). However, in 2012/13 and 2013/14, the Murray Estuary and North Lagoon showed a higher range of average salinities (from 7–21 to 9–30 psu and from 23–66 to 31–69 psu, respectively); whilst average salinities in the South Lagoon remained lower than the previous two years with ranges of 76–79 in 2012/13 and 61–77 psu in 2013/14.

River Murray inflows were correlated with a decline in transparency throughout the entire Coorong Lagoon in 2010/11–2012/13, however in 2013/14, transparency in the Murray Estuary returned to levels similar to those in 2006/07 (Figure 3.2). In addition, there was a general increase in pH in the region in 2010/11, 2011/12 and 2012/13 compared to the drought years. Level of pH in 2013/14, however, was similar to 2006/07, with three sites (M5, N1 and N2) showing lower records, but all were within the previously observed range. Average water temperatures have been relatively consistent throughout the sampling years, with slightly higher water temperature in the South Lagoon in 2011/12 and 2012/13.

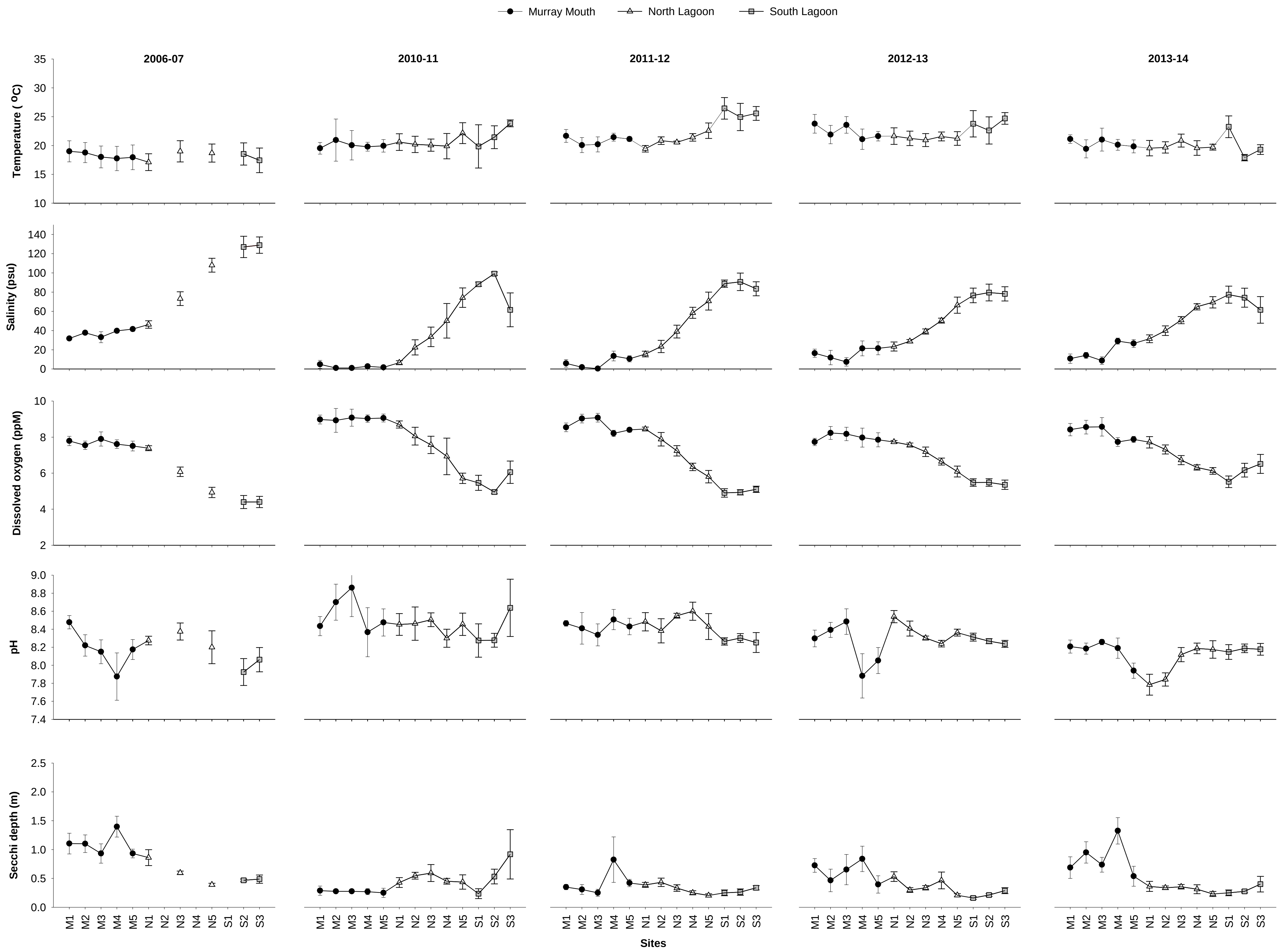

Figure 3.2. Mean values ± (S.E.) for water temperature, salinity, dissolved oxygen, pH and Secchi depth for each sampling site (sampling occasions pooled) within the Murray Estuary and Coorong during 2006/07 and 2010/11–2013/14. (2006/07 data sourced from Noell *et al.* 2009).

3.3. Catch summary, species richness and abundance

3.3.1. *Seine net samples*

A total of 174,566 fish representing 23 species were sampled using seine nets in the Murray Estuary and Coorong in 2013/14 (Table 3.2), the highest catch in the four year study. Species richness was similar in all years, although the presence of specific species varied considerably between years. Five of seven freshwater species were found during 2012/13 and 2013/14, whilst all of them were recorded in 2010/11 and 2011/12. The two species not sampled during the later two surveys were golden perch and goldfish, albeit in previous years they had been collected in very low numbers.

Similarly to previous years, sandy sprat and smallmouthed hardyhead were the most abundant species collected in 2013/14 (Table 3.2). Noticeably, sandy sprat became the most abundant species in 2012/13 samples, and maintained dominant in 2013/14. Similarly to 2012/13, the next four most abundant species included the opportunistic yelloweye mullet, the estuarine Tamar goby and Scary's Tasman goby, and the catadromous congolli in 2013/14. Furthermore, five freshwater species (carp, redfin perch, Australian smelt, bony herring and flat-headed gudgeon) were collected in much lower numbers than in 2010/11–2012/13. It is notable that in the South Lagoon (where smallmouthed hardyhead were the only fish present in 2006/07 and 2010/11) that additional species (i.e. congolli, black bream, bony herring, yelloweye mullet and Scary's Tasman goby) have been sampled since 2011/12 (Table 3.2).

A comparison of mean species richness among subregions showed a general decrease from the Estuary to the South Lagoon (i.e. Estuary>North Lagoon>South Lagoon), with the only exception of 2012/13, when mean species richness was higher in the North Lagoon than in the Murray Estuary (Table 3.2). In terms of annual trends within each subregion, the Estuary showed a sharp increase in species richness from 2006/07 to 2010/11, followed by a decrease in the following two years and then a slight increase in 2013/14. In contrast, the North and South lagoons showed a general increase in species richness since 2010/11, peaking in 2012/13 and remaining relatively high in 2013/14.

The overall abundance of fish sampled by seine net was similar across all subregions during this study, with the exception of 2006/07 when fish numbers were extremely low in the South Lagoon (Figure 3.3). In all subregions, the total abundance of fish showed a general increase from the drought (2006/07) to post drought (after 2010/11) years. In the Estuary, the mean of total abundance appeared to increase more than three-fold from 2012/13 to 2013/14 (Figure 3.3); however, the sampling variability (between sites and months) was noticeably high for 2013/14 as indicated by a high value of standard error (Figure 3.3). In the North Lagoon and South Lagoon, abundance generally maintained at similar levels over the last four years (2010/11–2013/14).

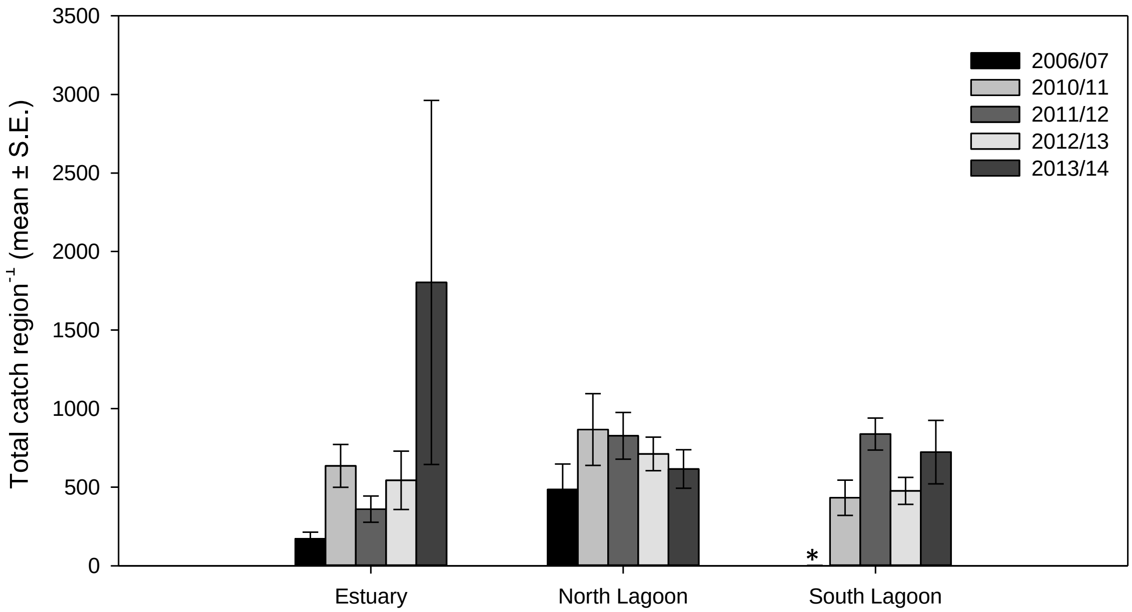

Figure 3.3. Mean (± S.E.) total fish abundance sampled by seine net at different sites in the Murray Estuary and Coorong lagoons in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. * Total abundance <2 in 2006/07.

Table 3.2. Fish species and numbers collected using a standard seine net during 2010/11, 2011/12, 2012/13 and 2013/14 barrage release intervention monitoring in the Murray Estuary and Coorong. 2006/07 fish data for relevant months are also presented for comparison. ME = Murray Estuary, NL = North Lagoon and SL = South Lagoon.

	Classification	2006/07				2010/11				2011/12				2012/13				2013/14			
Common Name		**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**
Common galaxias	C	10			10	48	1		49	6			6	113			113	32			32
Congolli	C	1	3		4	101	45		146	30	48		78	529	640	7	1,176	111	770	15	896
Black bream	E	13			13					1		1	2			2	2	2		1	3
Bluespot goby	E	3			3	12	2		14		4		4		215		215		64		64
River garfish	E	290	16		306	90	37		127	39	90		129	44	54		98	92	45		137
Scary's Tasman goby	E	8	1		9	68	60		128	69	45		114	62	1,264	4	1,330	117	1,074		1,191
Smallmouthed hardyhead	E	1,209	12557	35	13,801	1,488	33,819	15,636	50,943	330	27,190	30,184	57,704	768	22,196	17,124	40,088	5,492	29,505	26,178	61,175
Tamar goby	E	35	39		74	941	26		967	41	2		43	135	289		424	1,144	532		1,676
Bridled goby	E&M	1			1	307			307	23	2		25	15	249		264				-
Goldspot mullet	E&M	2			2	4			4		1		1	1			1	1	1		2
Soldier	E&M	6			6	1	6		7								-	3	1		4
Toadfishes	E&M	123	1		124	1	3		4	5	7		12	115	25		140				-
Carp	FE					262	3		265	22			22	16			16	6			6
Goldfish	FE					1			1	1			1				-				
Redfin perch	FE					2,900	253		3,153	743			743	226			226	12			12
Australian smelt	FN	1			1	1,148	330		1,478	364	12		376	243	173		416	10			10
Bony herring	FN	3			3	4,267	818		5,085	2,052	69		2,121	227	42	3	272	306	33	1	340
Flat-headed gudgeon	FN					844	16		860	6			6	8	2		10	1	2		3
Golden perch	FN					19	2		21	1			1				-				-
Greenback flounder	O	127	105		232	242	59		301	103	45		148	68	117		185	139	50		189
Australian herring	O	70			70					3			3				-	35	4		39
Longsnout flounder	O	52	54		106	78	5		83	15	25		40	11	21		32	101	11		112
Sandy sprat	O	3,949	287		4,236	15,506	246		15,752	17,002	21,740		38,742	28,740	16,653		45,393	101,529	4,358		105,887
Western Australian salmon	O	853	9		862					372	17		389	238	1		239	69	2		71
Yelloweye mullet	O	918	29		947	484	185		669	383	295	1	679	1,040	767	29	1,836	2,514	188	11	2,713
Mulloway	O	57			57									5	4		9				-
Australian anchovy	S	12			12													3			3
Little weed whiting	S																	1			1
Southern garfish	S	6			6																
Sea mullet	S						1		1								-				-
Southern eagle ray	S	1			1												-				-
Southern Longfin goby	S					81	2		83					6			6				-
Total		**7,750**	**13,101**	**35**	**20,886**	**28,893**	**35,919**	**15,636**	**80,448**	**21,611**	**49,592**	**30,186**	**101,389**	**32,610**	**42,712**	**17,169**	**92,491**	**111,720**	**36,640**	**26,206**	**174,566**
% catch		**37**	**63**	**0**		**36**	**45**	**19**		**21**	**49**	**30**		**35**	**46**	**19**		**64**	**21**	**15**	
Mean No. of fish species		**5.9**	**2.8**	**0.3**		**10.3**	**4.4**	**0.9**		**5.6**	**4.2**	**1.1**		**5.7**	**6.6**	**1.6**		**6.8**	**5.6**	**1.5**	

3.3.2. *Gill net samples*

A total of 1,995 fish representing 9 medium to large-bodied species were sampled using gill nets in the Murray Estuary, North and South lagoons in 2013/14 (Table 3.3). The total number was the lowest recorded since 2010/11 with a noticeable decline (66%) since 2012/13. The number of species caught was the lowest in 2013/14 out of the five study years. Despite this, fish sampled included a diverse range of life history strategies, such as freshwater (native and exotic), catadromous, estuarine (resident and opportunist) and marine species. Similar to the previous three flow years, yelloweye mullet, bony herring and mulloway were the most abundant species, although the only difference was that in 2013/14 yelloweye mullet became the most dominant species in place of bony herring.

Average species richness was higher in the Estuary than in the North Lagoon in 2006/07 and 2013/14, whilst in all other years the level remained similar between the two subregions (Table 3.3). Total fish abundance was consistently higher in Estuary and North Lagoon than in the South Lagoon, where the abundances in 2012/13 and 2013/14 were comparable to those observed in the North Lagoon during 2006/07 (the drought year) (Figure 3.4). Despite the variability between years, the total abundances in each subregion showed an increase from the drought (2006/07) to high flow years (2010/11–2013/14). The highest total abundances in the Estuary and North Lagoon were recorded in 2011/12. Over the last three years, however, the total abundance showed a steady decline in both regions, whereas the abundance seemed to maintain in the South Lagoon despite at a low level.

Table 3.3. Fish species and numbers collected using gill nets during 2010/11, 2011/12, 2012/13 and 2013/14 barrage release intervention monitoring in the Murray Estuary and 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			2012/13				2013/14			
Common_Name	**Classification**	**MM**	**NL**	**Total**	**MM**	**NL**	**Total**	**MM**	**NL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**
Congolli	C	3	4	7	2		2	3	33	36		4		4		2	1	3
Black bream	E	1		1	5	3	8				1			1	2			2
River garfish	E	1		1					6	6		2		2	9			9
Goldspot mullet	E&M							25	4	29	9	2		11	33		2	35
Toadfishes	E&M		2	2														
Soldier	E&M											1		1				
Carp	FE				21	22	43	119	2	121	69			69	31			31
Goldfish	FE				1		1	1		1	3			3				
Redfin perch	FE				12	9	21	32	12	44	3			3				
Bony herring	FN	20	1	21	336	4,109	4,445	2,742	2,889	5,631	1,183	1,927	14	3,124	428	313	1	742
Golden perch	FN				1		1	3	1	4	2	1		3				
Greenback flounder	O	6	2	8	1		1		7	7		7		7				
Australian herring	O	11		11		2	2					2		2				
Mulloway	O	135	54	189	16	11	27	53	275	328	208	135		343	124	100		224
Western Australian salmon	O	209	5	214	2	207	209	620	189	809	310	10		320	27	1		28
Yelloweye mullet	O	104	153	257	24	627	651	190	627	817	450	1,425	137	2,012	222	589	110	921
Western striped grunter	S	4		4														
Sea mullet	S	1	2	3	2		2				2	1		3				
Yellowfin whiting	S				1		1											
Total		**495**	**223**	**718**	**424**	**4,990**	**5,414**	**3,788**	**4,045**	**7,833**	**2,240**	**3,517**	**151**	**5,908**	**876**	**1,005**	**114**	**1,995**
% catch		**69**	**31**		**8**	**92**		**48**	**52**		**38**	**59**	**3**		**44**	**50**	**6**	
Mean No. of fish especies		**3.8**	**2.2**		**3.7**	**3.6**		**4.6**	**5.4**		**4.1**	**4.0**	**1.0**		**4.0**	**2.9**	**0.7**	

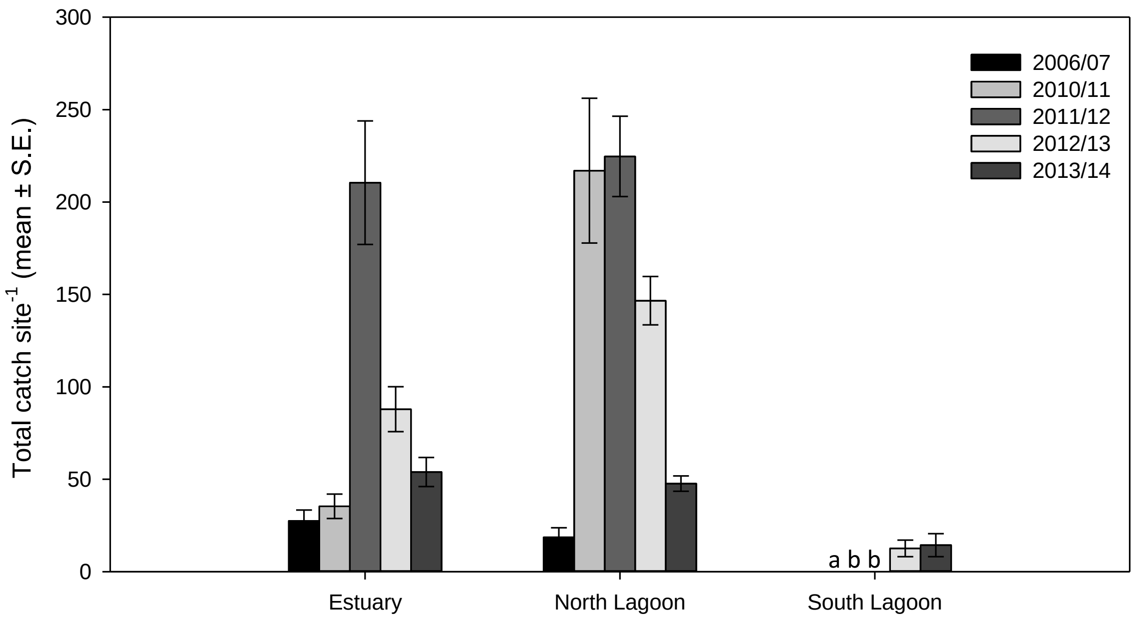

Figure 3.4. Mean (± S.E.) total fish abundance sampled by gill net at different sites in the Murray Estuary and Coorong Lagoons in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. a–abundance=0; b–no formal sampling.

3.4. Spatio-temporal variation in fish assemblage structure and link to environmental variables

3.4.1. *Seine net samples*

When comparing fish assemblage structure, PERMANOVA detected a significant interaction between the two factors - Year (i.e. 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14) and Subregion (i.e. Estuary, North Lagoon and South Lagoon) (Table 3.4), suggesting inconsistent inter-annual and spatial patterns. Pairwise comparisons revealed a significant temporal difference in fish assemblage between all years ($P<0.003$) for the Estuary and North Lagoon. The exception to this pattern was in the South Lagoon - where the assemblage did not differ between 2012/13 and 2013/14. Similarly, a significant spatial difference was detected between all subregions ($P=0.001$) in each year.

Table 3.4. PERMANOVA results for fish assemblage comparison based on seine net (Log (x+1) transformed data) amongst years and subregions of the Murray Estuary and Coorong. Bold p values are significant.

Source	df	MS	P(perm)
Year	4	33105	**0.001**
Subregion	2	2.05E+05	**0.001**
Year x Subregion	8	17664	**0.001**

For the Estuary, SIMPER analysis indicated that the greatest dissimilarity (67.3%) in fish assemblage structure occurred between 2013/14 and 2011/12 (Table 3.5). This was largely driven by increased abundances of sandy sprat, smallmouthed hardyhead, yelloweye mullet and Tamar goby and the decrease of bony hearing in 2013/14. In the same subregion, dissimilarity was lowest between 2013/14 and 2012/13 (63.2%).

For the North Lagoon fish assemblage, 2013/14 was the most dissimilar to 2006/07 (56.8%), mainly driven by increased abundances of smallmouthed hardyhead, sandy sprat and congolli (Table 3.6); whereas it was least dissimilar to 2012/13 (51.8%).

In the South Lagoon, the greatest dissimilarity in assemblage structure also occurred between 2006/2007 and 2013/14 (85.9%) (Table 3.7). This was mainly driven by a greater abundance of smallmouthed hardyhead in 2013/14. The assemblage in 2013/14 was least dissimilar to 2011/12 (20.5%); the dissimilarity was mainly explained by the slightly decreased abundance of smallmouthed hardyhead and an increase abundance of yelloweye mullet.

Table 3.5. SIMPER analysis for fish assemblage pairwise comparisons between 2013/14 and 2012/13, 2011/12 2010/11 and 2006/07, 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 50% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

	Mean abundance		**Mean dissimilarity = 64.42**		
Species	**2013/14**	**2006/07**	**CR**	**Contrib%**	**Cum.%**
Sandy sprat	4.13	2.15	1.32	17.92	17.92
Smallmouthed hardyhead	2.2	1.55	1.2	11.99	29.91
Yelloweye mullet	2.26	2.29	1.3	11	40.91
Tamar goby	1.98	0.35	1.23	10.01	50.92
	Mean abundance		**Mean dissimilarity = 66.87**		
Species	**2013/14**	**2010/11**	**CR**	**Contrib%**	**Cum.%**
Bony herring	0.66	3.49	1.63	10.94	10.94
Australian smelt	0.1	3.02	2.17	10.42	21.37
Redfin perch	0.09	3.03	1.87	10.22	31.59
Sandy sprat	4.13	3.85	1.24	9.78	41.36
Yelloweye mullet	2.26	0.74	1.13	7.78	49.15
Smallmouthed hardyhead	2.2	2.11	1.29	7.77	56.92
	Mean abundance		**Mean dissimilarity = 67.27**		
Species	**2013/14**	**2011/12**	**CR**	**Contrib%**	**Cum.%**
Sandy sprat	4.13	3.51	1.25	16.08	16.08
Smallmouthed hardyhead	2.2	0.66	1.11	11.52	27.6
Yelloweye mullet	2.26	0.95	1.21	11.27	38.86
Bony herring	0.66	2.28	1.33	10.82	49.68
Tamar goby	1.98	0.29	1.21	9.96	59.65
	Mean abundance		**Mean dissimilarity = 63.22**		
Species	**2013/14**	**2012/13**	**CR**	**Contrib%**	**Cum.%**
Sandy sprat	4.13	3.62	1.24	16.52	16.52
Smallmouthed hardyhead	2.2	1.01	1.14	12.42	28.94
Yelloweye mullet	2.26	1.9	1.28	11.41	40.36
Tamar goby	1.98	0.59	1.23	10.16	50.52

Table 3.6. SIMPER analysis for fish assemblage pairwise comparisons between 2013/14 and 2012/13, 2011/12, 2010/11 and 2006/07 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 50% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

	Mean abundance		Mean dissimilarity = 56.79		
Species	**2013/14**	**2006/07**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	4.93	4.73	0.87	22.14	22.14
Sandy sprat	1.99	0.46	0.92	15.36	37.5
Congolli	1.56	0.08	1.2	11.55	49.05
Scary's Tasman goby	1.41	0.03	0.87	9.33	58.37
	Mean abundance		**Mean dissimilarity = 54.55**		
Species	**2013/14**	**2010/11**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	4.93	5.55	1.17	15.73	15.73
Sandy sprat	1.99	0.39	0.91	13.59	29.31
Bony herring	0.28	1.61	1.11	10.61	39.92
Congolli	1.56	0.33	1.19	10.11	50.04
	Mean abundance		**Mean dissimilarity = 54.27**		
Species	**2011/12**	**2013/14**	**CR**	**Contrib%**	**Cum.%**
Sandy sprat	3.01	1.99	1.17	21.64	21.64
Smallmouthed hardyhead	4.74	4.93	0.99	19.31	40.94
Congolli	0.32	1.56	1.22	10.29	51.23
	Mean abundance		**Mean dissimilarity = 51.81**		
Species	**2012/13**	**2013/14**	**CR**	**Contrib%**	**Cum.%**
Sandy sprat	4.07	1.99	1.31	20.2	20.2
Smallmouthed hardyhead	4.41	4.93	1.11	15.52	35.72
Scary's Tasman goby	2.03	1.41	1.27	11.7	47.42
Congolli	1.79	1.56	1.42	9.8	57.22

Table 3.7. SIMPER analysis for fish assemblage pairwise comparison between 2013/14 and 2012/13, 2011/12, 2010/11 and 2006/07 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).

	Mean abundance			Mean dissimilarity = 85.92	
Species	**2013/14**	**2006/07**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	5.47	0.56	2.73	88.16	88.16
	Mean abundance			**Mean dissimilarity = 42.77**	
Species	**2013/14**	**2010/11**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	5.47	4.01	1.09	82.77	82.77
	Mean abundance			**Mean dissimilarity = 20.51**	
Species	**2013/14**	**2011/12**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	5.47	6.39	0.94	71.41	71.41
Yelloweye mullet	0.53	0.02	0.53	19.59	91.01
	Mean abundance			**Mean dissimilarity = 24.00**	
Species	**2013/14**	**2012/13**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	5.47	5.61	1	61.53	61.53
Yelloweye mullet	0.53	0.41	0.79	23.96	85.49

In 2013/14, the difference in fish assemblage between the Estuary and North Lagoon was mainly attributed to a higher abundance of smallmouthed hardyhead, and lower abundances of sandy sprat, yelloweye mullet and Tamar goby in the North Lagoon (Table 3.8). The difference between the Estuary and South Lagoon was the greatest, driven by the absence of sandy sprat in the South Lagoon along with higher abundance of smallmouthed hardyhead and lower abundance of yelloweye mullet. In the two least dissimilar subregions, North and South lagoons, difference between fish assemblages was caused by greater abundance of smallmouthed hardyhead, the absence of sandy sprat, and lower abundance of congolli in the South Lagoon.

Table 3.8. SIMPER analysis for fish assemblage pairwise comparisons between the Murray Estuary, Coorong Lagoons for seine net samples during 2013/14. 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 50% 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		Mean dissimilarity = 63.97		
Species	**Estuary**	**North Lagoon**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	2.2	4.93	1.4	18.96	18.96
Sandy sprat	4.13	1.99	1.29	17.81	36.77
Yelloweye mullet	2.26	0.9	1.17	10.75	47.52
Tamar goby	1.98	1.05	1.18	10	57.52
	Mean abundance		**Mean dissimilarity = 78.56**		
Species	**Estuary**	**South Lagoon**	**CR**	**Contrib%**	**Cum.%**
Sandy sprat	4.13	0	1.71	23.09	23.09
Smallmouthed hardyhead	2.2	5.47	1.55	22.74	45.83
Yelloweye mullet	2.26	0.53	1.16	12.55	58.38
	Mean abundance		**Mean dissimilarity = 51.86**		
Species	**North Lagoon**	**South Lagoon**	**CR**	**Contrib%**	**Cum.%**
Smallmouthed hardyhead	4.93	5.47	1.14	22.1	22.1
Sandy sprat	1.99	0	0.88	16.56	38.66
Congolli	1.56	0.2	1.26	12.89	51.55

The PCO of fish assemblage data for the Estuary accounted for 49% of the total variation in the first two axes (Figure 3.5A). There was distinct separation of 2010/11 samples from 2006/07, mainly explained by increased abundance of freshwater species such as Australian smelt, bony herring, carp, redfin perch and the low abundance or absence of estuarine opportunistic species like yelloweye mullet and Australian salmon. Samples from 2011/12, 2012/13 and 2013/14 were interspersed between the drought (2006/07) and flood (2010/11) year, with a general reduction of freshwater species and an increase of opportunistic estuarine species.

In the North Lagoon, 58.3% of the total variation was captured by PCO1 and PCO2 (Figure 3.5B). Generally, the samples of the 2006/07 and 2010/11 were more closely grouped and those from 2011/12 onwards were separated, associated with increased abundances of sandy sprat, congolli, and goby species in later years.

In the South Lagoon, the two axes captured 93.5% of total variation in fish assemblage differences between years, with a clear shift from 2006/07 to 2010/11, then to 2011/12 and 2012/13, mainly explained by increasing abundance of smallmouthed hardyhead with years. It is also worth mentioning that vertical separation of points in the late years is due to the presence of yelloweye mullet in this subregion (Figure 3.5C).

Applying PCO to the fish assemblage data collected from the three subregions during 2013/14, 71.6% of the total variation was captured by PCO1 and PCO2 (Figure 3.5D). There was a clear separation of Estuary, North Lagoon and South Lagoon samples along the horizontal axis, which was associated with bony herring, sandy sprat and greenback flounder in one direction and smallmouthed hardyhead in the opposite direction. There was also some vertical separation of the data cloud. Yelloweye mullet, Australian salmon and Australian herring were associated with the distribution of some Estuary samples, whilst three goby species were associated with both Estuary and North Lagoon samples.

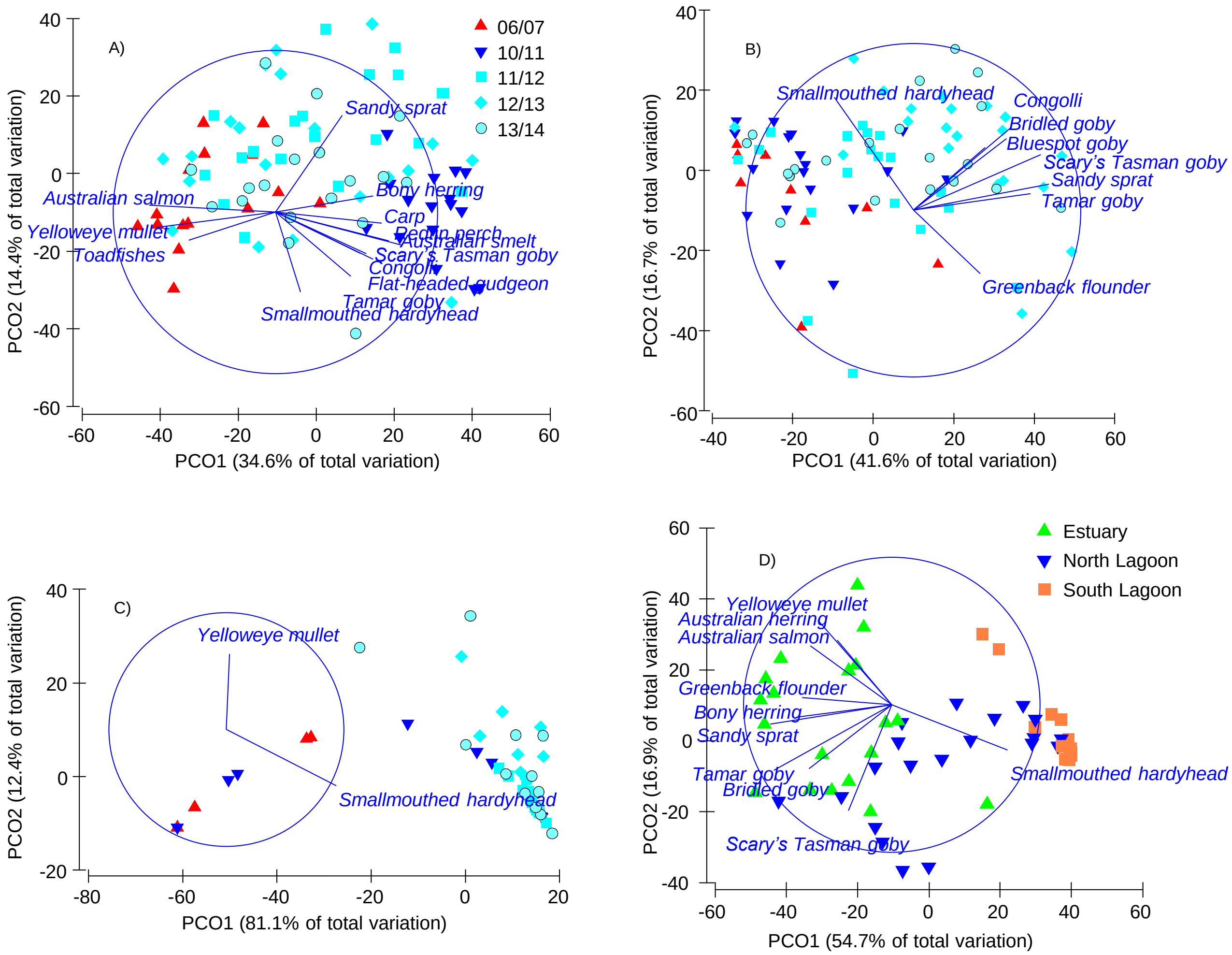

Figure 3.5. PCO of abundance samples of fish species collected by seine net in different years from A) Estuary, B) North Lagoon, C) South Lagoon. D) Samples from different regions during 2013/14. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

The best combination of environmental predictor variables for assemblage structure of seine net samples were salinity and transparency. Together these two variables explained 59.6% of the variation (Figure 3.6). Temperature did not significantly contribute to explain the distribution of samples (Table 3.9). Salinity was the best environmental variable to explain the horizontal separation of the data cloud, whilst transparency best explained the vertical separation (Figure 3.6).

Table 3.9. DistLM sequential results indicating which environmental variable significantly contributed most to the relationship with the multivariate data could (collected by seine net). Proportion of the variation explained (Prop) and cumulative variation explained Cumul).

Variable	Pseudo-F	P	Prop.	Cumul.
Salinity	37.887	**0.001**	0.38705	0.38705
Transparency	11.987	**0.001**	0.10536	0.49021
Temperature	-0.2105	1	-0.00219	0.39486

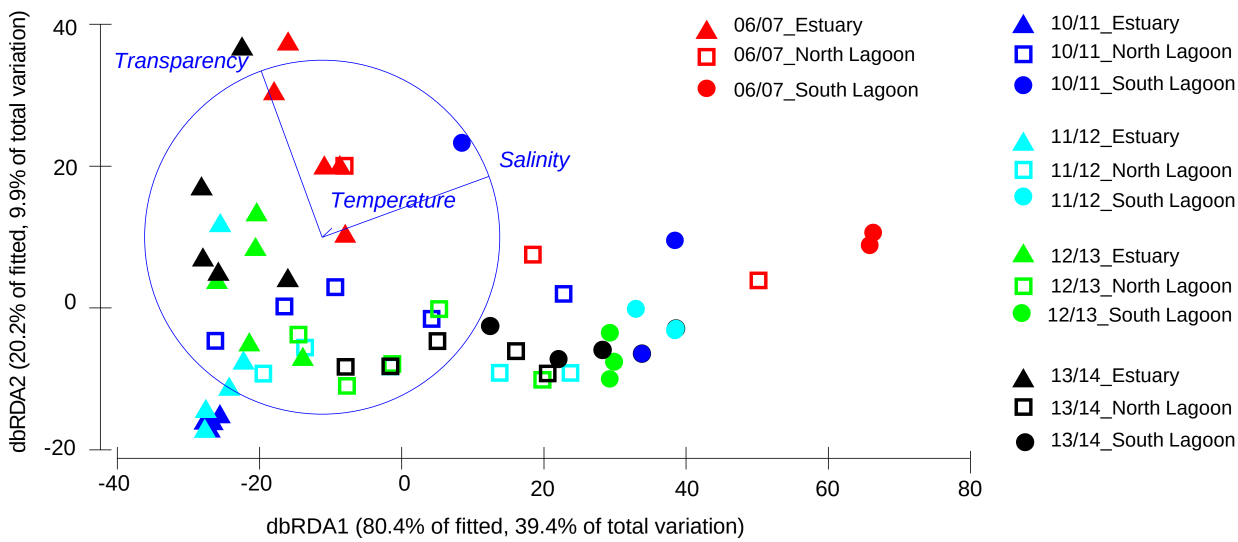

Figure 3.6. dbRDA ordination of the fitted model of species-abundance data collected by seine net (based on Bray-Curtis measure of log x+1 transformed abundances) *versus* the predictor variables salinity, transparency and temperature. The vector overlay indicates multiple partial correlations between the predictor variables and dbRDA axes 1 and 2.

3.4.2. *Gill net samples*

PERMANOVA detected a significant interaction when comparing large-bodied fish assemblages amongst five years (i.e. 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14) and subregions (Table 3.10), suggesting inconsistent spatio-temporal variation. Pairwise comparisons revealed a significant temporal difference in fish assemblage structure in each subregion (P<0.02), and a significant spatial difference in all years (P<0.02).

Table 3.10. PERMANOVA results for fish assemblage comparison based on gill net data (square root transformed) amongst years and subregions of the Murray Estuary and Coorong. Bold P values are significant.

Source	df	MS	Pseudo-F	P(perm)
Year	4	21092	23.077	**0.001**
Subregion	2	31101	8.6477	**0.002**
Year x Subregion	5	3778.5	4.1341	**0.001**

SIMPER analysis indicated that, in the Estuary, the greatest difference in fish assemblages occurred between 2013/14 and 2006/07 (dissimilarity = 63.6%), driven by the increased abundance of bony herring and yelloweye mullet and decreased abundance of Australian salmon and mulloway in 2013/14 (Table 3.11). A relatively smaller change in assemblage structure occurred from 2012/13 to 2013/14, attributed to lower abundances of bony herring and Australian salmon, and greater abundances of yelloweye mullet and mulloway (Table 3.11).

For the North Lagoon, the greatest dissimilarity (66.8%) in fish assemblages also occurred between 2006/07 and 2013/14, mostly driven by increased abundances of yelloweye mullet, bony herring and mulloway in 2013/14 (Table 3.12). Similar to the Estuary, the least difference (29%) in fish assemblage was between 2013/14 and 2012/13 in the North Lagoon, and was mainly driven by decreased abundances of bony herring and Australian salmon in 2013/14.

The South Lagoon was only sampled regularly in 2012/13 and 2013/14, and the assemblage dissimilarity of 71.6% was solely attributed to the increased abundance of yeloweye mullet in 2013/14 (Table 3.13).

Table 3.11. SIMPER analysis for fish assemblage pairwise comparisons between 2013/14 and 2012/13, 2011/12, 2010/11 and 2006/07 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).

	Mean abundance			Mean dissimilarity = 63.57	
Species	**2013/14**	**2006/07**	**CR**	**Contrib%**	**Cum.%**
Bony herring	4.81	0.57	2.37	32.08	32.08
Australian salmon	0.33	2.72	1.47	17.71	49.79
Yelloweye mullet	3.54	2.01	1.2	16.14	65.93
Mulloway	2.24	2.38	1.35	13.01	78.94
	Mean abundance			Mean dissimilarity = 52.05	
Species	**2013/14**	**2010/11**	**CR**	**Contrib%**	**Cum.%**
Yelloweye mullet	3.54	0.68	1.74	27.73	27.73
Bony herring	4.81	4.88	1.2	18.77	46.51
Mulloway	2.24	0.53	1.38	17.62	64.13
Carp	0.9	1.07	1.28	10.08	74.2
Redfin perch	0	0.73	1.02	6.21	80.42
	Mean abundance			Mean dissimilarity = 59.41	
Species	**2013/14**	**2011/12**	**CR**	**Contrib%**	**Cum.%**
Bony herring	4.81	11.37	1.92	32.21	32.21
Australian salmon	0.33	4.62	1.37	19.96	52.17
Yelloweye mullet	3.54	1.85	1.59	15.95	68.12
Mulloway	2.24	1.09	1.28	9.32	77.44
	Mean abundance			Mean dissimilarity = 46.86	
Species	**2013/14**	**2012/13**	**CR**	**Contrib%**	**Cum.%**
Bony herring	4.81	6.1	1.15	23.01	23.01
Australian salmon	0.33	2.77	1.22	19.45	42.46
Yelloweye mullet	3.54	2.82	1.33	18.78	61.25
Mulloway	2.24	1.78	1.37	15.29	76.53

Table 3.12. SIMPER analysis for fish assemblage pairwise comparisons between 2013/14 and 2012/13, 2011/12, 2010/11 and 2006/07 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).

	Mean abundance			Mean dissimilarity = 66.76	
Species	**2013/14**	**2006/07**	**CR**	**Contrib%**	**Cum.%**
Yelloweye mullet	4.63	2.64	1.17	37.08	37.08
Bony herring	3.36	0.08	1.51	35	72.09
Mulloway	1.62	1.6	1.22	16.03	88.12
	Mean abundance			**Mean dissimilarity = 54.23**	
Species	**2013/14**	**2010/11**	**CR**	**Contrib%**	**Cum.%**
Bony herring	3.36	11.2	1.63	48.77	48.77
Yelloweye mullet	4.63	4.5	1.38	19.67	68.44
Australian salmon	0.05	2.36	1.21	14.85	83.29
	Mean abundance			**Mean dissimilarity = 53.29**	
Species	**2013/14**	**2011/12**	**CR**	**Contrib%**	**Cum.%**
Bony herring	3.36	12.21	2.44	46.2	46.2
Yelloweye mullet	4.63	5.21	1.37	16.47	62.68
Australian salmon	0.05	2.57	1.29	12.94	75.62
	Mean abundance			**Mean dissimilarity = 40.30**	
Species	**2013/14**	**2012/13**	**CR**	**Contrib%**	**Cum.%**
Bony herring	3.36	8.58	1.89	44.58	44.58
Yelloweye mullet	4.63	7.19	1.47	31.73	76.31

Table 3.13. SIMPER analysis for fish assemblage pairwise comparisons between 2013/14 and 2012/13, 2011/12 for gill net samples from the South 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).

	Mean abundance			Mean dissimilarity = 71.56	
Species	**2013/14**	**2012/13**	**CR**	**Contrib%**	**Cum.%**
Yelloweye mullet	2.88	2.32	1.62	88	88

When comparing between subregions in 2013/14, the greatest dissimilarity (77.4%) occurred between the Estuary and South Lagoon, and was mainly due to greater abundances of yelloweye mullet in the Estuary, as well as the absence of bony herring and mulloway in the South Lagoon (Table 3.14).

Table 3.14. SIMPER analysis for fish assemblage comparison between Estuary, North Lagoon and South Lagoon for gill net samples during 2013/14. 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).

	Mean abundance			Mean dissimilarity = 40.05	
Species	**Estuary**	**North Lagoon**	**CR**	**Contrib%**	**Cum.%**
Yelloweye mullet	3.54	4.63	1.24	28.7	28.7
Bony herring	4.81	3.36	1.36	24.01	52.71
Mulloway	2.24	1.62	1.36	19.66	72.36
Carp	0.9	0	0.85	10.53	82.9
		Mean abundance		**Mean dissimilarity = 77.36**	
Species	**Estuary**	**South Lagoon**	**CR**	**Contrib%**	**Cum.%**
Bony herring	4.81	0	3.24	40.99	40.99
Yelloweye mullet	3.54	2.88	1.36	23.08	64.07
Mulloway	2.24	0	1.47	17.27	81.35
		Mean abundance		**Mean dissimilarity = 70.62**	
Species	**North Lagoon**	**South Lagoon**	**CR**	**Contrib%**	**Cum.%**
Bony herring	3.36	0	1.6	39.41	39.41
Yelloweye mullet	4.63	2.88	1.2	39.19	78.6

Temporal variation of large-bodied fish assemblages between years in the Estuary was well captured by the first two axes of the PCO, which accounted for 84.3% of the variation (Figure 3.7A). There was a clear separation of the data cloud between 2006/07, 2010/11, 2011/12; whilst samples for 2012/13 and 2013/14 were interspersed. Samples from 2006/07 were mainly associated with high abundances of mulloway, yelloweye mullet and Australian salmon. Whilst those from 2010/11 and 2011/12 were more attributable to the freshwater species including bony herring, golden perch, carp and redfin perch.

For the North Lagoon, PCO1 and PCO2 captured 63.1% of the total variation in the fish assemblage data (Figure 3.7B). There was a more distinct separation of 2006/07 samples from all other years, mainly driven by increased abundances of bony herring and Australian salmon, and to a lesser extent, carp and redfin perch in the flood/flow years (2010/11–2013/14).

In 2013/14, fish assemblages showed a distinct difference in the South Lagoon from the other two subregions (Figure 3.8). The Estuary data cloud was grouped closely whilst the data of the North and South lagoons were sparsely distributed. The vertical distribution of data was more associated with the abundance of yelloweye mullet, congolli and greenback flounder, whilst the horizontal distribution is more associated with the abundance of bony herring, mulloway, black bream, river garfish and goldspot mullet.

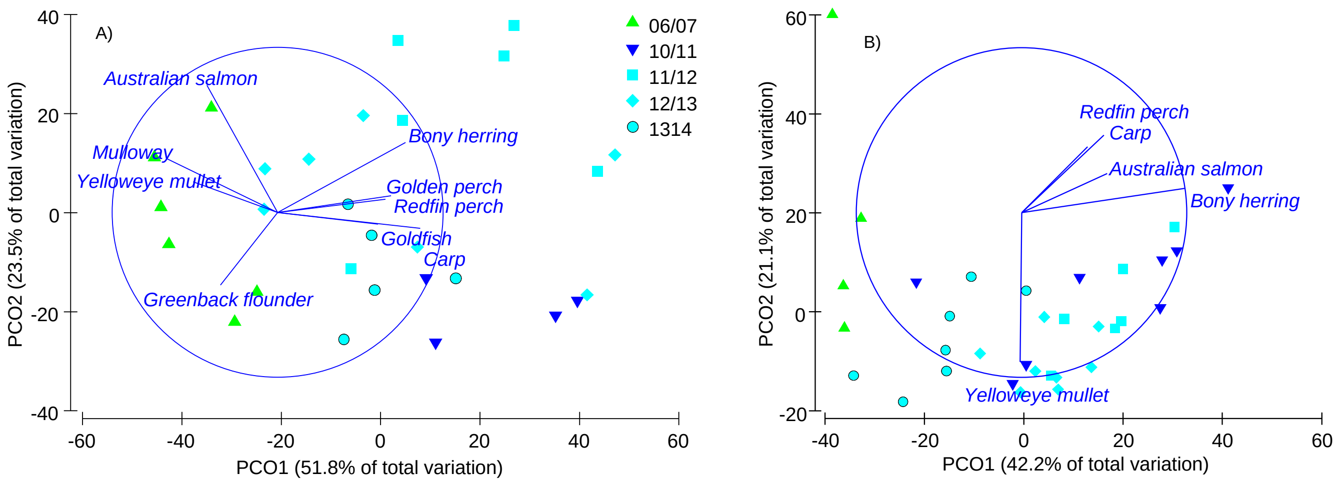

Figure 3.7. PCO of samples on the basis of the Bray-Curtis measure of square root transformed abundances of fish species collected by gill net in different years from each region A) Murray Estuary and B) North Lagoon. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

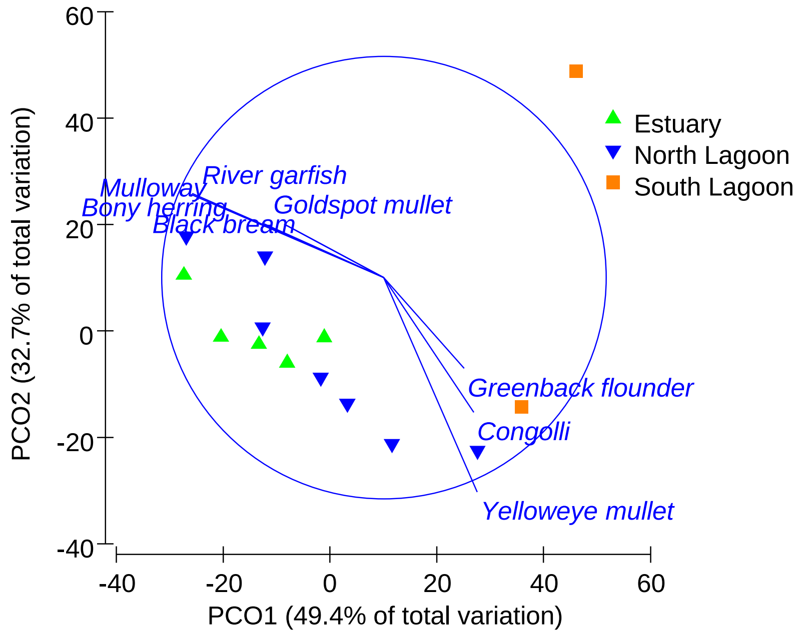

Figure 3.8. PCO of samples on the basis of the Bray-Curtis measure of square-root transformed abundances of fish species collected by gill net from the three subregions during 2013/14. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

The DistLM analysis showed that salinity and transparency were the two environmental variables that significantly contributed to explaining fish assemblage variations across the three subregions. Together they explained 32.6% of the variation, with salinity strongly correlated to the distribution of the data cloud along horizontal axis, e. g. 2006/07 associated with high salinity, whilst transparency was correlated with the distribution of the data points along the vertical axis, e. g. higher transparency occurring in 2006/07 and in post-drought years at some estuary sites. (Table 3.15 and Figure 3.9).

Table 3.15. DistLM sequential results indicating which environmental variable contributed most to the relationship with the multivariate data cloud (collected by gill net). Proportion of the variation explained (Prop) and cumulative variation explained (Cumul).

Variable	Pseudo-F	P	Prop.	Cumul.
Salinity	19.513	**0.001**	0.23089	0.23089
Temperature	1.0309	0.401	1.22E-02	0.24308
Transparency	8.9034	**0.001**	9.37E-02	0.33681

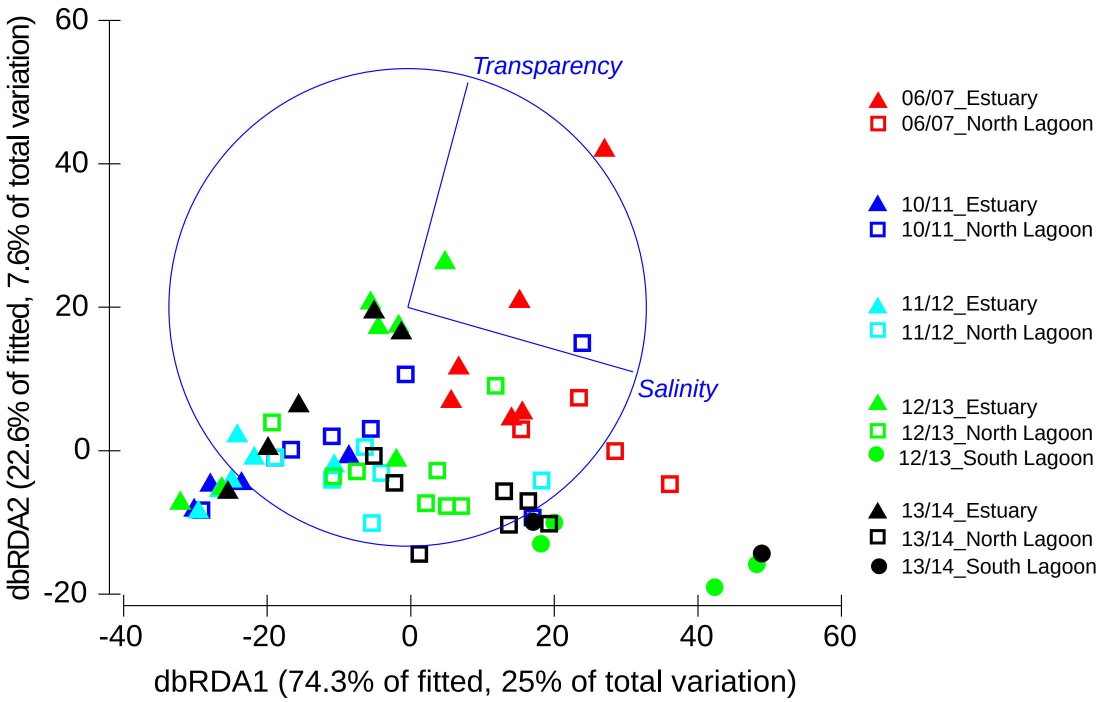

Figure 3.9. dbRDA ordination of the fitted model of species-abundance data collected by gill net (based on Bray-Curtis measure of square root transformed abundances) *versus* the predictor variables salinity, pH, temperature and transparency. The vector overlay indicates multiple partial correlations 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 and opportunistic species*

Over the last four years, the small-bodied estuarine and opportunistic species responded well to freshwater inflows. All three species, smallmouthed hardyhead, sandy sprat and Tamar goby, showed increased abundance after 2010/11 compared to 2006/07 (Figures 3.10A, B and 3.11), with the latter two species also showing a southward range extension throughout the North Lagoon following high flows after 2010/11 (Figure 3.10B and 3.11). Nevertheless, both sandy sprat and Tamar goby were absent in the South Lagoon in all study years.

In 2013/14, the abundance and distribution of smallmouthed hardyhead was similar to the previous year's (i.e. 2012/13), whereas the overall abundances of Tamar goby and sandy sprat were more than triple compared to 2012/13 with most increases occurred in the Estuary subregion. From 2012/13 to 2013/14, the distribution range of Tamar goby showed a small northward contraction to the middle of the North Lagoon; for sandy sprat, the range maintained although the abundance started to decline in the southern part of the North Lagoon.

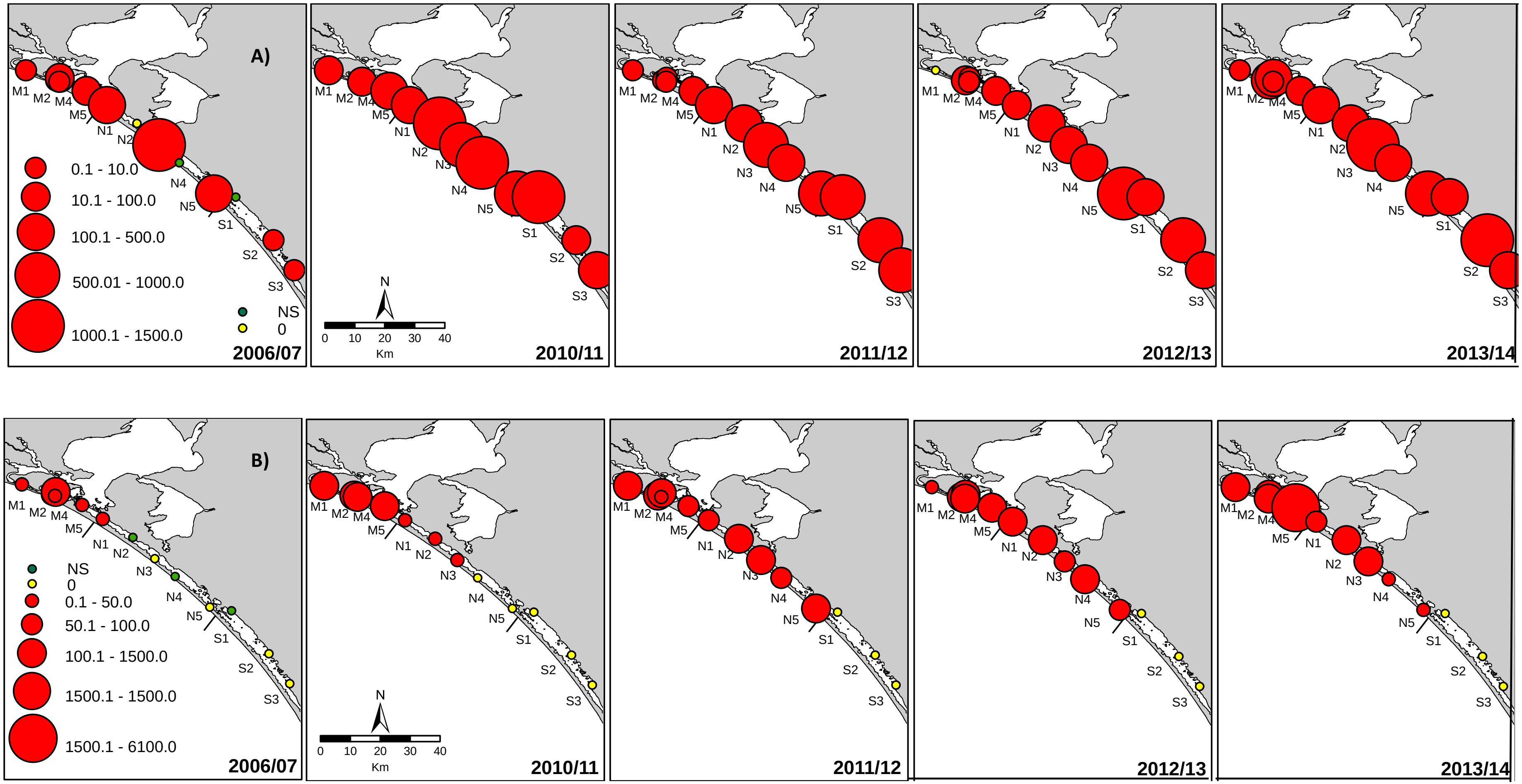

Figure 3.10. A) Smallmouthed hardyhead and B) sandy sprat relative abundance (fish.seine net shot^{-1}) and distribution in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

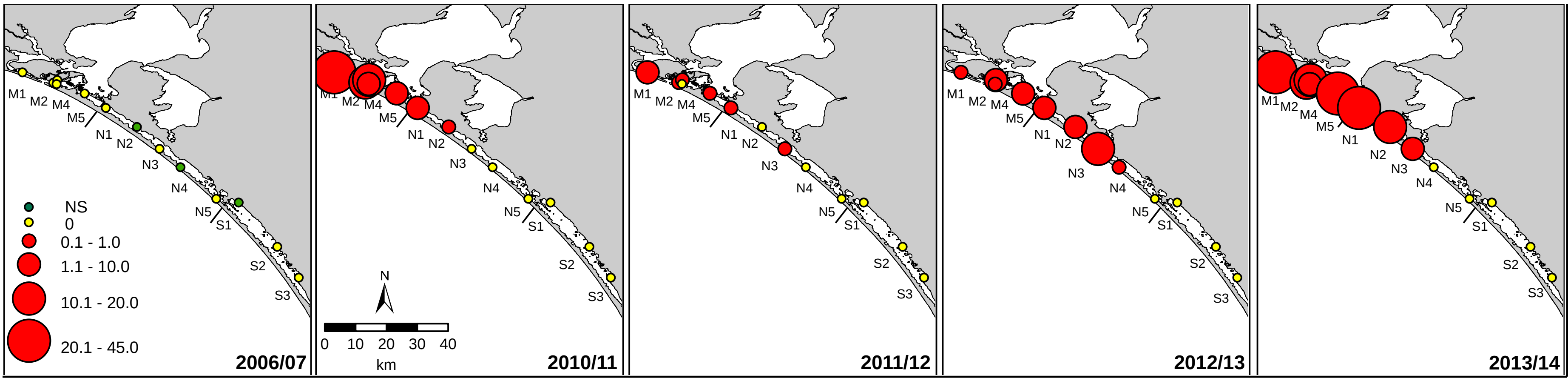

Figure 3.11. Tamar goby relative abundance (fish.seine net shot^{-1}) and distribution in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

3.5.2. *Catadromous species*

Juvenile congolli have showed a positive response to the flows since 2010/11. A southward extension in distribution was observed consistently throughout the flow years, with considerable increases in abundance in 2012/13 and 2013/14, for the Estuary and North Lagoon (Figure 3.12A). In 2012/13, juveniles of congolli were sampled in the South Lagoon for the first time in the study, and continued to be present in this subregion in 2013/14, although in lower abundance. There was a general increase in abundance of adult congolli in 2011/12, followed by a decrease in 2012/13. In 2013/14, the abundance remained at similar levels to the previous survey, but indicated an expansion in spatial distribution into the South Lagoon (Figure 3.12B).

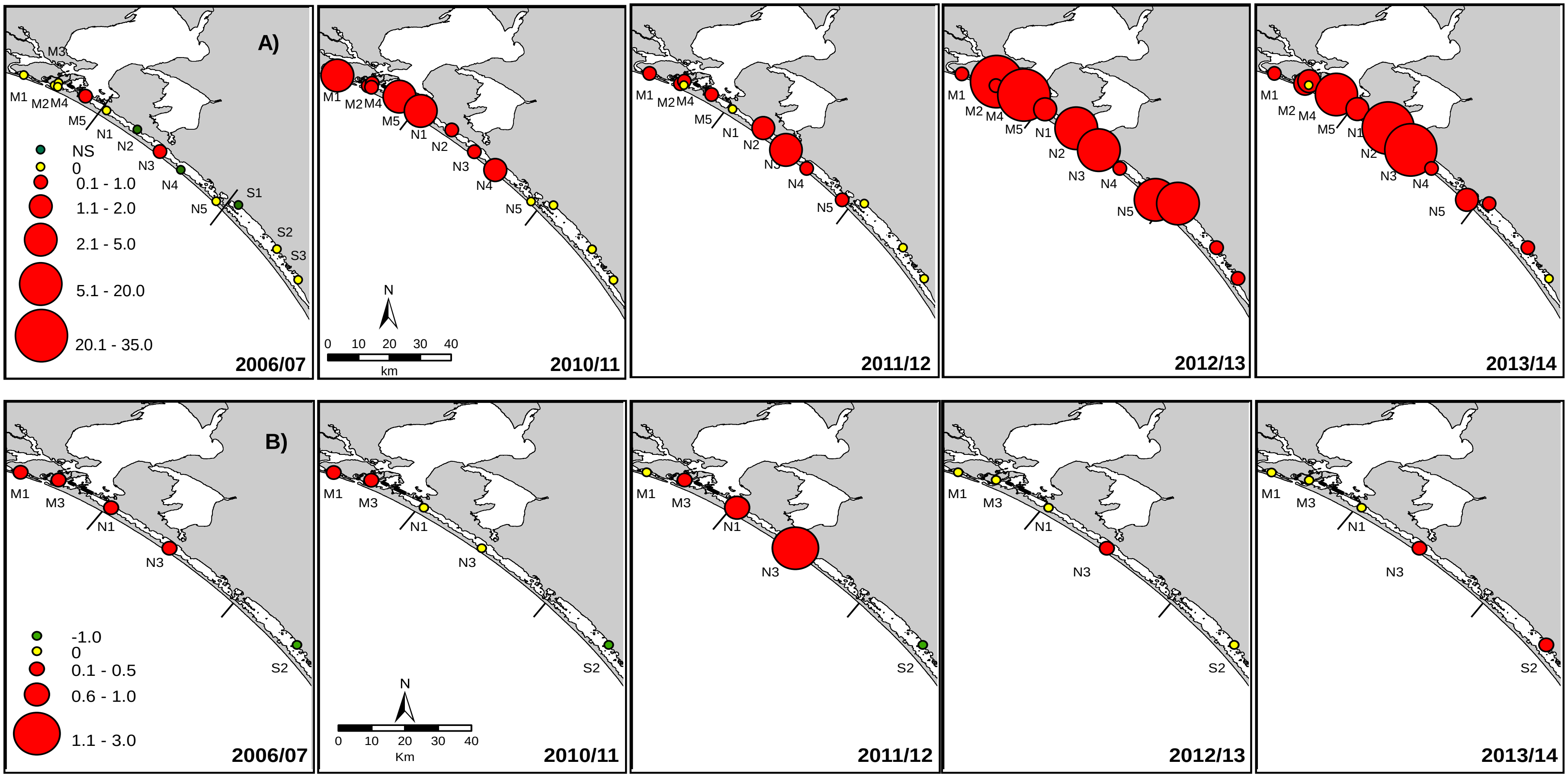

Figure 3.12. Congolli relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

3.5.3. *Large-bodied estuarine and opportunistic species*

Juvenile greenback flounder showed an increase in distribution throughout the North Lagoon following the flood and high flows in 2010/11–2013/14 (Figure 3.13A). In contrast, there was a general decline in relative abundance, particularly in the Estuary subregion. No greenback flounder were sampled in the South Lagoon over the five study years. The most southern site they were present, in 2011/12 and 2013/14, was Hells Gate (N5) (the southern end of the North Lagoon). Similarly, since 2010/11 the relative abundance of adult greenback flounder have declined in the Estuary but increased and remained relatively stable in the North Lagoon after 2011/12 (Figure 3.13B).

For yelloweye mullet, there was a clear southward range extension of seine net catches (mainly juveniles) from 2011/12 onwards; remarkably, juveniles were found first time in the South Lagoon in 2011/12. In the following two years (2012/13 and 2013/14), the distribution showed an increase with greater numbers of juveniles caught at more sites in the South Lagoon (Figure 3.14A). Furthermore, adult fish were caught in gill nets in all three regions in 2012/13 and 2013/14; however the highest relative abundance was consistently in the North Lagoon (Figure 3.14B).

The data indicated a low abundance of black bream in the Coorong in all five years. In 2006/07, both seine net and gill net catches were predominant in the Estuary subregion (Figure 3.15A and B). 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) and no black bream were caught by gill net. In the following two years (2012/13 and 2013/14), black bream continued to be sampled by seine net in the Estuary and South Lagoon and by gill nets in the Estuary in very low numbers (≤3 per year per gear type) (Figure 3.15A and B).

Catch of small juvenile mulloway by seine net was restricted to the Estuary in 2006/07, and had extended to the North Lagoon in 2012/13 (Figure 3.16A). In 2013/14, no juvenile mulloway were collected by seine net, whilst the gill net samples collected larger mulloway in both the Estuary and North Lagoon, in similar abundances to 2012/13. There was a general decline in the gill net catch of mulloway in 2010/11, followed by a considerable increase in 2011/12, particularly in the North Lagoon. In 2012/13 and 2013/14, gill net catches in the Estuary and North Lagoon were at similar levels of 2006/07 (Figure 3.16B).

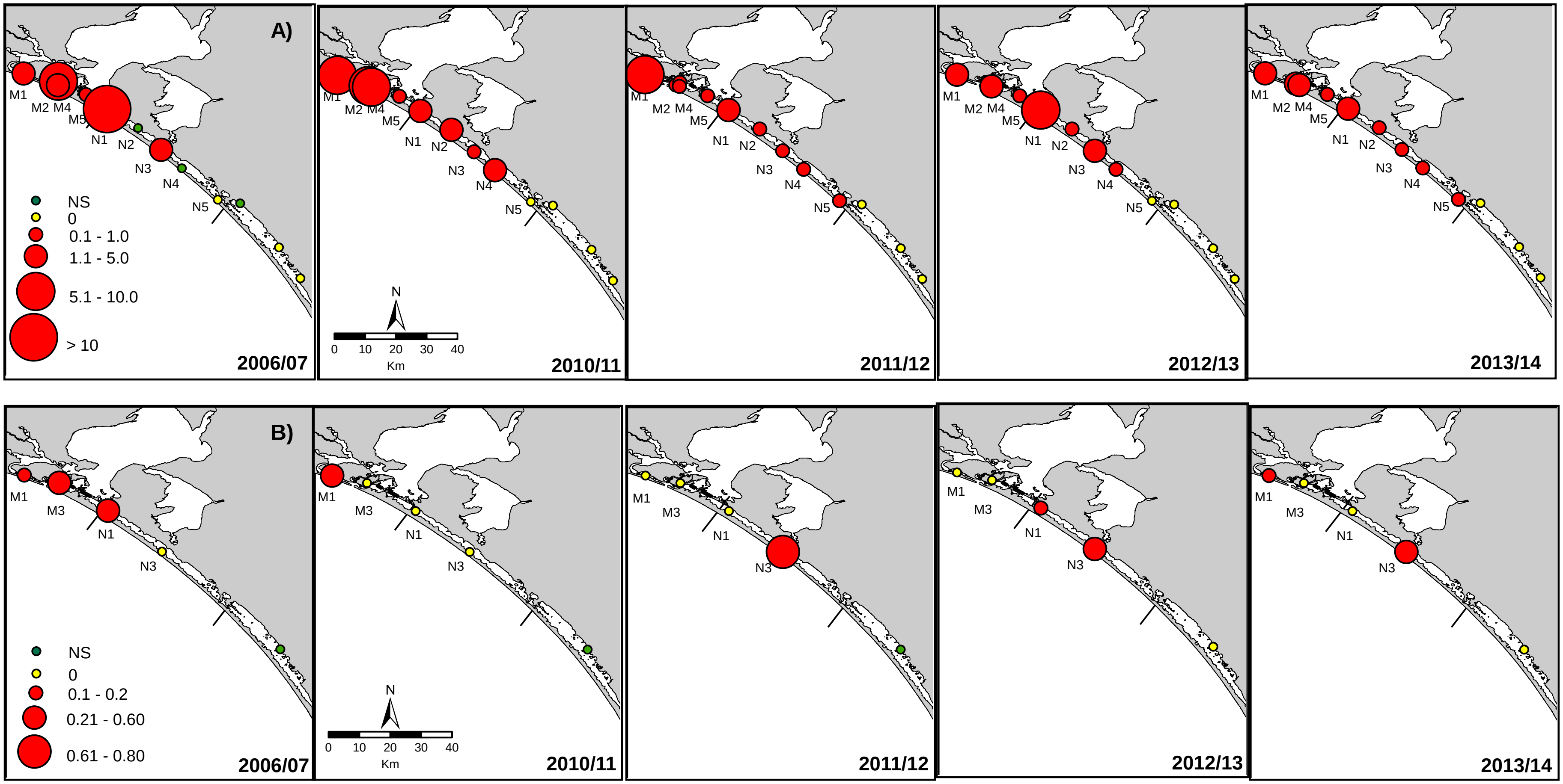

Figure 3.13. Greenback flounder relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

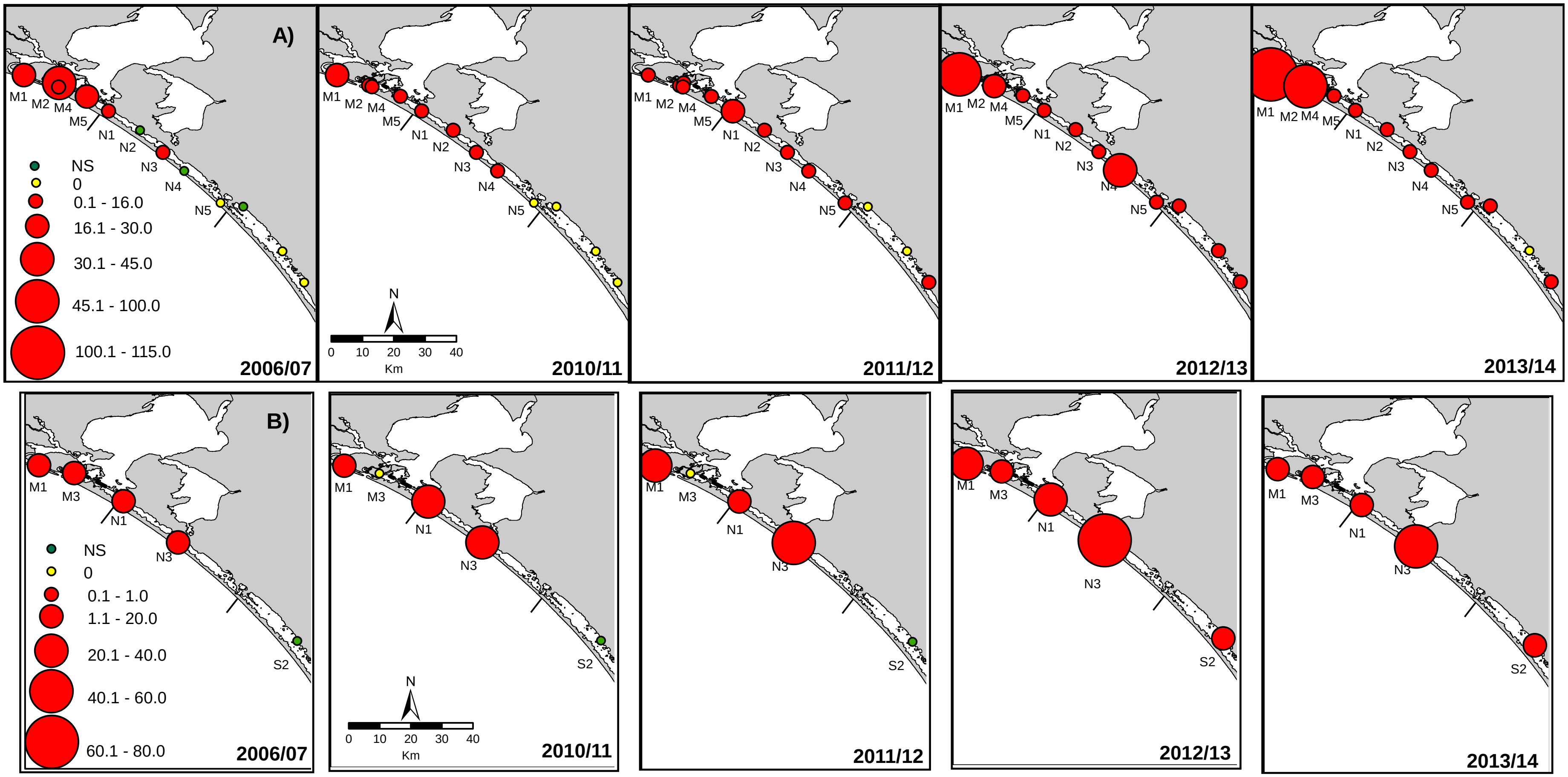

Figure 3.14. Yelloweye mullet relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

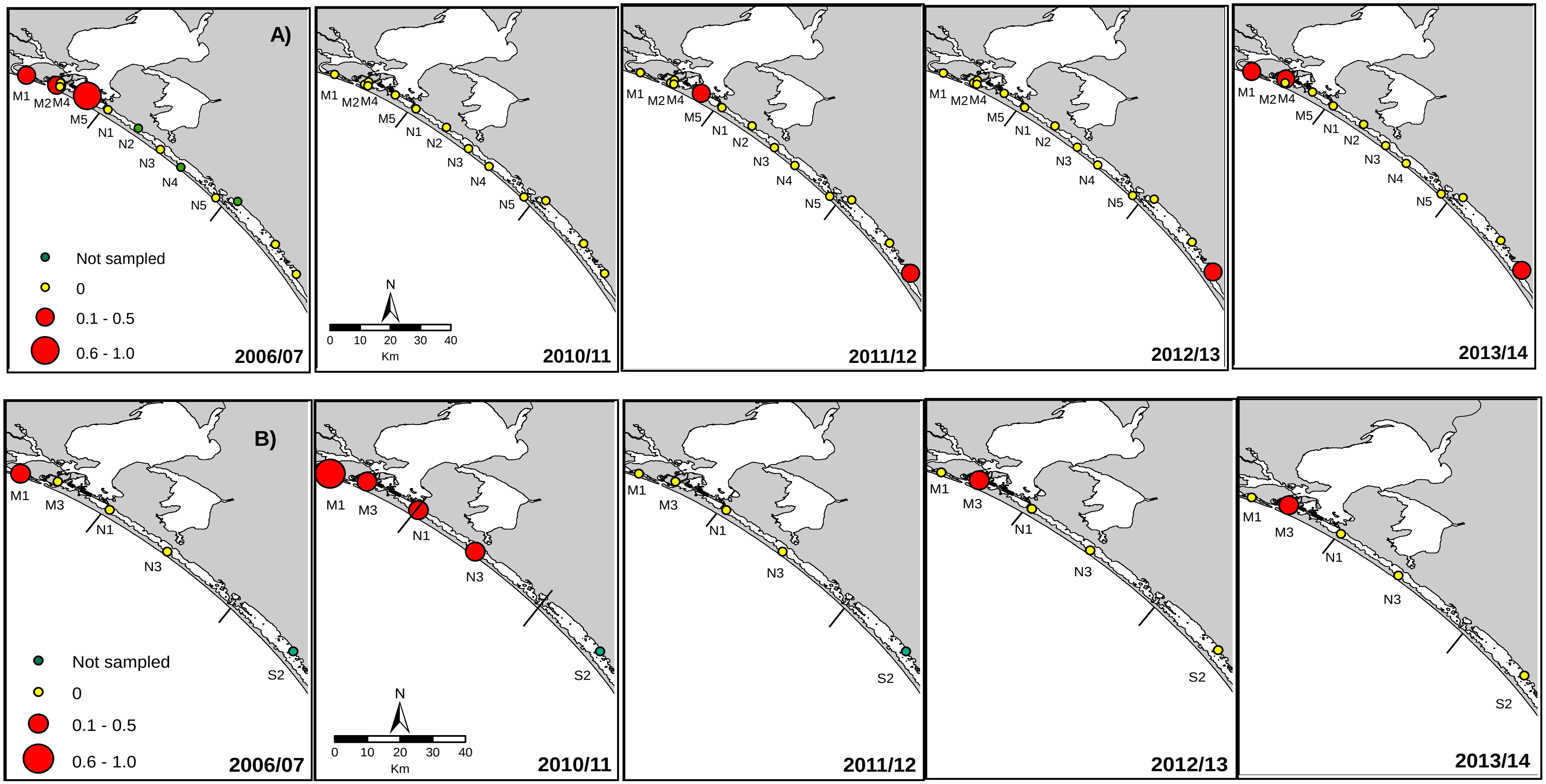

Figure 3.15. Black bream relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

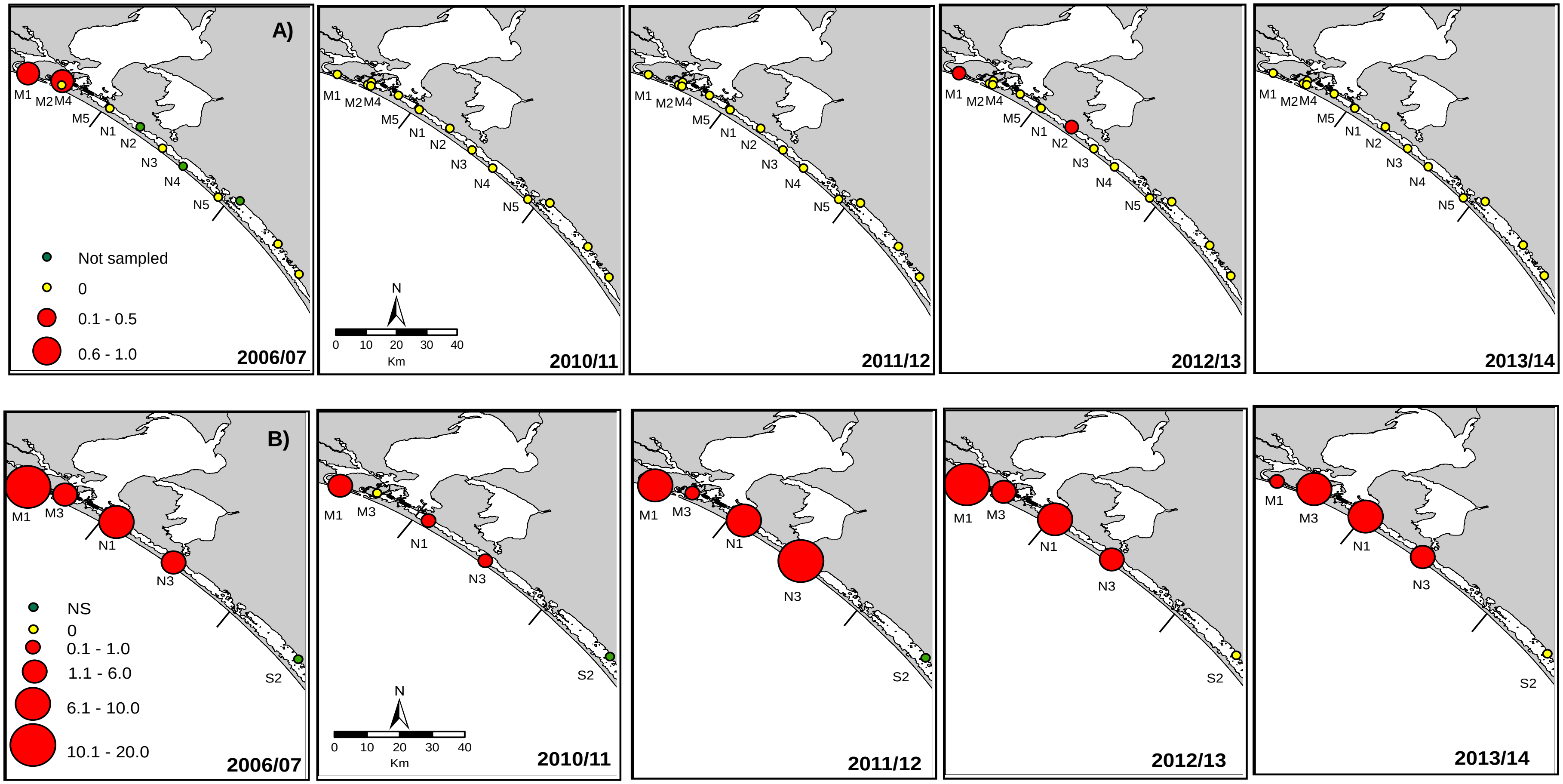

Figure 3.16. Mulloway relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

3.5.4. *Freshwater native species*

Bony herring showed a sharp increase in abundance and distribution throughout the Murray Estuary and Coorong during the flood and substantial barrage releases in 2010/11, compared to 2006/07. In the following years, there was a general decline in abundance corresponding to reduced inflows to the Coorong. However, bony herring continue to be broadly distributed in the region, with fish sampled in both gear types in the South Lagoon in 2012/13 and 2013/14 (Figures 3.17A and B).

3.5.5. *Freshwater exotic species*

Carp and redfin perch, previously absent in the Coorong in the drought year (2006/07), showed an extensive increase in abundance in the Estuary, and to a lesser extent in northern part of the North Lagoon, during the 2010/11 flood. They were sampled by both gear types in 2010/11, (Figures 3.18 and 3.19), with peaked abundances of juveniles occurring in 2010/11, whilst adults occurred in the following year for both species. In 2012/13 and 2013/14, catches of both species collected by seine and gill nets were limited to the Estuary subregion only with considerable reduction in numbers (Figure 3.18 and 3.19).

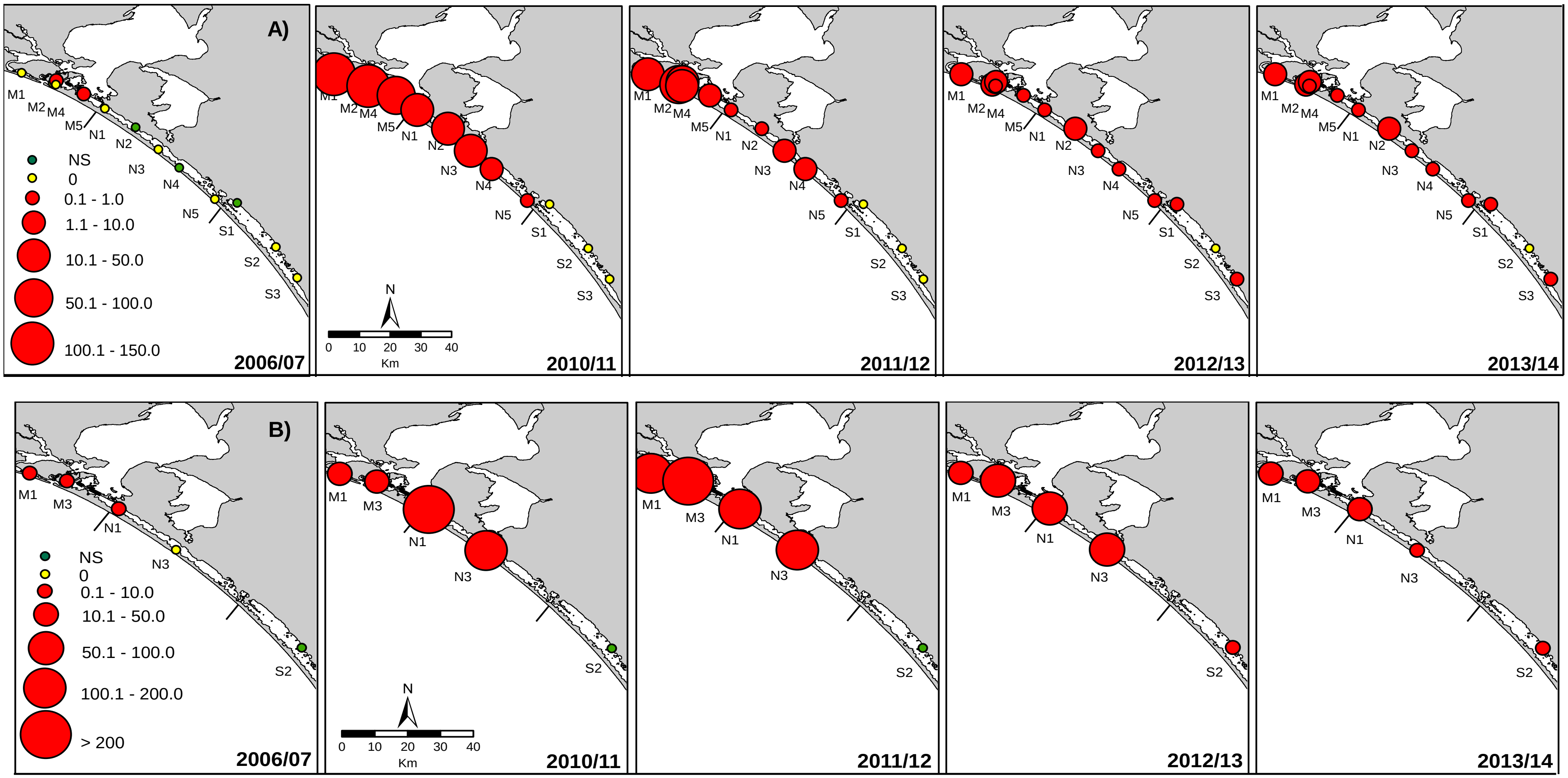

Figure 3.17. Bony herring relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

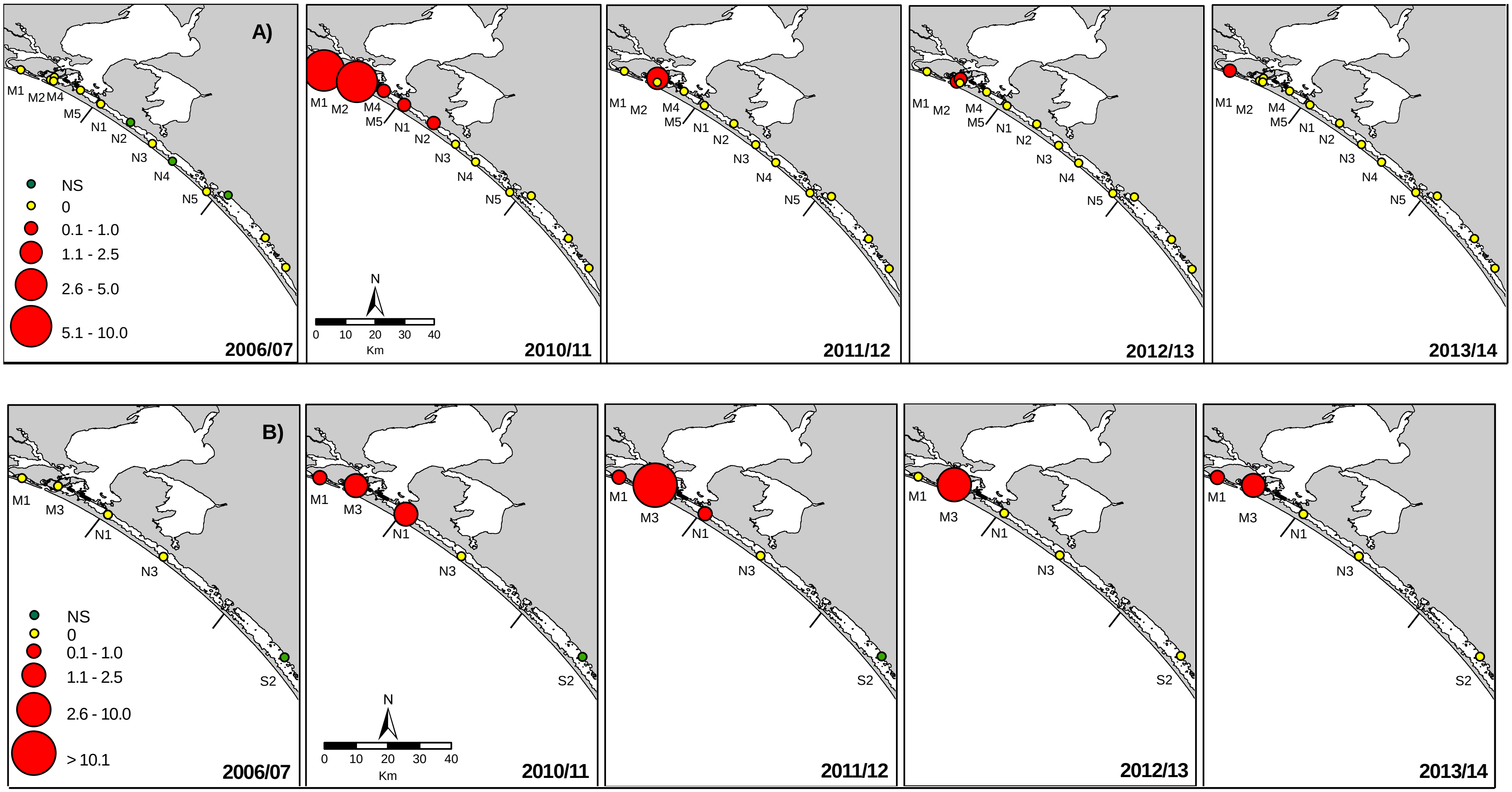

Figure 3.18. Carp relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

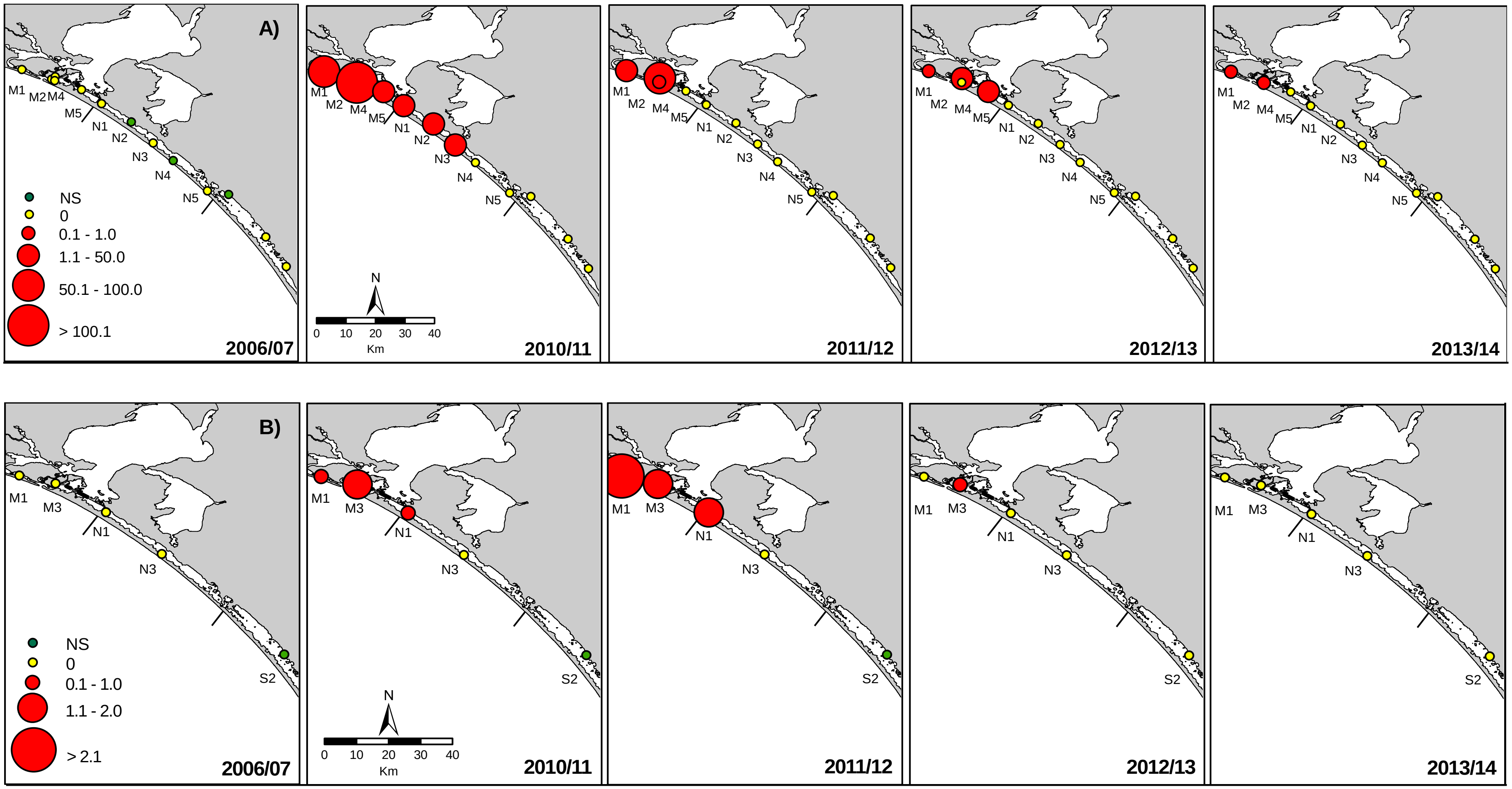

Figure 3.19. Redfin perch relative abundance and distribution for A) seine net (fish.seine net shot^{-1}) and B) gill net (fish.gill net night^{-1}) in the Murray Estuary and Coorong from 2006/07–2013/14. NS – No sampling

3.6. Length frequency distributions of key species

Length measurement data were obtained from fish collected using both seine nets and gill nets. 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.

3.6.1. *Small-bodied estuarine and opportunistic species*

The length frequency distributions for smallmouthed hardyhead and Tamar goby generally showed broad size ranges (Figure 3.20 and 3.22, respectively), whilst sandy sprat had a narrower size class distribution (Figure 3.21). These size structures, in conjunction with the presence of very small fish, indicated successful recruitment for these species (Figure 3.20, 3.21 and 3.22). Importantly for smallmouthed hardyhead, many new recruits were sampled in the North and South lagoons in the years post flood (2010/11-2013/14) (Figure 3.20). In contrast, the majority of new recruits were present in the Estuary for sandy sprat (before 2010/11) and for Tamar goby (before 2012/13). In the last two years (2012/13 and 2013/14), a large proportion of the new recruits of sandy sprat and Tamar goby were sampled from the North Lagoon (Figure 3.21 and 3.22).

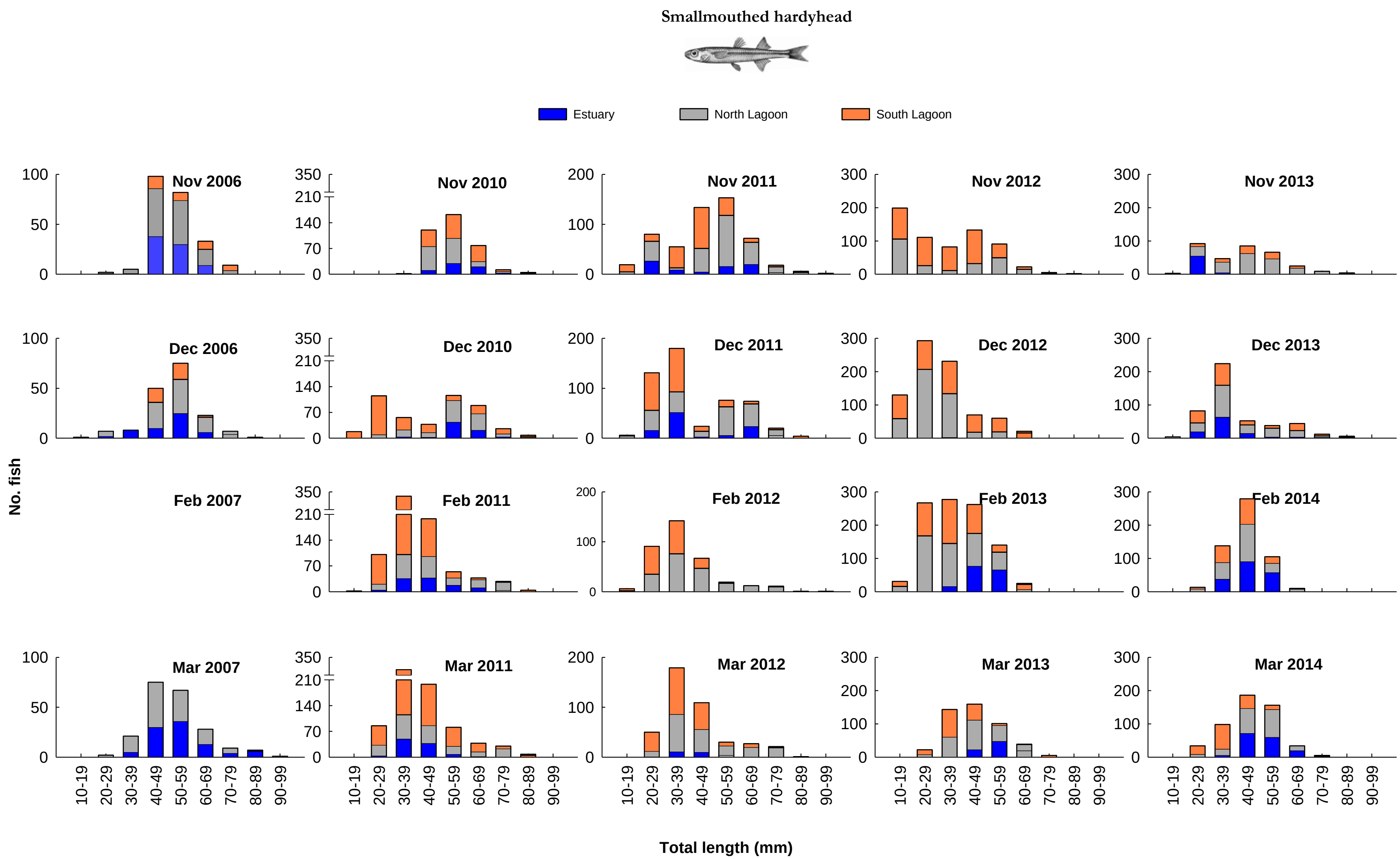

Figure 3.20. Length frequency distributions of smallmouthed hardyhead from seine net samples in the Murray Estuary, Coorong lagoons in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. Note the scale differences on the y-axis

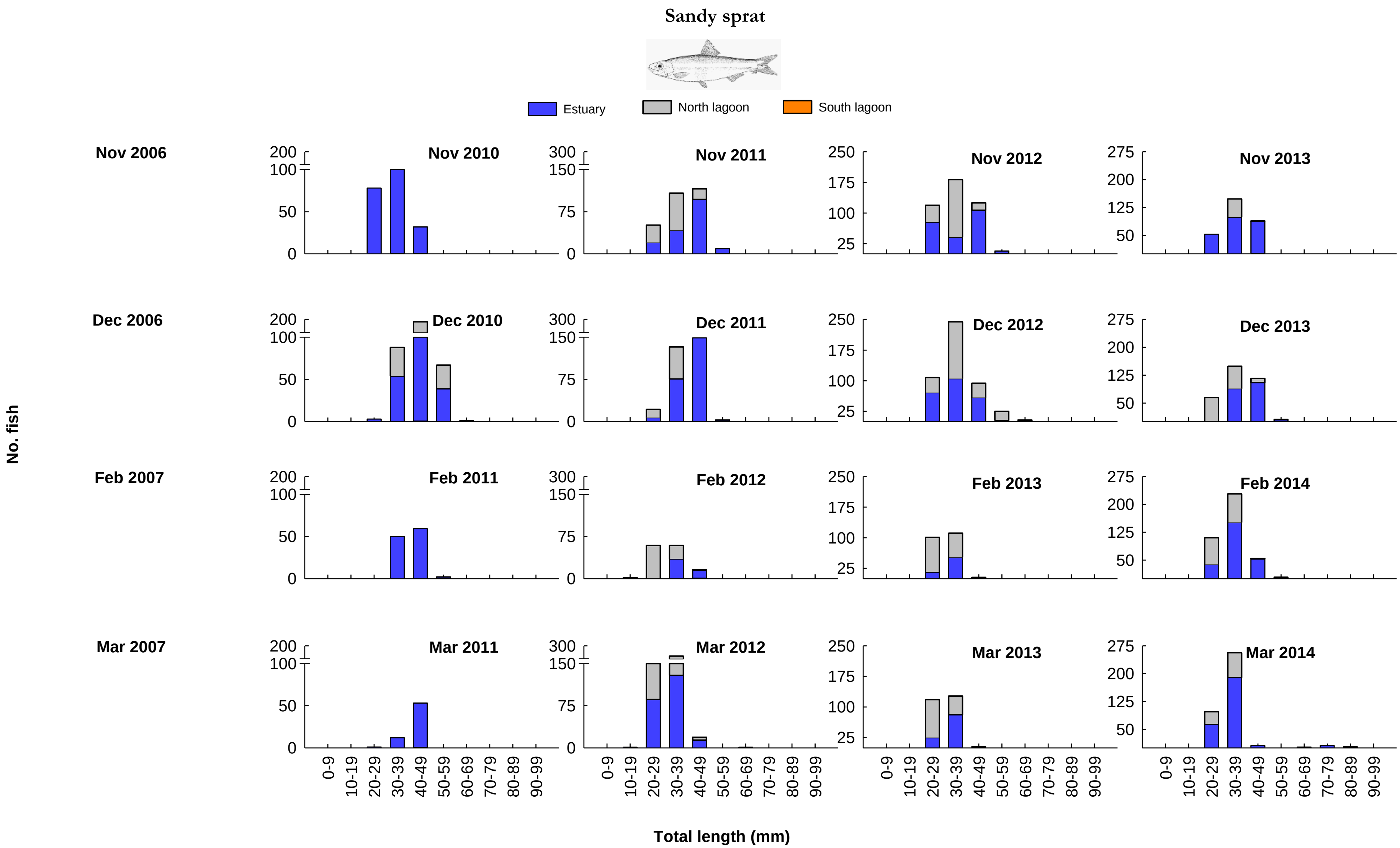

Figure 3.21. Length frequency distributions of sandy sprat from seine net samples in the Murray Estuary and North Lagoon of the Coorong in 2010/11, 2011/12, 2012/13 and 2013/14. Note the scale differences on the y-axis.

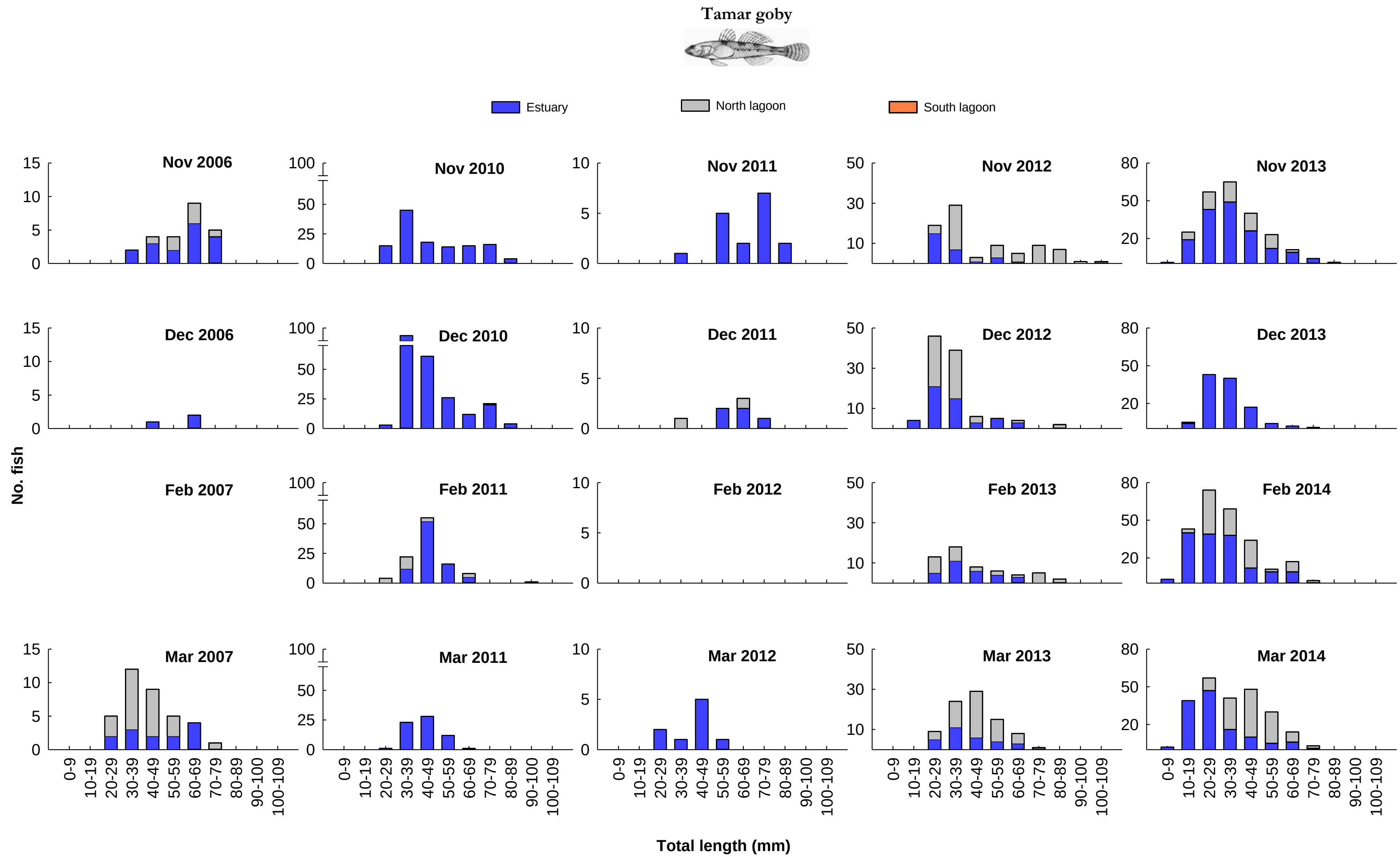

Figure 3.22. Length frequency distributions of Tamar goby from seine net samples in the Murray Estuary North Lagoon of the Coorong in 2006/07, 2010/11, 2011/12 , 2012/13 and 2031/14. Note the scale differences on the y-axis.

3.6.2. *Catadromous species*

Congolli, a medium-bodied species, were sampled by both seine and gill nets in all years. New recruits (fish <100 mm TL) were present in both the Estuary and North Lagoon with considerable increases in numbers after 2010/11. In 2012/13 and 2013/14, the abundance of new recruits increased about 7–12 times to that of the previous two years'. The length frequency distributions indicated strong cohorts coming through from the Estuary and the North Lagoon, and there was even presence of YOY (fish < 50 mm) in the South Lagoon, albeit in much smaller abundances, over the last two years. Adult congolli were present in the Estuary and North Lagoon in 2006/07 and 2011/12, with greater numbers in the later year (Figure 3.23).

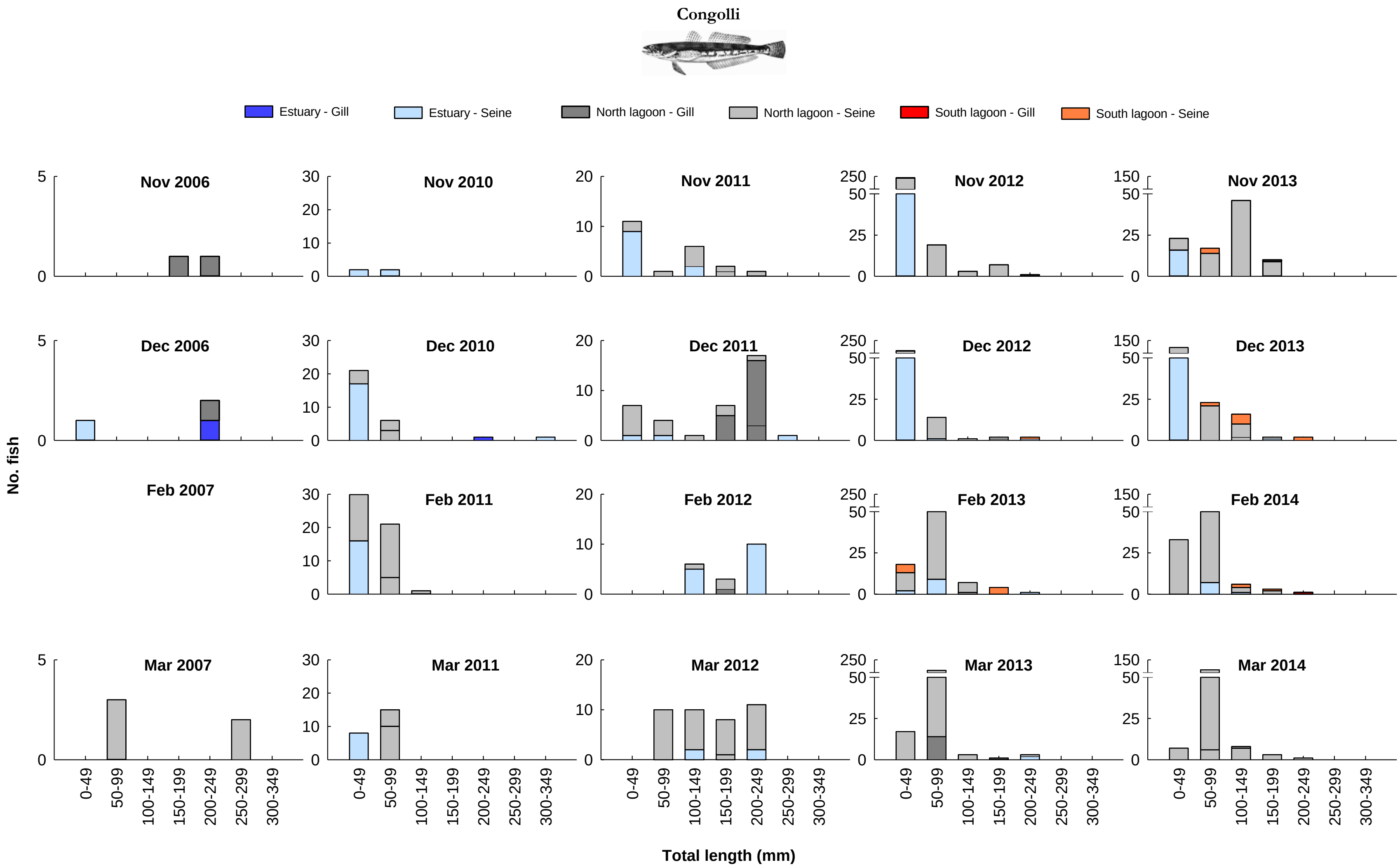

Figure 3.23. Length frequency distributions of juvenile and adult congolli from seine and gill net samples in the Murray Estuary, Coorong lagoons in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. Note the scale differences on the y-axis.

3.6.3. *Large-bodied estuarine and opportunistic species*

The greenback flounder collected in the Coorong showed a broad range of size classes (i.e. 0–349 mm). In all sampling years, the length frequency distribution was unimodal, with fish < 100 mm TL dominating the catches (Figure 3.24). The size compositions of juvenile greenback flounder in 2013/14 were similar to those in the previous two years, with a strong mode of fish from 50–99 mm TL. This modal size was larger than for fish sampled in corresponding months in 2006/07 and 2010/11 (i.e. 0–49 mm TL) (Figure 3.24). Seine netting appeared to be effective for sampling juvenile greenback flounder, as well as adult fish. Gill nets collected adult greenback flounder in low numbers. Length frequency distributions indicated the presence of new recruits in all years, in both the Estuary and North Lagoon.

Yelloweye mullet length frequency data showed a broad size class distribution (i.e. 0–399 mm). Both seine and gill nets were effective in collecting juvenile and adult fish, respectively. Some modal progression could be identified in fish sampled by both gear types in the Estuary and in the North Lagoon (Figure 3.25). In 2013/14, there was a clear bimodal size distribution in all sampled months. The smaller cohort was found in all three subregions in November 2013, whereas in later months it was mainly sampled from the Estuary with a small contribution from the North Lagoon. Conversely, the larger cohort was found in all three subregions except during March.

The length frequency distributions of Mulloway were represented by fish sampled from both Estuary and North Lagoon, mainly by gill nets in all sampled years (Figure 3.26). In 2013/14, size of mulloway collected ranged from 160 to 639 mm – with no distinct modal progression observed in this year, unlike in 2012/13. The dominant size class of 160–239 mm TL which occurred in December in the previous years was not shown in 2013/14; however, a size mode of 240–319 mm TL appeared in February 2014, suggesting that new recruits may have entered the Coorong slightly later in the year.

Black bream were collected in very low numbers throughout the study period. Length frequency data were patchy; hence it was not clear whether recruitment occurred (Figure 3.27).

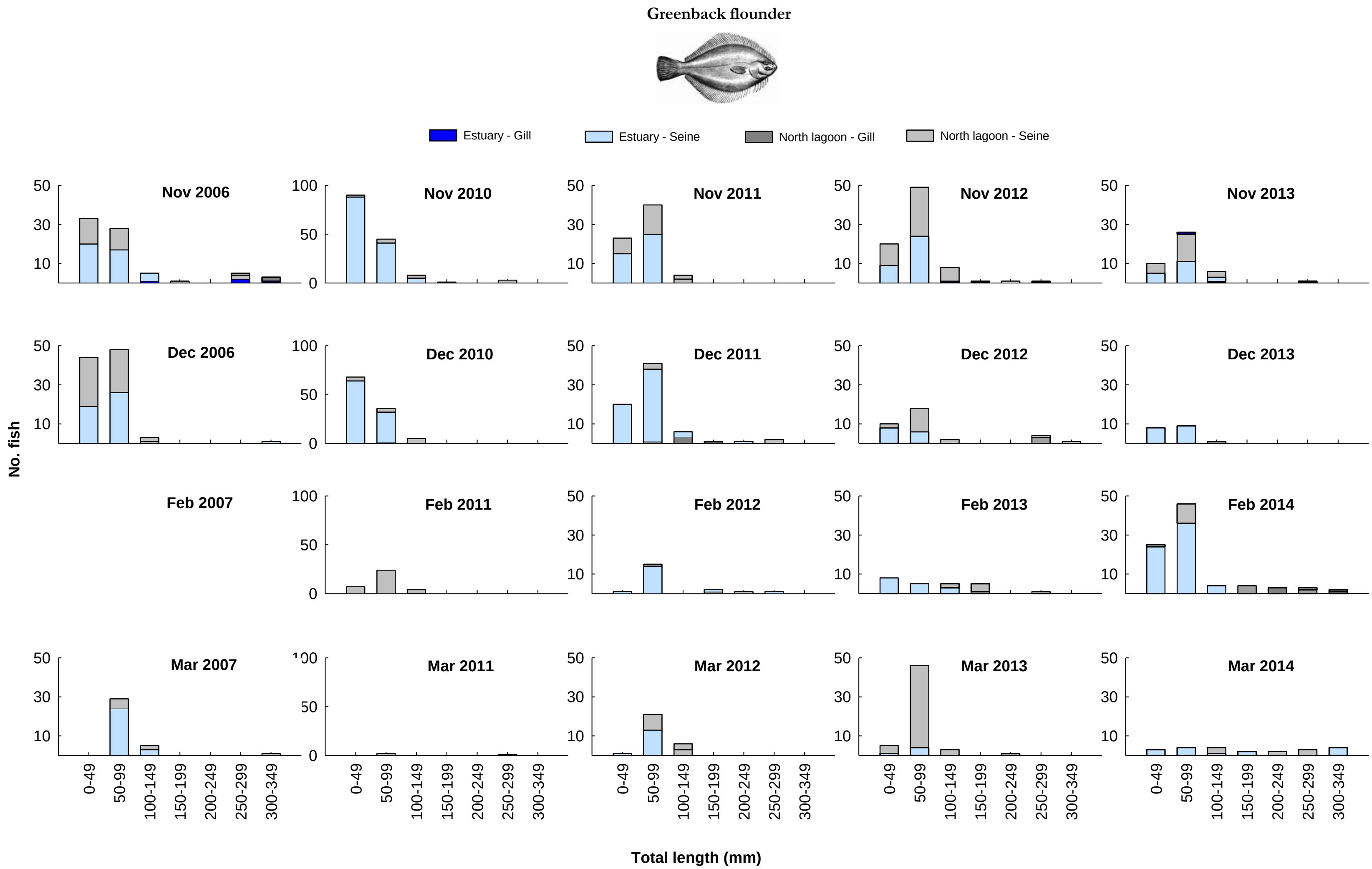

Figure 3.24. Length frequency distributions of juvenile and adult greenback flounder from seine and multipanel gill net samples in the Murray Estuary and North Lagoon of the Coorong in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. Note the scale differences on the y-axis.

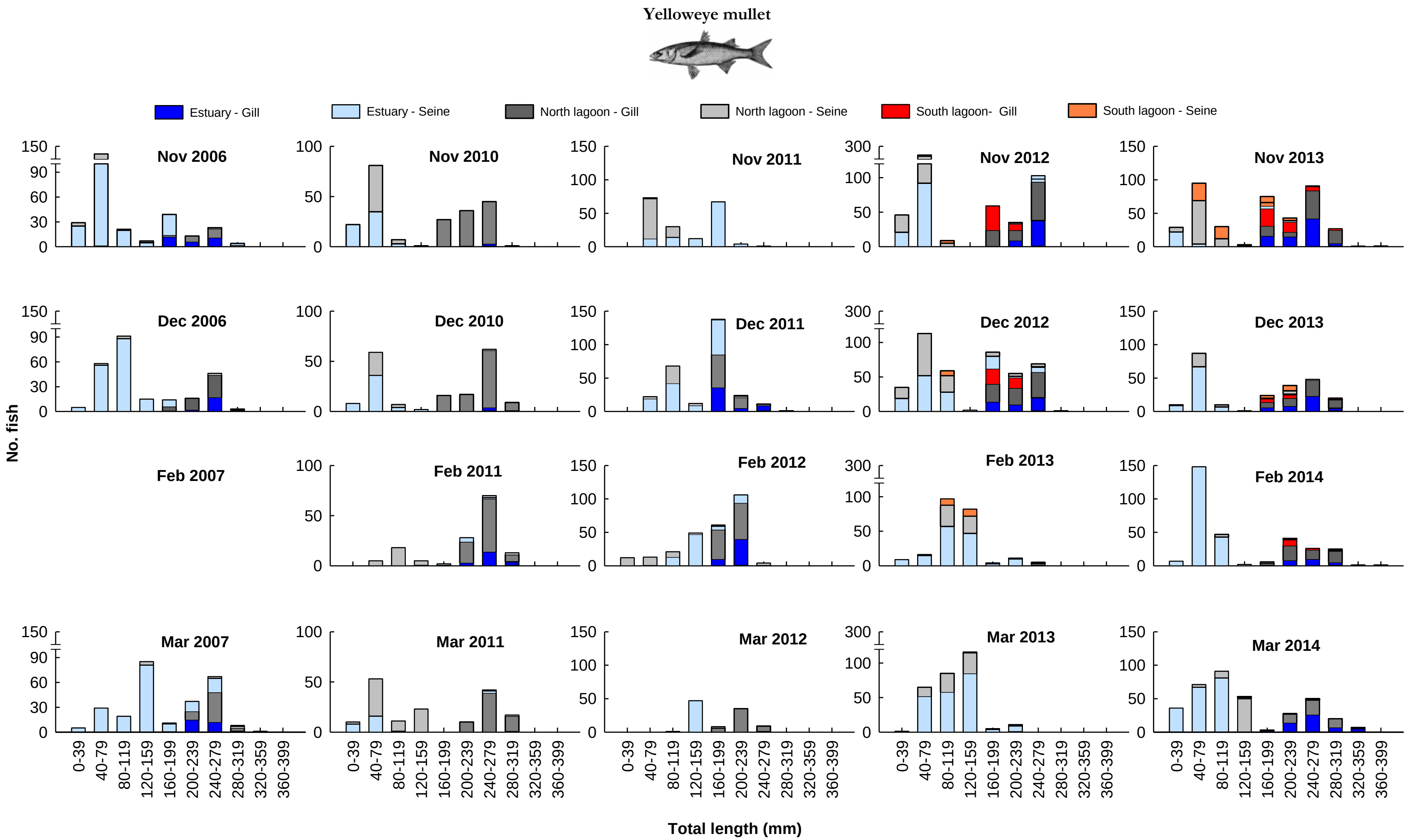

Figure 3.25. Length frequency distributions of juvenile and adult yelloweye mullet from seine and multipanel gill net samples in the Murray Estuary and Coorong lagoons in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. Note the scale differences on the y-axis.

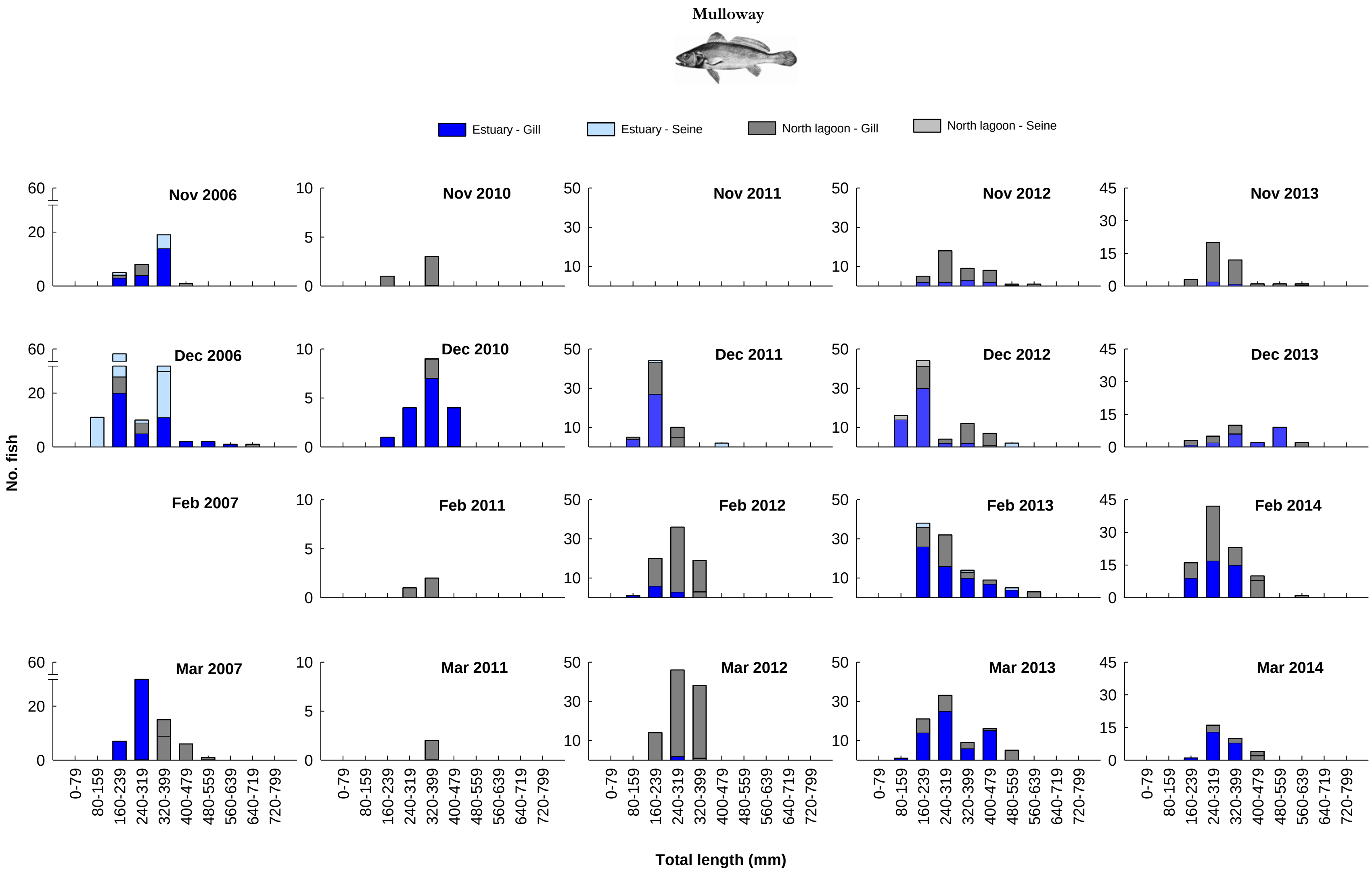

Figure 3.26. Length frequency distributions of juvenile and larger mulloway from seine and multipanel gill net samples in the Estuary and North Lagoon of the Coorong in 2006/07, 2010/11, 2011/12, 2012/13 and 2012/13. Note the scale differences on the y-axis.

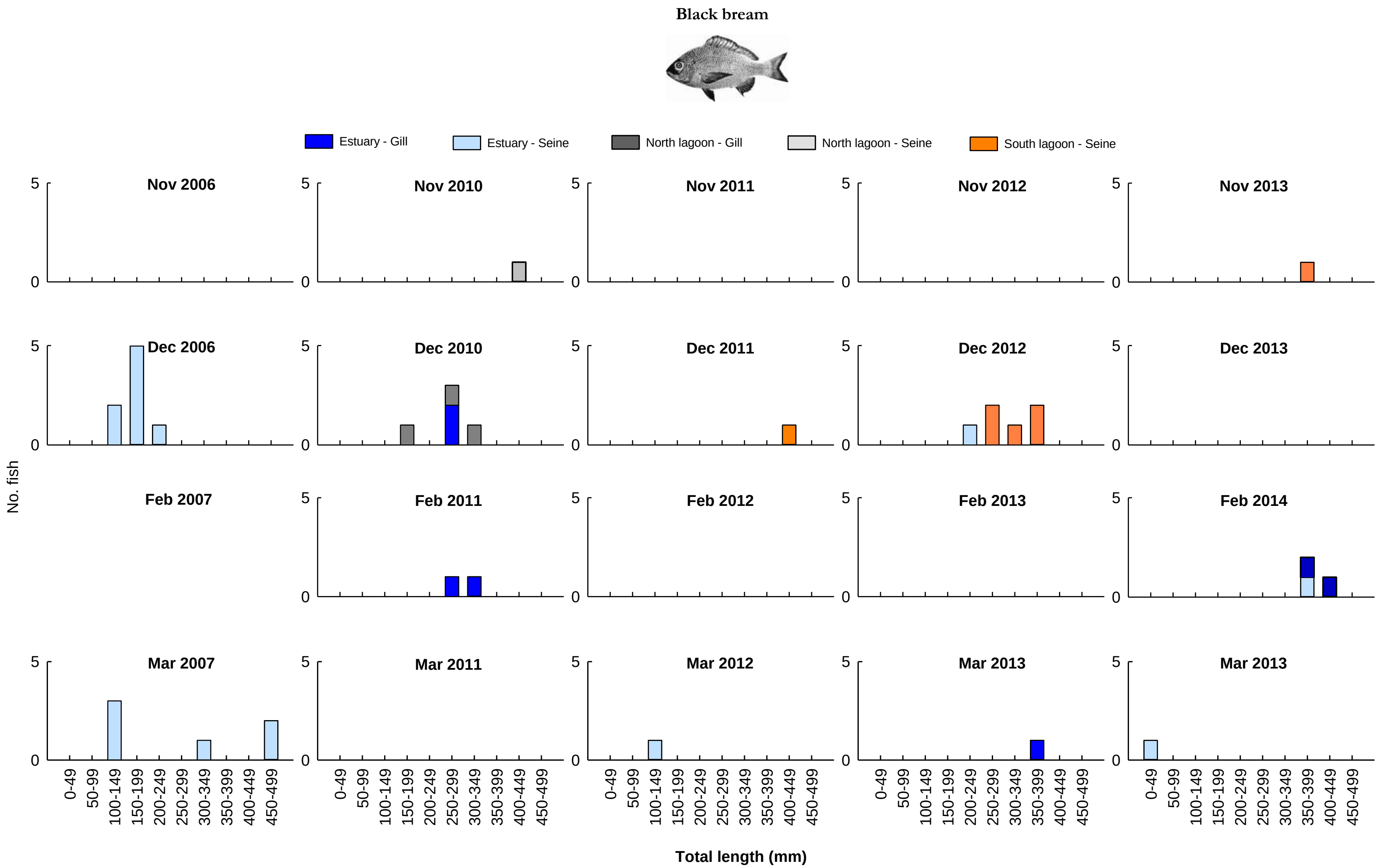

Figure 3.27. Length frequency distributions of juvenile and adult black bream from seine and multipanel gill net samples in the Estuary, North Lagoon and South Lagoon of the Coorong in 2006/07, 2010/11, 2011/12, 2012/13 and 2013/14. Note the scale differences on the y-axis.

4. DISCUSSION

4.1. Barrage flow and salinity (Key question 1a)

The extensive and well documented drought that affected the MDB during 2001–2010 significantly reduced freshwater flows to the Murray Estuary and Coorong. Annual discharge during this period was <1,000 GL y^{-1}, including a period of zero discharge between 2007/08 and 2009/10. One of the most obvious impacts of the drought on water quality in the Coorong was increased salinity. The Estuary subregion remained at typically marine salinities, whilst the entire North Lagoon and South Lagoon reached hypersaline conditions. The drought was broken in 2010 due to high rainfall in the MDB which increased flow in the River Murray, Lower Lakes and the Coorong. During 2010/11 and 2011/12, the high flows into the Coorong continued. Salinities were consequently reduced to levels previously recorded (Geddes and Butler 1984) in each subregion, namely fresh, brackish (<30 psu) and slightly hypersaline (55–70 psu) for the Estuary, North Lagoon and South Lagoon, respectively.

Flows in 2012/13 and 2013/14 were lower than those observed in the previous two flow years. The effects of the reduction in flow on salinity were evident in the Estuary and North Lagoon. This could potentially have resulted from the intrusion of sea water owing to insufficient freshwater flow through the mouth of the River Murray. In the South Lagoon, salinity remained slighter lower than in the previous three years, suggesting that there may be a time lag in salinity response in this subregion due to its distance from the mouth. In addition, the flow releases from Salt Creek likely contributed to refreshing the South Lagoon (Ye *et al.* 2015). Nevertheless, if low River Murray flows into the Coorong continue, salinity in all the subregions is expected to increase, albeit at differential rates.

Transparency was the other important water characteristic that significantly changed with return of freshwater flows to the Coorong in 2010/11. During the drought, transparency was relatively high but, following the onset of barrage releases, was reduced by more than 1 m in 2010/11. The transparency started to revert in the Estuary subregion in 2012/13, reaching approximately the drought levels in 2013/14. Transparency may affect individual species behaviour, predator/prey interactions, as well as the habitat structure and water column productivity – all of which may influence fish communities (e.g. Marais 1988; Griffiths 1996; Gray *et al.* 2012).

Both salinity and transparency were variables strongly associated with changes in fish assemblages in the Coorong. The return of flow to the Coorong caused changes in water conditions that affect fish species. Population level responses of fish to the changes in these two variables seemed to be species specific; some species showed an immediate response whilst others changed over several years (Livore *et al.* 2013). This was exemplified by the iconic diadramous species congolli - which showed significantly enhanced recruitment after three consecutive flow years, highlighting the importance of maintaining connectivity and freshwater flows into the Coorong.

4.2. Fish assemblages, species richness and abundance

4.2.1. *Total species*

Overall, 24 species were recorded from both seine and gill net samples during the monitoring for barrage releases in 2013/14. The total number of species was reduced in comparison to 2012/13 (29 species). This was due to the absence of some freshwater (golden perch and goldfish), estuarine and marine (bridled goby and toadfish) and marine straggler species (sea mullet and southern longfin goby) in 2013/14 samples, associated with shifts in environmental conditions (i.e. freshwater flow reduction and a general increase of salinity in the Estuary and North Lagoon of the Coorong). The total species number in 2013/14 was similar to that during the drought year (2006/07, 26 species), although the presence of species varied. The number of freshwater species remained higher in 2013/14 (five species) than in the drought period (two species), whereas several marine straggler species (e.g. southern eagle ray, western striped grunter and southern garfish) and estuarine and marine species (e.g. toadfishes) sampled in the drought year were absent in 2013/14. Whilst the number of opportunistic species differed slightly over the flood/high flow years, it is significant that the abundances of some of these species increased substantially, especially during 2012/13–2013/14, including species that support important commercial and recreational fisheries like yelloweye mullet, and key prey species for the food web in the Coorong like sandy sprat (Giatas and Ye 2015). Similarly, the two catadromous species, common galaxias and congolli, also showed a more than tenfold increase compared to the drought period, particularly so in the case of congolli, for which the abundance in 2012/13 was a >250 fold increase from 2006/07. Concurrently the six estuarine resident species generally increased abundances in post flood years (2010/11–2013/14) although with some species specific variations. 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 2010–2014, 31 species were sampled by seine netting a total area of ~78,144 m^2 in each year across >100 km. The overall species richness is higher than 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), noting that the total number of fish collected was 4–8 times higher during the post flow study in 2010–2014. Primary contributors to the substantial increases in abundance during the flow years were smallmouthed hardyhead, an estuarine resident species, and sandy sprat, a marine estuarine opportunistic species. These small-bodied, pelagic and planktivorous species are important prey items for piscivorous fishes and birds in the Coorong (Rogers and Paton 2009; Deegan *et al*. 2010; Giatas and Ye 2015). The enhanced abundances of these fish were likely attributed to reduced salinities and increased productivity as a result of freshwater releases to the Coorong. Furthermore, 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. However in the following years, the numbers generally declined and distribution contracted to the Estuary subregion; by 2013/14; only small numbers of freshwater fish were present in the Coorong, with the exception of bony herring. This native freshwater species has a high salinity tolerance to at least 39 psu (Lintermans 2007).

Like previous fish studies in the Coorong, a general decline in species richness and diversity with increasing distance from the Murray Mouth was observed in this study, likely related to a salinity gradient (Geddes 1987; Noell *et al*. 2009). The trend was most distinct in the post flood year (in 2010/11) following substantial barrage releases and increased species and abundance of freshwater fish in the Estuary. Along the 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). The remaining species which tolerate such environmental conditions would have benefitted from broader access to food resources, habitat and space, and expanded their ecological niche (Colburn 1988). However, there was one exception in our study in 2012/13 when the subregion with greatest species richness was the North Lagoon, followed by the Estuary and South Lagoon. This was a consequence of most of the decrease in species richness during the drought year (2006/07) having occurred in the northern part of the North Lagoon. In 2012/13, these same sites in the North Lagoon were the ones that showed the greatest increase in overall species richness within the Coorong. Mean salinities for these sites in 2012/13 ranged between ~20 and ~66 psu, providing a broad range that allows for fish with various salinity tolerances (i.e. catadromous, estuarine resident, estuarine and marine, freshwater and opportunistic species) to successfully exploit the subregion.

Smallmouthed hardyhead, an estuarine species that is tolerant of hypersaline and highly variable salinities (Lui 1969; Noell *et al.* 2009), was the most (or second most) abundant fish in seine net samples in every sampled year. This species comprised ~48% of the total number of fish collected in 2006–2014, and continued to dominate (almost 100% by number) the South Lagoon even after salinities decreased to ~61–77 psu. The prominence 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). Atherinid species are important and often dominant 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).

Sandy sprat was the next most abundant species in years prior to 2012/13 and the most abundant in 2012/13 and 2013/14. This small-bodied clupeid, a marine estuarine opportunist species that regularly enters estuaries in large numbers (Potter and Hyndes 1999; Whitfield 1999), comprised 45% of the catch throughout the study (i.e. 2006–2014). Sandy sprat constituted an increasing proportion of the total catch from 20%, 38%, 49% to 61% in 2010/11, 2011/12, 2012/13 and 2013/14, respectively. This small-bodied pelagic species spawns in inshore waters of marine environments, with larvae and juveniles entering the Coorong and using the estuary as a nursery ground (Rogers and Ward 2007). The substantial increase in sandy sprat abundances in 2010–2014 was probably due to the barrage flows and subsequent enhanced productivity in the Coorong.

The next few most abundant species were the small-bodied estuarine resident species, Tamar goby and Scary's Tasman goby, and estuarine opportunistic yelloweye mullet in 2012/13–2013/14. The goby species continued to show increased abundances compared to the previous years (2006/07–2011/12); importantly, many of these fish were sampled in the North Lagoon. This suggests that the prolonged estuarine conditions favoured the recruitment and re-establishment of these small-bodied estuarine fish in the Coorong. The yelloweye mullet on the other hand is an opportunistic species that has been present in the Coorong in all sampling years in relatively high numbers; however, its abundance in the North and South Lagoons during 2012/13 and 2013/14 noticeably increased.

The two catadromous species present in the Coorong, namely the common galaxias and congolli, showed a similar response. During the drought, these species were virtually absent in the North and South Lagoons, and even in the Estuary their numbers were extremely low. Since flow increased in 2010/11, the abundances of catadromous species have increased, with higher numbers of common galaxias in the Estuary and a more extensive increase of congolli abundance throughout the Estuary and North Lagoon. Congolli was even present in the South Lagoon in 2012/13 and 2013/14. The changes in abundance of the catadromous species are likely related not only to the reduced salinities but also to sustained connectivity of the estuary and the upper reaches of the river through barrage opening and fishway operation. Zampatti *et al.* (2010) found that abundance of young-of-the-year congolli declined drastically with reduced flows, and they suggested that even small flows could enhance recruitment of these species.

Over the last three sampling years, 2011/12–2013/14, freshwater species which were abundant in the flood year (i.e. 2010/11) generally decreased in abundance and distribution in the Coorong. This was expected as estuarine conditions in the Coorong stabilised with consistent lower flows after the flood. 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). However, if flows into the Coorong keep declining, it is likely that the abundance of these fish will decrease. This was evident in the Coorong during the 2006–2008 drought period with little freshwater inflows, when only a few individuals of the native freshwater bony herring and Australian smelt were caught downstream of the barrages, and no other freshwater fish were sampled throughout the study period (Noell *et al.* 2009).

In freshwater environments such as the Lower Lakes and River Murray, freshwater exotic species pose 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 show diet overlap with some large-bodied native fish (i.e. golden perch) (Wedderburn et al. 2014). This species also carries a virus (Epizootic haematopoietic necrosis) that is potentially damaging to native species (Langdon and Humphrey 1987). Carp are known to have effects on turbidity and other water quality parameters that can affect the entire aquatic community (Koehn *et al.* 2000). Although there has been a substantial decrease of freshwater exotic species (e.g. carp and redfin perch) in the Coorong over the last two years, these species remain in the freshwater systems and continue to be a threat to native communities. Control and management of the exotic species is integral for ecological restoration in the MDB.

4.2.3. *Gill net samples*

Complementary gill net sampling, which targeted medium to large-bodied species, was only conducted at five of the thirteen sampling sites. Total catches from gill nets were much lower than seine net catches. The nine species caught using gill nets during 2013/14 were also sampled in the 2010–2013 period, and samples in 2013/14 showed the lowest species richness. For example, seven species, namely freshwater fish (golden perch, goldfish and redfin perch), estuarine opportunistic species (greenback flounder and Australian herring), marine and estuarine species (solder fish) and marine straggler (sea mullet) collected in 2012/13 were not sampled in 2013/14.

The overall abundance of fish was significant higher in the flood/high flow years (2010/11–2013/14) compared to the drought year (2006/07), but noting there has been a general trend of decline since 2011/12. Despite this, yelloweye mullet increased substantially in 2012/13 (almost three times greater than 2011/12) then reduced in 2013/14 to similar level of 2011/12. Noticeably, yelloweye mullet extended its range to the South Lagoon in 2012/13–2013/14, representing >90% of the total catch by gill nets in that subregion. Yelloweye mullet can tolerate salinities up to ~82 psu during summer (McNeil *et al.* 2013), and was sampled in this study in the Coorong with salinities up to 79 psu. Other species present in the South Lagoon were bony herring, goldspot mullet and congolli. These large-bodied species were absent in the South Lagoon during the drought period (Noell *et al.* 2009).

The most abundant species in gill net samples was the freshwater bony herring for three consecutive years after the flood and barrage releases, numerically accounting for 82%, 72% and 53% of the total catch in 2010/11, 2011/12 and 2012/13, respectively. Even with the reduction of freshwater inflows, this species was still ranked as the second most abundant fish in the Coorong (just after yelloweye mullet). Although bony herring is a common freshwater species, they are known to tolerate high salinities (as well as high temperatures, high turbidity and low dissolved oxygen) (Briggs and McDowall 1996;

Lintermans 2007). Nevertheless, their occurrence in the South Lagoon in this study at salinities as high as 78 psu probably represents the upper salinity tolerance for this species, which has been suggested to be at least 39 psu (Lintermans 2007).

Other abundant species in gill net catches included the marine estuarine opportunist yelloweye mullet, Australian salmon and mulloway. These species are also common in several south-western Australian estuaries (Potter and Hyndes 1999). All these species showed an increase in abundance in 2011/12 after two consecutive flow years. In 2012/13 (the third flow year), the changes in abundance varied between species (i.e. maintained for mulloway, increased for yelloweye mullet but decreased for Australian salmon), whereas there was a considerable decline for all three species in 2013/14, associated with further reduced freshwater flows. For both Australian salmon and yelloweye mullet, there seemed to be a shift of abundance from the Estuary to the North Lagoon in 2010/11 (the first high flow year), followed by an increase in numbers in the Estuary during 2011/12 (the second flow year). This may reflect the short-term flow disturbance in the Estuary followed by a return of suitable conditions for these species. In contrast, mulloway abundance significantly reduced in 2010/11 in both Estuary and North Lagoon subregions, possibly due to the extremely high flows. This was followed by a significant increase in 2011/12, particularly in the North Lagoon (with 84% of the catch). In 2012/13 and 2013/14, there appeared to be a shift of the distribution of the mulloway catch towards the Estuary (>55% of the total catch), potentially due to the contraction of available habitat as a result of continued reduction in flow and elevated salinities in the North Lagoon.

For gill net samples, the increase in species richness from drought to flow years was most apparent in the North Lagoon and South Lagoon. In the North Lagoon, this was accompanied by salinity changes at Noonameena (middle of the North Lagoon) where values reduced from ~73 psu in 2006/07 to ~37 psu in 2010–2014. Similarly, in the South Lagoon, species richness increased in 2012/13 and 2013/14 when average salinities reduced to <79 psu, whereas no gill net catch was recorded in 2006/07 with average salinities of >127 psu. The total abundance of fish in gill net catches increased in the North Lagoon during 2010/11 and throughout the Estuary and North Lagoon during 2011/12, but generally decreased in 2012/13, followed by a further substantial decline in 2013/14. Not surprisingly, the primary contributors to these changes were the most abundant freshwater species (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 (Key question 3)

Following barrage releases in 2010–2014, fish assemblage structure changed significantly compared to the drought year (i.e. 2006/07) in the Murray Estuary and Coorong. There was a general shift from marine/estuarine to freshwater/estuarine species assemblages, particularly in the Estuary and North Lagoon subregions. However, the reduction in salinity in the South Lagoon did not immediately affect the assemblage in this subregion. It was only in 2012/13 and 2013/14, two to three years after the return of flows to the Coorong, when a noticeable increase in species richness was observed in this subregion.

Some species seemed to respond more rapidly to the barrage releases and the decrease in salinity. For example, the abundance of freshwater species (bony herring, redfin perch, Australian smelt, flatheaded gudgeon and carp) increased rapidly and substantially, particularly in the Estuary subregion, during 2010/11 (the first year with significant freshwater flows). Similarly, in the same year, several small-bodied estuarine species (Tamar goby and Scary's Tasman goby), estuarine opportunists (sandy sprat) and catadromous species (congolli) showed increased abundances in the Estuary and smallmouth hardyhead in the North Lagoon through enhanced recruitment. Notably, the increases in the North Lagoon for the small-bodied estuarine species (gobies), opportunistic species (sandy sprat) and congolli only became apparent after 2011/12, contributing to the further shift in assemblage structure in this subregion. 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 estuarine opportunistic species (i.e. mulloway, yelloweye mullet and Australian salmon), the abundance reduction in the Estuary in 2010/11 also contributed to the distinct difference in assemblage structure compared to the drought and other flow years. This suggests that the major flood in 2010/11 may have created a short-term disturbance to 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 2011/12 and 2012/13 (i.e. the second and third flow years), and a subsequent reduction in 2013/14 (the fourth year) when freshwater flow decreased substantially.

Despite the lower barrage releases in 2013/14 (~1,000 GL y^{-1}), fish assemblage structure remained relatively similar to the previous year (2012/13) across all subregions in the Coorong, and continued to be distinctly different from the drought year (2006/07). However, from 2012/13 to 2013/14, several estuarine opportunistic and resident species (sandy sprat, yelloweye mullet and gobies) showed decreases in abundance in the North Lagoon but increases in the Estuary. These changes, in addition to the overall decrease in freshwater fish and increase in abundance of smallmouthed hardyhead (the most salt tolerant species), suggest that elevated salinities as a result of reduced flows to the Coorong had impacted on a number of species, leading to contraction of favourable estuarine habitat toward the Estuary subregion. If the freshwater flows continue to decline, the fish assemblage structure will eventually resemble that of the drought period.

Overall, this study demonstrated a marked shift in assemblage structure after the high flow event in 2010/11 from marine estuarine opportunists to freshwater species dominant as would be expected during a major flood event. After this, a gradual reduction of freshwater species abundance as well as an increase in abundance of estuarine resident, estuarine opportunistic and catadromous species occurred. In the last three years (i.e. 2011/12–2013/14) the changes in fish assemblages were moderate. The current composition of species in the Coorong seems to be more closely related to what is typically found in estuaries in other parts of the world, where fish communities are dominated by estuarine species with a smaller contribution from marine and freshwater species; albeit owing to the the dynamic nature of estuarine systems, they often result in high species richness (Potter and Hyndes 1999; Whitfield *et al.* 2006).

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.* 2012; Livore et *al.* 2013; Ye *et al.* 2015). 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 life history processes such as spawning, nursery and protection, food availability and recruitment (Drinkwater and Frank 1994; Gillanders and Kingsford 2002).

In this study, salinity and transparency were identified as the main drivers influencing spatio-temporal patterns of fish assemblage structure in the Coorong. 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).

In addition to salinity, water transparency also showed a significant effect on fish assemblages in this 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 and 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 through trophic links. Many studies have 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 of fish, which can determine recruitment success, are particularly vulnerable to low oxygen (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 co-vary with DO and moderate or intensify the effects of oxygen depletion (Rose *et al.* 2009).

4.4. Temporal changes in distribution, abundance, and recruitment of key species (Key question 1b and 2)

Following the barrage releases and substantial salinity reductions in the Coorong during 2010/11–2013/14, a number of freshwater species and all the key estuarine, opportunistic and catadromous species showed a southward range extension, with several species expanding their distribution into the South Lagoon (black bream, yelloweye mullet, congolli, Scary's Tasman goby and bony herring). These species were sampled for the first time in the South Lagoon in this study after two to three consecutive flow years (in 2011/12 and 2012/13) and most of them remained present with an additional species, goldspot mullet, caught in this subregion in 2013/14. Similarly, a previous study in 1983/84 found a number of large-bodied fish (e.g. black bream, yelloweye mullet and congolli) in the northern part of the South Lagoon, when salinities reduced to 55 psu following above average barrage flows (Geddes 1987). Conversely, during the extended drought period, no fish or only a single species, smallmouthed hardyhead, was found in low numbers in the South Lagoon of the Coorong (Noell *et al.* 2009; Ye *et al.* 2011c, d). In 2013/14, all key species generally maintained the ranges observed in the Coorong in 2012/13 except for Tamar goby and congolli, which started to show northward contractions in distribution. This was expected given the reduced freshwater inflows and a general increase in salinity in the Estuary and North Lagoon.

4.4.1. *Freshwater native and exotic species*

For freshwater species, bony herring (native fish) had a substantial increase in abundance and extended its distribution into the southern end of the North Lagoon in 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 range was maintained throughout the Estuary and North Lagoon (Goolwa to Hells Gate). Bony herring, although a freshwater species, can tolerate higher salinities and is often caught in brackish water as was the case in this study. In 2012/13, bony herring distribution range extended to the South Lagoon with salinities of 76–79 psu, whereas in 2013/14, the range appeared to reduce to the northern part of the South Lagoon despite slightly lower salinities (61–77 psu) in this subregion. This may be related to their further reduced abundance in the southern part of the Coorong. Furthermore, salinities in the South Lagoon clearly represented extreme levels of the tolerance range of this freshwater fish despite their strong ability of salinity tolerance (up to 39 psu) (Lintermans 2007). In contrast, 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. This trend continued throughout 2012/13 and 2013/14, when they were only found in the Estuary in decreased numbers compared to the flood year (2010/11). Exotic freshwater species are less tolerant of high salinities compared to Australian native species of marine origin.

4.4.2. *Small-bodied estuarine and opportunist species*

Several small-bodied estuarine/opportunist species (e.g. smallmouthed hardyhead, Scary's Tasman goby, Tamar goby and sandy sprat) and the catadromous congolli showed a strong recruitment response to the high flows since 2010/11 and subsequently their abundances increased in the Coorong, with many new recruits occurring in the North Lagoon. In 2012/13, this pattern was markedly increased for sandy sprat, congolli, Scary's Tasman goby and Tamar goby. In the following year (2013/14), the abundance of these species generally maintained (congolli and Scary's Tasman goby) or further increased (sandy sprat and Tamar goby), suggesting ongoing recruitment success. However, all species except congolli seemed to show a spatial shift with increasing dominance of abundance in the Estuary, likely due to increased salinities in the North Lagoon after flow reductions. Smallmouthed hardyhead showed a substantial increase in abundance and distribution following the flood and high flows, although the pattern varied between years. The increase of this species was exponential in the South Lagoon after salinities reduced from 105–168 psu in 2006/07 to below 100 psu since 2010/11. 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 (Ye *et al.* 2015). Importantly, the presence of many fish <30 mm TL in this subregion in all flow years suggested recruitment success. Smallmouthed hardyhead continued to be broadly distributed and highly abundant in the North and South lagoons over the last three flow years. Such responses by this keystone species has high ecological significance, as smallmouthed hardyhead provide important food source for various piscivorous fish and water birds, particularly in the North Lagoon and South Lagoon of the Coorong (Paton 1982; Rogers and Paton 2009; Deegan *et al.* 2010; Giatas and Ye 2015). Noticeably, in 2012/13 and 2013/14, the third and fourth year since the return of flows, sandy sprat overtook smallmouthed hardyhead, becoming the most dominant species in numbers. Sandy sprat is another key prey item for inshore pelagic fishes and small coastal seabirds (Hoedt and Dimmlich 1994; Hoedt *et al.* 1995; Giatas and Ye 2015).

4.4.3. *Catadromous species*

For the catadromous species congolli, an increase in abundance, distribution and recruitment after the restoration of connectivity and increased freshwater inflows to the Coorong were well illustrated in this study. 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 (Ye *et al.* 2012). The remarkably increased abundance and distribution of juvenile fish, as indicated by size composition of samples, in 2012/13 clearly showed a strong recruitment in the Estuary and North Lagoon. The 2012/13 cohort was much stronger than any previously recorded for the Coorong over the studied period. 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 (i.e. salinities, productivity) (Zampatti *et al.* 2010). This probably explains the decreased abundance of juveniles in the Estuary with reduced barrage releases in 2013/14. 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). The recording of the strongest cohort after three consecutive flow years (in 2012/13) for both catadromous species supports the notion that connectivity is needed and should be maintained through time as it was after three continuous flow years that a substantial increase in abundances through recruitment success was observed.

4.4.4. *Large-bodied estuarine and marine opportunist species*

Of the large-bodied estuarine opportunistic species, yelloweye mullet showed a general decline in abundance (both juveniles and adults) in the Estuary, likely due to disturbance by extremely high flows, but an increase in the North Lagoon following the barrage releases in 2010/11. Although there appeared to be a slight recovery in adult abundance in the Estuary during 2011/12 (the second flow year), the greatest increase occurred in 2012/13 with a strong new cohort recorded in both the Estuary and North Lagoon, along with a larger size cohort that was present across the three subregions. In 2013/14, the abundance further increased in the Estuary whilst decreased in the North Lagoon although this species remained broadly distributed across three subregions. Yelloweye mullet have a relatively high salinity tolerance (i.e. laboratory estimates of 50% lethal concentration (LC_{50}) range between 82–91 psu; McNeil *et al.* 2013). They can move southward to explore more saline environments, particularly in the North Lagoon and South Lagoon, where salinities reduced significantly after the continuous flow years (e.g. salinities in the South Lagoon ranging 61–77 psu in 2013/14).

For mulloway, another estuarine opportunistic species, although gill net samples indicated a much lower catch throughout the Coorong in 2010/11 compared to 2006/07, the overall abundance increased after consecutive flow years (2011/12–2013/14). The reduction in catch of mulloway in 2010/11 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 may have occurred too early to detect a flow related recruitment response in mulloway during 2010/11, or the very high flows might have reduced their catchability. This was confirmed by the presence of a 1+ year old cohort of juvenile mulloway in 2011/12 (Ye *et al.* 2012), which originated from successful recruitment in 2010/11. This cohort was still evident in 2012/13 and 2013/14 as 2+ and 3+

year olds, respectively (SARDI unpublished data). Similarly, new recruits were detected in the Coorong for 2011/12 and 2012/13 year classes as 1+ year old fish in the following year after spawning (SARDI unpublished data). The successful recruitment after flow years contributed to the improved catch of mulloway, being most distinct in 2011/12 and 2012/13; this was likely attributable to the greater flow discharges in 2010/11 and 2011/12 compared to the following two years (2012/13 and 2013/14). 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 responded positively to the barrage releases during 2010–2014 by extending their nursery grounds into the southern part of the North Lagoon (to Hells Gate after 2011/12), as evident by the increased range of juveniles. Although the relative abundance of juveniles showed a general decline in the Coorong, this at least partially related to their dispersion throughout a much broader habitat. Targeted investigation on greenback flounder populations during fish condition monitoring indicated increased numbers of juveniles at specific sites (e.g. Mark Point, Noonameena) in the North Lagoon after flow resumption in the Coorong (Ye *et al.* 2015). 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 fertilization rates occurring between 35–45 psu and egg tolerance range of 14–45 psu after fertilization (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 ~77 and 128 psu respectively) as a favourable 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 2010–2013 restored a more favourable salinity gradient, and probably increased habitat quality and availability for greenback flounder throughout most of the North Lagoon (average salinities 40–45 psu), which likely benefited spawning and recruitment. During 2013/14, distribution of juvenile greenback flounder maintained as observed in previous flow years; although juvenile abundance showed a general decline in the North Lagoon, they increased in the Estuary, suggesting enhanced recruitment. Increased fishery catch and proportional catch from the North Lagoon also suggested that this species was highly responsive to flow releases to the Murray Estuary and Coorong and was showing positive signs of recovery (Ye *et al.* 2015).

Large-bodied estuarine resident species

Many estuarine associated species had positive responses to the barrage releases in 2010–2014. However black bream, an iconic large-bodied estuarine resident species showed little signs of a population recovery. The relative abundance of black bream remained low in the Coorong for both adults and juveniles. Whilst salinity reductions throughout the Coorong have allowed adult black bream to recolonise the North and South lagoons, the numbers were low and very few juveniles were collected between 2010/11 and 2013/14, suggesting the population of black bream has not yet successfully recovered. This was consistent with the findings of black bream condition monitoring in the Coorong (Ye *et al.* 2015).

Overall, a number of 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 studies indicated that population abundances of black bream and greenback flounder had declined significantly, particularly during the decadal drought (2001–2010) (Ye *et al.* 2015). Their relative abundances were at historical lows in 2008/09–2010/11. 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 (Earl 2014). 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 2010–2013. This emphasizes the importance of freshwater flows, habitat rehabilitation and fishery management in restoring and improving large-bodied fish populations in the Murray Estuary and Coorong.

Given the uncertainty in population trajectory for some of these large-bodied long-lived species (black bream) and the observed general reduction in abundance associated with reduced flows in 2013/14, monitoring will be required in subsequent years to continue to investigate the recruitment response and population recovery in these commercially and ecologically important species and the requirement of freshwater inflows to maintain/rebuild population resilience of these species in the Coorong. Further investigation is required to understand the dynamic movement patterns of the estuarine and marine and 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

5.1. Project summary

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 2010/11–2013/14, salinities were reduced significantly from marine to extremely hypersaline (up to ~170 psu) to the current levels of 9–30 psu in the Estuary, 31–69 psu in the North Lagoon, and 61–77 psu in the South Lagoon. Broadly decreased salinities, coupled with other freshwater induced environmental changes (e.g. transparency, dissolved oxygen, productivity), elicited significant ecological responses in fish assemblages in the region. The fish assemblage composition changed significantly compared to that of the drought years, mainly due to increased diversity and abundances of freshwater species, as well as small-bodied estuarine resident and opportunistic species (smallmouthed hardyhead, Tamar goby and sandy sprat), catadromous species (congolli) and some large-bodied estuarine opportunists (yelloweye mullet) through enhanced recruitment. Changes in fish assemblages continued in response to ongoing but reduced freshwater releases in 2013/14 (i.e. the fourth year) although the assemblage structure remained different from that of the drought period. Comparing to 2012/13, the abundance of freshwater fish (bony herring) continued to decline throughout the region in 2013/14, and there was a general increase in estuarine and opportunistic species (e.g. smallmouthed hardyhead, Tamar goby, sandy sprat, yelloweye mullet, mulloway) in the Estuary but a decrease in some of these species (e.g. sandy sprat, yelloweye mullet) and catadromous congolli in the North Lagoon. This was likely attributed to the elevated salinities in the Estuary and North Lagoon as a result of reduced flows in 2013/14. In the South Lagoon, salinities remained lower (61–77 psu) in 2013/14 than in the previous year (2012/13) (76–79 psu), probably reflecting a time lag in the influence of the Murray flow to this subregion and localised effect on salinities by inflows from Salt Creek.

The freshening of the Coorong also resulted in a southward range expansion for all key species, including black bream, yelloweye mullet, congolli, Scary's Tasman goby, bony herring, greenback flounder, Tamar goby and sandy sprat. Remarkably, a number of these species were present in the South Lagoon, along with smallmouthed hardyhead, after consecutive flow years (2011/12–2013/14). However in 2013/14, some species (Tamar goby and congolli) started to show a northward contraction, likely due to reduced freshwater inflows to the Coorong. Length frequency distributions indicate recruitment success at different levels in all key species (except for black bream) during 2010–2014. Some species (for example, catadromous congolli and the large-bodied opportunistic yelloweye mullet) showed significantly improved recruitment in 2012/13 and 2013/14 compared to the first two flow years (2010/11–2011/12). This highlights the importance of sustained estuarine conditions and maintenance of connectivity (freshwater-estuarine-marine systems). In the current study, many of these 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. Sandy sprat also showed a consistent increase in abundance since the barrage releases that led to a 10 times increase in 2012/13 and 25 times in 2013/14 compared to the drought year. Such responses are of particular ecological significance, given the important role of these prey species in the trophic ecology of the ecosystem in the Coorong.

Overall, the monitoring for barrage releases in 2010–2014 following years of minimal freshwater inflows into the Murray Estuary and Coorong demonstrated changes in estuarine fish assemblages. The dynamic response in the fish assemblage was attributable to a species-specific response to freshwater flows and subsequent changes in environmental conditions. Species with diverse life history strategies respond differently and at different time scales to freshwater flows. This variation causes fish assemblages in this estuarine environment to change accordingly. Further targeted research is required to determine the mechanisms involved in these responses, and how they are linked to flow regimes (e.g. magnitude, timing and duration) and other environmental conditions needed for the maintenance of a healthy fish community and resilient populations. In addition to freshwater flow, other factors that require attention in order to elucidate ecosystem function in the Coorong may include critical habitat requirements and food resources that contribute to recruitment success for key estuarine fish species. Given the uncertainty in the population trajectory for some large-bodied estuarine dependent species (black bream and mulloway), and the observed general reduction in abundance associated with reduced flows in 2013/14, long-term monitoring will be required to continue to investigate the biological performance of these commercially and ecologically important species and evaluate potential benefits of freshwater inflows to the Coorong for these fishes. Knowledge of flow related fish ecology specific to this region is critical to underpin the conservation and sustainable management of fish populations in this iconic freshwater-deprived estuarine system.

5.2. Summary responses to key questions

The following points are provided to address the key questions with reference to "fish response monitoring in the Coorong in 2013/14" (Appendix I):

- In the Estuary and North Lagoon, salinity continued to increase after 2012/13 with the average level of 2013/14 being the highest since 2010/11. In contrast, salinity in the South Lagoon reduced further in 2013/14, being the lowest since 2010/11. Regardless, a north-to-south increasing salinity gradient was maintained (9–77 psu) in this region with salinities being well below that observed during the drought period (31–129 psu).
- Recruitment for most species (diadromous and estuarine fish) that were seen to recruit in 2011–2013 continued in 2013/14, although some species (e.g. sandy sprat, yelloweye mullet, Tamar goby, greenback flounder) showed an increased dominance of juvenile abundance in the Estuary in contrast to the North Lagoon.
  - The recruitment of sandy sprat further increased in 2013/14 and the numbers more than doubled compared to 2012/13. The abundance in 2013/14 was 25 times higher than in the drought period.
  - Yelloweye mullet showed an overall increase in recruitment in 2013/14, with an increase of juvenile numbers in the Estuary but a decrease in the North Lagoon compared to 2012/13.
  - Enhanced recruitment in diadromous species was particularly significant in 2012/13, with substantially increased abundance of juvenile congolli sampled in the Estuary and North Lagoon. The level of juvenile abundance in 2013/14 was comparable the previous year's in the North Lagoon although there was a noticeable reduction in the Estuary to a similar level of 2010/11's. This was probably due to the effect of flow reduction in 2013/14.
- Most key species were able to maintain their distribution ranges as observed in 2012/13, although some species (e.g. Tamar goby and congollis) started to show a range reduction toward north. The continued presence of multi-species in the South Lagoon was significant, including species sampled in 2012/13 (black bream, yelloweye mullet, congolli, bony herring and smallmouthed hardyhead) and an addition estuarine and marine species (goldspot mullet).

- The non-native freshwater species, carp and redfin perch, further declined with a patchy distribution confined within the Estuary subregion.
- The fish assemblage structure differed significantly across differing flow scenarios (drought versus flood/high flows). In general, the assemblage structure observed in 2013/14 were relatively more similar to those observed in 2012/13, whilst they were vastly different to those present in the drought years.

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APPENDIX I. KEY QUESTIONS AND PREDICTIONS FOR FISH RESPONSE MONITORING IN THE COORONG

Key Questions	Predictions
1. Are there indications of continued system recovery in 2013-2014 following the significant flows of 2010-2011 and further flows in 2011-2013, when a recovery was first documented?	
a) Will environmental conditions within the Murray Mouth reflect true estuarine conditions and have they further improved in the North and South Lagoons since flows recommenced in 2010?	- Salinity in the Murray Mouth in 2013-2014 will not be reduced as significantly as observed in 2010-2011 - Salinity in the North and South Lagoons will be maintained at levels lower than those measured from 2008-2011.
b) Have fish species shown signs of recruitment in 2013/14?	- Diadromous and estuarine fish seen to recruit in 2011-2013 will continue to recruit in 2013-14; - Additional species will show recruitment events in 2013-14.
2. Will species be able to maintain any range increases observed in 2012-13?	- Fish populations will maintain or improve the ranges observed in the Coorong in 2012-13.
3. Are there similarities or differences in the community structure of fish across differing flow scenarios (drought/flood)? - How do 2013-2014 fish populations compare to previous monitoring?	- Changes in the fish assemblages will be observed in relation to differing flows i.e. drought and flood periods.
4. Has the collection and analysis of otoliths from key species (Black Bream, Greenback flounder, etc) been able to determine age structures? *	- Age structures will indicate assemblages >5 years, due to lack of recruitment in the Coorong until 2012/13.
5. Are trends in abundance and distribution of selected species (e.g. Mulloway and Australian Salmon) in relation to prey availability? *	

**questions to be addressed in the 2014/15 final report*