Inland Waters & Catchment Ecology

SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

Fish response to flows in the Coorong during 2012/13

Juan P. Livore, Qifeng Ye, Luciana Bucater and David Short

SARDI Publication No. F2013/000486-1
SARDI Research Report Series No. 732

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

September 2013

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Fish response to flows in the Coorong during 2012/13

Juan P. Livore, Qifeng Ye, Luciana Bucater and David Short

SARDI Publication No. F2013/000486-1
SARDI Research Report Series No. 732

September 2013

This Publication may be cited as:
Livore, J.P., Ye, Q., Bucater, L. and Short, D. (2013). Fish response to flow in the Coorong during 2012/13. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000486-1. SARDI Research Report Series No. 732. 80pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

Printed in Adelaide: September 2013

SARDI Publication No. F2013/000486-1
SARDI Research Report Series No. 732

Author(s): Juan P. Livore, Qifeng Ye, Luciana Bucater and David Short

Reviewer(s): Jason Earl (SARDI), Adam Watt (DEWNR)

Approved by: Dr. Stephen Mayfield
Principal Scientist – Fisheries

Signed: 

Date: 18 September 2013

Distribution: DEWNR, Murray-Darling Basin Authority, SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library

Circulation: Public Domain

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

This project is part of the South Australian Government's Murray Futures program, funded by the South Australian Government's *Water for the Future* initiative, and supported by the *Living Murray* program. The *Living Murray* is a joint initiative funded by the New South Wales, South Australian, ACT and Commonwealth governments, coordinated by the Murray-Darling Basin Authority. The authors would like to thank Neil Wellman, Jason Earl, Hanru Wang, David Fleer, Arron Strawbridge and Greg Ferguson (SARDI) for assistance with fieldwork and/or laboratory analyses. Thanks to Maylene Loo (SARDI) for assistance with statistical analysis. Also thanks to Rebecca Quin, Adam Watt, Adrienne Frears, Sorell Lock, Ann-Marie Jolly and Alec Rolston (DEWNR) for support and management of this project. Finally, thanks to Rebecca Quin (DEWNR), Adam Watt (DEWNR) and Jason Earl (SARDI) for reviewing and commenting on this report. This report was approved for release by Dr Stephen Mayfield (SARDI).

EXECUTIVE SUMMARY

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region is recognised as a wetland of ecological importance under the Ramsar convention and an 'Icon Site' under the Murray-Darling Basin Authority's Living Murray program. From 2001 to 2010, the Coorong ecosystem was severely impacted due to an extended drought in the Murray-Darling Basin (MDB). The lack of freshwater inflows, increases in salinity, and loss of connectivity between freshwater and estuarine/marine habitats degraded ecologically important habitats and communities. Populations of native fish species that reside in the Coorong estuary and depend upon its habitat as a breeding, nursery and feeding area were severely affected by the drought conditions. In 2010/11, increased flows in the River Murray led to significant barrage releases (~13,000 GL y^{-1}) into the Coorong. Broadly decreased salinities in the Coorong, coupled with other freshwater induced environment changes, led to significant ecological responses in fish assemblages in the region. These included increased diversity and abundance of freshwater species; enhanced recruitment and subsequent abundances of small-bodied estuarine/opportunist species (smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (congolli); and a southward range expansion for several key species, such as black bream, yelloweye mullet, congolli, greenback flounder, Tamar goby and sandy sprat (Ye *et al.* 2012a). Ongoing flow conditions and barrage releases in 2012/13 provided the opportunity to continue investigating the responses of estuarine fish assemblages and their recovery. The monitoring undertaken in this study augments the data collected during 2010/11 and 2011/12 and was compared against fish baseline information collected during the severe drought in 2006/07 (Noell *et al.* 2009).

Barrage releases in 2012/13 were lower than in the previous two years (i.e. 2010/11 and 2011/12) with an inflow of ~4500 GL. During the sampling period, November 2012-March 2013, flows decreased from ~182 to ~63 GL per month. The salinities in the Coorong were higher, particularly in the Estuary subregion, and to a lesser extent in the North Lagoon when compared to 2011/12. During 2011/12, salinities in the Estuary and North Lagoon ranged between 0-14 psu and 11-71 psu, respectively, whilst in 2012/13 they ranged between 7-21 psu and 20-76 psu. Contrastingly, in the South Lagoon salinities decreased from a range of 86-94 psu in 2011/12 to 76-79 psu in 2012/13.

In comparison with 2010/11 and 2011/12, freshwater species continued to be present in the Coorong region, although abundance generally declined and ranges contracted mainly to the Estuary subregion, except for bony herring which extended its range into the South Lagoon. Furthermore, fish assemblage structure (seine net catch) changed in the three subregions during 2012/13 due to the greater abundances of estuarine opportunistic species (i.e. yelloweye mullet and mulloway) and catadromous species (congolli and common galaxias) in the Estuary and North Lagoon. The South Lagoon

experienced a noticeable increase in species richness with the presence for the first time since the drought of congolli, Scary's Tasman goby and bony herring in 2012/13. Concurrently black bream and yelloweye mullet maintained their presence in the subregion. For large-bodied species (gill net catch), increased abundances of yelloweye mullet and mulloway along with a decrease in bony herring and carp were the key drivers for the inter-annual differences (i.e. 2010/11-2012/13) in fish assemblage in the Estuary and North Lagoon.

Distribution ranges during 2012/13 of most key species in the Coorong remained similar to those observed in 2011/12, with the exception of congolli, Scary's Tasman goby and bony herring, all of which extended their range into the South Lagoon. Diadromous fish continued to recruit in 2012/13; importantly the recruitment success of congolli was conspicuous. The ongoing connectivity between freshwater-estuary-marine systems and prolonged (i.e. >3 years) estuarine condition in the Estuary and North Lagoon subregions, which provide suitable nursery grounds for many fish species may be associated with the successful recruitments observed.

The positive responses in fish assemblages following the significant flows of 2010/11, and further flows in 2011/12 and 2012/13 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 to the Coorong; 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. However, it is of concern that black bream, an iconic estuarine resident species, showed little signs of population recovery in the Coorong after three years of flows. Further monitoring will be required in subsequent years to continue to investigate the biological performance of these commercially and ecologically important species to evaluate the effects and potential benefits of prolonged freshwater inflows on these species in the Coorong. 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, including flow regimes, critical habitat and food resources that contribute to recruitment success for key estuarine fish species. In addition, the dynamic movement patterns need to be investigated for estuarine and marine/estuarine opportunistic species within the Coorong and between the Coorong, freshwater and marine environments under different flow conditions. Such knowledge will improve the conceptual understanding of the population dynamics of key species in the Coorong and facilitate the development of well-informed ecologically sustainable management strategies for estuarine fish populations in the

Coorong. 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 is recognised internationally as a Ramsar-listed wetland, providing an important breeding and feeding ground for waterbirds, and supporting significant populations of several species of fish and invertebrates (Phillips and Muller 2006). The region is classified as an 'icon site' under the Murray-Darling Basin Authority's Living Murray program, based upon its unique ecological qualities, hydrological significance, economic and cultural values (Murray-Darling Basin Commission 2006).

The Coorong is a long (~110 km) and narrow (<4 km wide) estuarine lagoon system with a strong north-south salinity gradient, generally ranging from brackish/marine in the Murray Mouth area to hypersaline in the North and South Lagoons (Geddes and Bulter 1984; Geddes 1987). 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 (~7 GL y^{-1}) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek.

As the terminal system of the Murray-Darling Basin (MDB), the Coorong region has been heavily impacted by river regulation and water extraction since European settlement. The average annual flow at the Murray Mouth has declined by 61% (from 12333 GL y^{-1} in1895 to 4733 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. In recent years, this situation has been exacerbated by severe drought in the Basin, with very low or no flow releases through barrages between 2002 and 2009 (DFW 2010). Subsequently, the Murray Mouth was closed due to siltation, requiring a dredging operation to maintain its opening since 2002 (DWLBC 2008). 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 nationally 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 reside 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).

Since the commencement of freshwater inflows to the estuary in spring 2010 and the re-established connectivity between the major regions of the CLLMM with the opening of the barrages, fish monitoring has been conducted as part of the CLLMM Monitoring and Adaptive Management Project since 2010/11 to investigate the response and recovery of estuarine fish assemblages to freshwater inflows and the changing environmental conditions in the Coorong (Ye *et al.* 2012a). Overall, the study found increased abundance of fish species, a change in fish assemblage structure (due to increased numbers of estuarine opportunistic and resident species), a distribution expansion for some fish species further into the southern part of the Coorong and recruitment success for several key fish species including congolli (*Pseudaphritis urvilii*), mulloway (*Argyrosomus japonicus*) and smallmouthed hardyhead (*Atherinosoma microstoma*). Despite the positive responses in fish assemblages following flows of 2010/11 and 2011/12, not all fish species are showing signs of recovery (e.g. black bream, *Acanthopagrus butcheri*) (Ye *et al.* 2012b).

With the continued high flows in 2012/13, further changes are expected in the Coorong, including improved water quality conditions, continued high water level, localised restoration of true estuarine conditions, and improved connectivity through the system and potential influx from the Southern Ocean to facilitate fish recruitment. To address the CLLMM Recovery Project's monitoring objectives, South Australian Research and Development Institute (SARDI) continued fish monitoring in the Murray Estuary and Coorong (North and South Lagoons) during 2012/13 to assess the responses of key assemblages to the continued freshwater inflows following the recent drought. This monitoring will build on previous investigations of flow-related fish responses in the region since 2006/07 (Noell *et al.* 2009; Ye *et al.* 2011; 2012a). The findings from this work will improve our understanding of flow-related ecology and resilience of fish species to drought and flood events in a temperate estuarine-lagoonal system of a large regulated river. 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 2012/13 to assess fish responses to the continued water availability (and associated environmental variables) following the recent drought. Specific objectives are:

1. to determine the changes in fish assemblage structure;

2. to determine the abundance and distribution of key species*;
3. to investigate recruitment response of key species*; and
4. to assess the extent of estuarine fish habitat, including nursery ground for key species*.

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

The following key questions will be addressed (with reference to Department of Environment, Water and Natural Resources' 'Request for Proposal', 2012). Key questions:

1. Are there indications of continued system recovery in 2012/13 following the significant flows of 2010/11 and further flows in 2011/12, when a recovery was first documented? Would fish populations maintain the ranges observed in the Coorong in 2010/11 and 2011/12?
    a) Did 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) Has recruitment continued for fish species which underwent recruitment in 2011/12 and is recruitment occurring for other species in 2012/13?
    c) Can the recruitment of species in 2012/13 be linked with the timing of differing flow scenarios to identify drivers of fish recruitment?
2. Were species able to maintain any range increases observed in 2011/12?
3. What are the differences in the community structure of fish between flow scenarios (drought/flood)?

2. METHODS

2.1. Field Sampling

Fish sampling was conducted at thirteen sites in the Murray Estuary and Coorong region on four occasions in 2012/13 (November 2012, December 2012, February 2013 and March 2013), following the same regime used for the 2010/11 and 2011/12 fish intervention monitoring (Ye *et al.* 2012a). 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 1 and Figure 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 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.

All fish collected using seine and gill nets were identified to species level, and the total number of individuals of each species recorded. For the key species, total length (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 in order for age determination in future years.

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 for 2012/13 was obtained from SA Water, as the MDBA modelled data (used in previous years) was not available at the time of the report preparation.

Table 1. Fish sampling sites and gear type used for barrage release intervention monitoring in the Coorong during 2010-2013.

Site	Latitude(°S)	Longitude (°E)	Distance from mouth	Sampling
Murray Estuary (ME)				
Beacon 19 (M1)	35.534	138.832	6.5	Seine and gill
Boundary Ck Lower (M2)	35.564	138.923	3.5	Seine net
Boundary Ck Structure	35.556	138.934	5.7	Seine and gill
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	Seine and gill
Long Point (N2)	35.693	139.166	31.5	Seine net
Noonameena (N3)	35.757	139.232	40.2	Seine and gill
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	Seine and gill
Salt Creek (S3)	36.132	139.638	98.4	Seine net

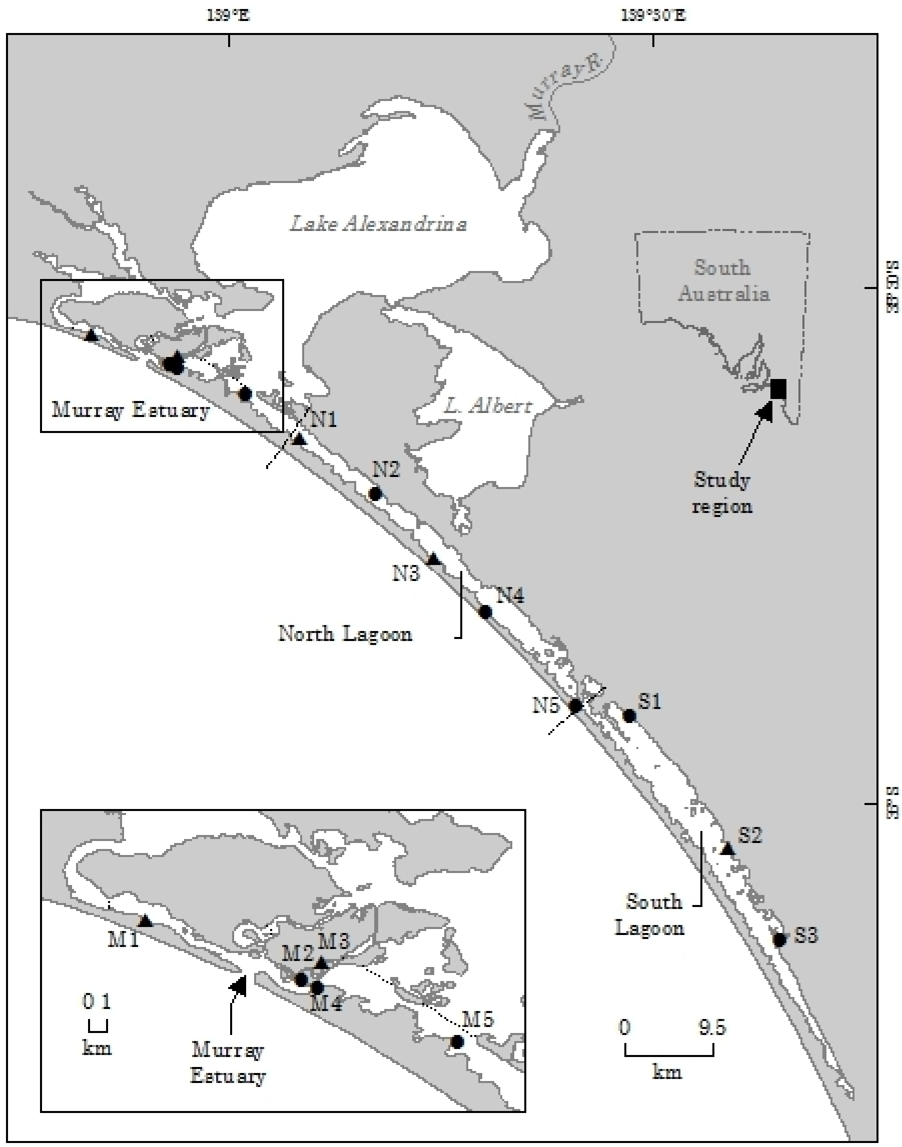


Figure 1. Fish sampling sites for barrage release intervention monitoring in the Coorong. (▲) both seine and gill netting; (●) seine netting only. Dotted lines represent the five barrages and dashed lines show approximate boundaries between the three subregions.

2.2. Life-cycle designations

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

2.3. Multivariate Analysis

Fish assemblage data collected during barrage releases from 2010/11, 2011/12 and 2012/13 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 three years' data (November, December, February and March) were compared against samples collected in November, December and March during 2006/07.

For each gear type, the mean relative abundances of fish (i.e. number of fish per seine or gill net) at each site on each sampling occasion were ordinated using non-metric multidimensional scaling (MDS). Prior to ordination, data transformation was performed on the mean relative abundances of fish from both seine net and gill net samples in order to down-weight excessive influence of highly abundant species. Log(x+1) transformation was used for the seine net data because a few species dominated the assemblages with extremely high numbers (e.g. >3000); while square-root transformation was applied for the gill net data to allow the intermediate abundance species to play a part in the similarity. In addition, a dummy species was added to adjust for samples with no catch, and the Bray-Curtis similarity measure was used to construct the association matrix. Permutational analysis of variance (PERMANOVA; Anderson 2001) was used to test whether the species abundance data differed between subregions and years. Where significant interactions occurred, pairwise analyses were also performed. All PERMANOVA analyses used 999 unrestricted permutations of raw data.

Principal coordinates (PCO) analysis for the ordination of samples in multivariate space was performed with vector overlays to indicate species that 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 determine which species contributed most to dissimilarities between groups (Clarke and Warwick 2001).

To model the relationship(s) between fish assemblage structure, as described by the Bray-Curtis resemblance matrix, and one or more water quality predictor variables, we used the DistLM (distance-based linear models) routine based on the *forward* 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 were important in driving variation along dbRDA axes. Four water quality parameters (i.e. salinity, transparency, temperature and pH) were included in the DistLM analysis; DO was not included because no *in situ* measurement data were available.

3. RESULTS

3.1. Barrage Releases

From 1984–2013, 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 10500 and 12000 GL y^{-1} with the exception of 1991/92 when it was just over 3000 GL y^{-1} (Figure 3.1). After 1993/94, inflows to the Coorong generally declined until 2007/08. No freshwater 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 ~13000 GL in 2010/11 and ~6500 GL in 2011/12. In 2012/13, freshwater inflows to the Coorong decreased to ~4500 GL. Peak monthly inflow of ~1500 GL was recorded in August 2012 (Figure 3.1). During the sampling period (i.e. November 2012-March 2013) inflow peaked in November at ~182 GL, with a mean inflow of ~63 GL per month.

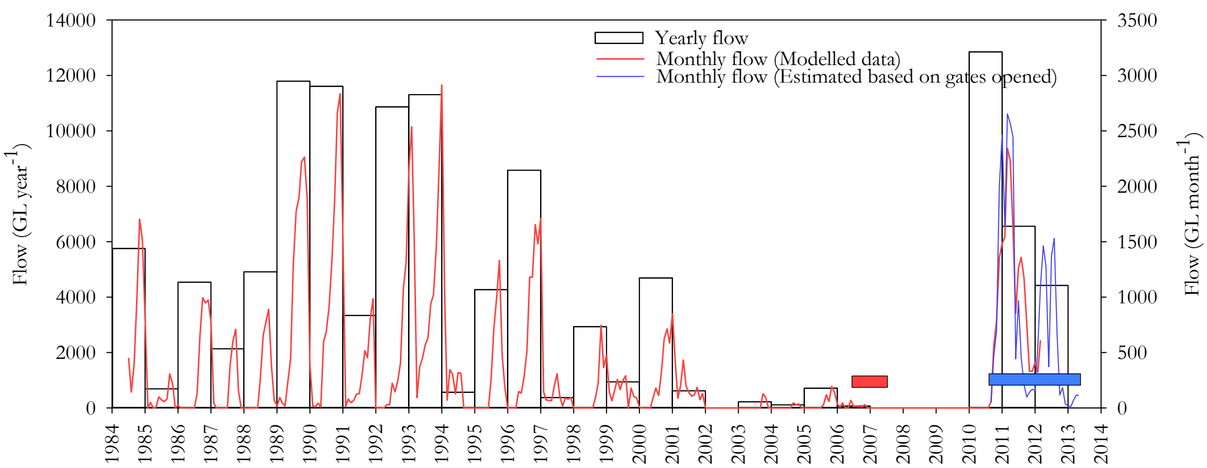


Figure 2. Average annual and monthly freshwater inflows across the barrages from July 1984 to March 2013 (Data sources: MDBA and SA Water as indicated in legend)(source: MDBA). Red bar indicates sampling period during the drought period in 2006/07 and blue bars indicate intervention monitoring following barrage releases from 2010–13.

Table 2. Annual and monthly peak discharge across the barrages from 1990/91 to 2012/13.

	Annual Discharge	Monthly Discharge Peak
1990/91	12169	2834
1991/92	3248	984
1992/93	10522	2536
1993/94	11553	2914
1994/95	631	319
1995/96	4239	1330
1996/97	8558	1709
1997/98	682	307
1998/99	2688	746
1999/2000	1008	290
2000/01	4729	851
2001/02	753	186
2002/03	0	0
2003/04	220	127
2004/05	109	46
2005/06	695	195
2006/07	78	29
2007/08	0	0
2008/09	0	0
2009/10	0	0
2010/11	12849	2342
2011/12	9679	1462
2012/13	4232	1530

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). 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 2012/13 compared to 2006/07. During 2006/07, mean salinities ranged from 31-40 psu in the Murray Estuary, 43-113 psu in the North Lagoon, and 137-138 psu in the South Lagoon. In contrast, salinities declined to 1-5 psu, 8-76 psu and 54-98 psu in 2010/11 and 0-14 psu, 11-71 psu and 86-94 psu in 2011/12, in the respective north to south subregions. However, in 2012/13, the Murray Estuary and North Lagoon had increased average salinities (7-21 and 20-76 psu, respectively); whilst the South Lagoon remained at lower average salinities than the previous two years with a range of 76-79 psu.

A decline in transparency accompanied River Murray inflows throughout the entire Coorong Lagoon in 2010/11 which persisted until 2012/13 (Figure 3). 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. Two sites (M4 and M5) in 2012/13 showed a large variation in pH with some low 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.

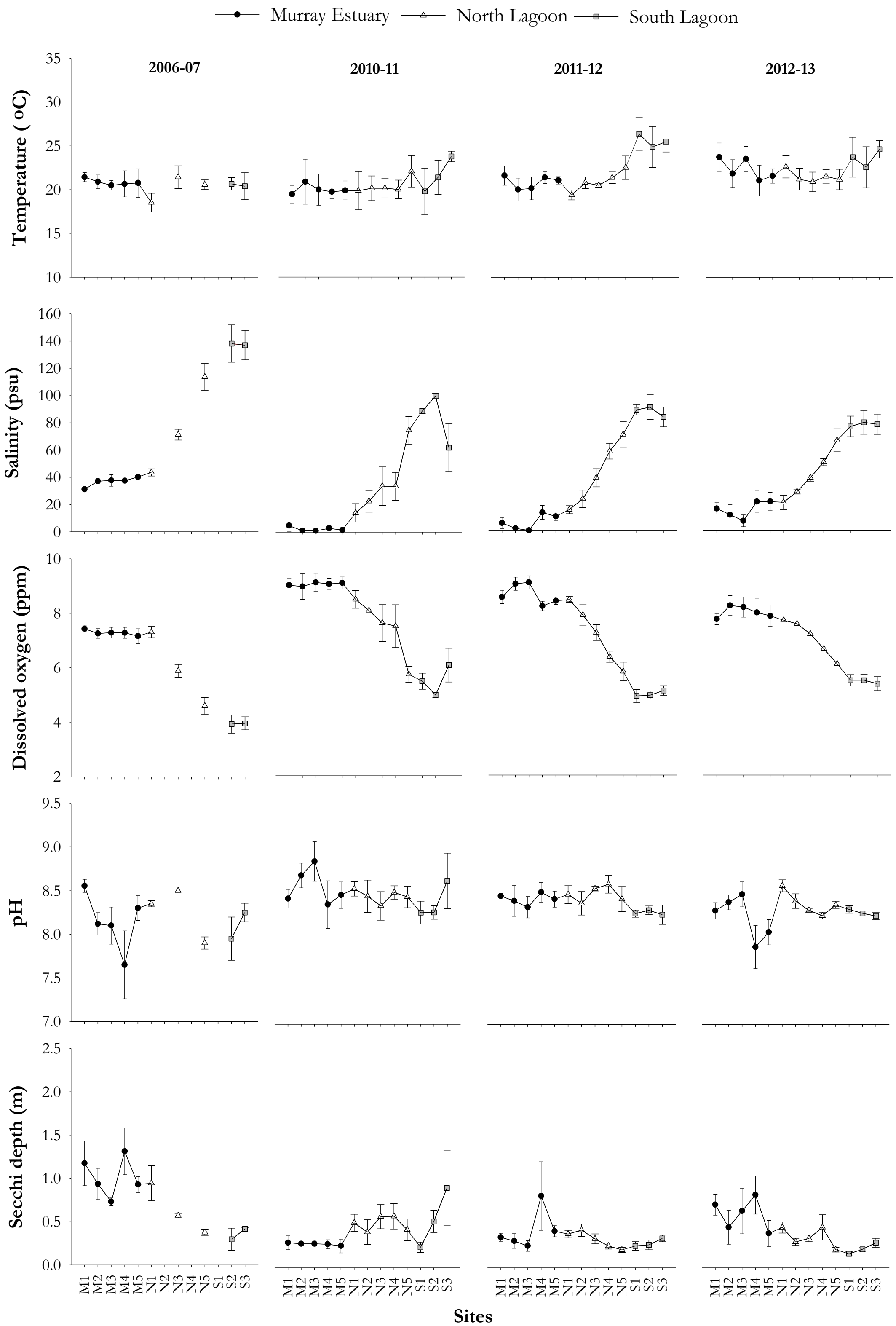


Figure 3. Mean values ± S.E. for water temperature, salinity, dissolved oxygen, pH and Secchi depth for each sampling site (sampling occasions pooled) within the Murray Estuary and Coorong region during 2006/07, 2010/11, 2011/12 and 2012/13. (2006/07 data sourced from Noell *et al.* 2009).

3.3. Catch summary, species richness and abundance

3.3.1. *Seine net samples*

A total of 92,491 fish representing 24 species were sampled using seine nets in the Murray Estuary and Coorong in 2012/13 (Table 3). Species richness was similar in all years, although the presence of specific species varied considerably between years. Of the seven freshwater species recorded in 2010/11 and 2011/12, five were found in 2012/13. The two species not present during the current study were golden perch and goldfish, albeit in previous years they had been caught in extremely low numbers.

Smallmouthed hardyhead and sandy sprat were the most abundant species collected in 2012/13 which is consistent with all previous years sampled (Table 3). However, for the first time since the drought the next most abundant species were the estuarine Scary's Tasman goby, the catadromous congolli and the opportunistic yelloweye mullet. There were two freshwater species, redfin perch and bony herring, which showed a noticeable and consistent decline in their abundance since 2010/11. It is worth noting that in 2011/12, black bream and yelloweye mullet were sampled in the South Lagoon in addition to smallmouthed hardyhead, which was the single species present in this subregion in 2006/07 and 2010/11. Furthermore, in 2012/13 the total number of species caught in the South Lagoon was six with the addition of congolli, Scary's Tasman goby and bony herring to previously mentioned species.

A regional comparison of species richness for 2012/13 showed a decrease from the Estuary to the South Lagoon (e.g. Estuary>North Lagoon>South Lagoon), following previous years' trends. When comparing annual trends within each subregion, there are important differences among them. The Estuary subregion showed a decline in species richness from 2010/11 to 2012/13. The North and South Lagoons on the other hand showed increased species richness as a whole and at each individual site for a third year in a row (Figure 4).

In contrast, total abundance of fish was highly variable and did not show any clear regional or annual trends. Further detailed analysis of fish assemblages can be found in Section 3.4.

Table 3. Fish species and numbers collected using a standard seine net during 2006/07, 2010/11, 2011/12 and 2012/13 barrage release intervention monitoring in the Coorong. 2006/07 fish data for relevant months are also presented for comparison. LCD= Life-cycle designation, ME = Murray Estuary, NL = North Lagoon and SL = South Lagoon.

			2006/07				2010/11				2011/12				2012/13			
Common Name	**Scientific Name**	**LCD**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**	**ME**	**NL**	**SL**	**Total**
Common galaxias	*Galaxias maculatus*	C	10			10	48	1		49	6			6	113			113
Congolli	*Pseudaphritis urvilli*	C	1	3		4	101	45		146	30	48		78	529	640	7	1,176
Black bream	*Acanthopagrus butcheri*	E	13			13					1		1	2			2	2
Bluespot goby	*Pseudogobius olorum*	E	3			3	12	2		14		4		4		215		215
River garfish	*Hyporhamphus regularis*	E	290	16		306	90	37		127	39	90		129	44	54		98
Scary's Tasman goby	*Tasmanogobius lasti*	E	8	1		9	68	60		128	69	45		114	62	1,264	4	1,330
Smallmouthed hardyhead	*Atherinosoma microstoma*	E	1,209	12,557	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
Tamar goby	*Afurcagobius tamarensis*	E	35	39		74	941	26		967	41	2		43	135	289		424
Australian anchovy	*Engraulis australis*	E&M	12			12												
Bridled goby	*Arenigobius bifrenatus*	E&M	1			1	307			307	23	2		25	15	249		264
Goldspot mullet	*Liza argentea*	E&M	2			2	4			4		1		1	1			1
Greenback flounder	*Rhombosolea tapirina*	E&M	127	105		232	242	59		301	103	45		148	68	117		185
Southern garfish	*Hyporhamphus melanochir*	E&M	6			6												
Prickly toadfish	*Contusus brevicaudus*	E&M					1	3		4		3		3	45	1		46
Carp	*Cyprinus carpio*	FE					262	3		265	22			22	16			16
Goldfish	*Carassius auratus*	FE					1			1	1			1				
Redfin perch	*Perca fluviatilis*	FE					2,900	253		3,153	743			743	226			226
Australian smelt	*Retropinna semoni*	FN	1			1	1,148	330		1,478	364	12		376	243	173		416
Bony herring	*Nematolosa erebi*	FN	3			3	4,267	818		5,085	2,052	69		2,121	227	42	3	272
Flat-headed gudgeon	*Philypnodon grandiceps*	FN					844	16		860	6			6	8	2		10
Golden perch	*Macquaria ambigua*	FN					19	2		21	1			1				
Australian herring	*Arripis georgianus*	O	70			70					3			3				
Longsnout flounder	*Ammotretis rostratus*	O	52	54		106	78	5		83	15	25		40	11	21		32
Sandy sprat	*Hyperlophus vittatus*	O	3,949	287		4,236	15,506	246		15,752	17,002	21,740		38,742	28,740	16,653		45,393
Sea mullet	*Mugil cephalus*	O						1		1								
Soldier	*Gymnapistes marmoratus*	O	6			6	1	6		7								
Southern eagle ray	*Myliobatis australis*	O	1			1												
Southern Longfin goby	*Favonigobius lateralis*	O					81	2		83					6			6
Toadfishes	Family Tetraodontidae	O	123	1		124	1	3		4	5	7		12	70	24		94
Australian salmon	*Arripis truttaceus*	O	853	9		862					372	17		389	238	1		239
Yelloweye mullet	*Aldrichetta forsteri*	O	918	29		947	484	185		669	383	295	1	679	1,040	767	29	1,836
Mulloway	*Argyrosomus japonicus*	O	57			57									5	4		9
Total			**7,750**	**13,101**	**35**	**20,886**	**28,894**	**35,922**	**15,636**	**80,452**	**21,611**	**49,595**	**30,186**	**101,392**	**32,610**	**42,712**	**17,169**	**92,491**
% catch			**37**	**63**	**0**		**36**	**45**	**19**		**21**	**49**	**30**		**35**	**46**	**19**	

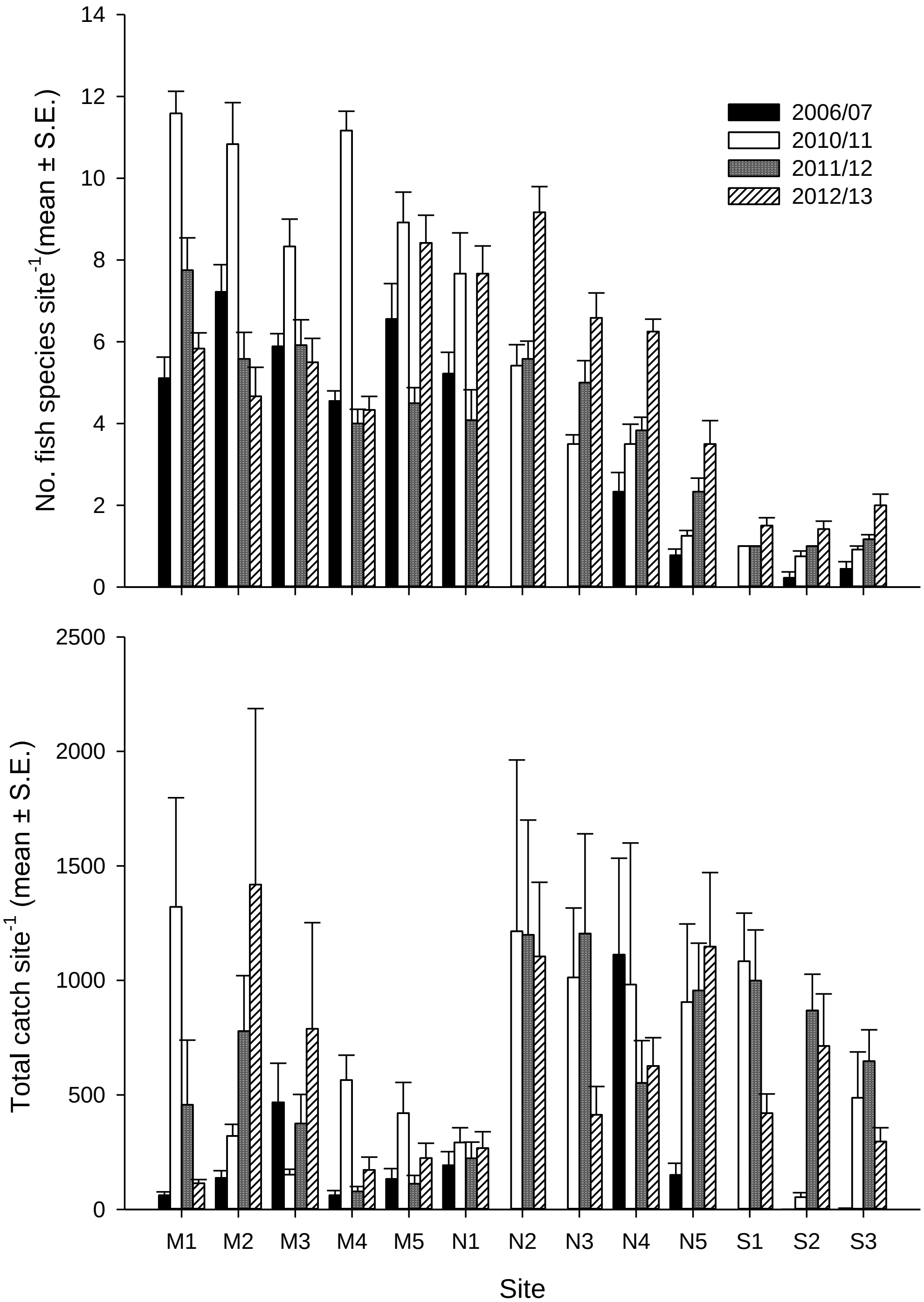


Figure 4. Mean ± (S.E.) species richness (top) and total fish abundance (bottom) sampled by seine net at different sites in the Estuary, North Lagoon and South Lagoon of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13.

3.3.2. *Gill net samples*

A total of 5,908 fish representing 16 medium to large-bodied species were sampled using gill nets in the Murray Estuary, North and South Lagoons in 2012/13 (Table 4). That is four species more than the previous year, with the addition of black bream, Australian herring and sea mullet which were only absent in 2011/12 but present in the previous two sampling years; and soldier which is recorded for the first time in gill nets in the Coorong (most likely an incidental capture as it is a small-bodied fish). Fish collected included freshwater (native and exotic), catadromous, estuarine resident, estuarine and marine to marine estuarine opportunist species. Similar to 2010/11 and 2011/12, bony herring was the most abundant species followed by yelloweye mullet and mulloway. A noticeable decline in Australian salmon was observed compared to 2011/12. The number of mulloway caught in 2011/12 and 2012/13 was considerably higher than 2010/11.

Average species richness per site in 2012/13 was slightly lower than 2011/12 but similar to that in 2010/11 and showed no clear spatial pattern (Figure 5). North Lagoon abundances were greater than Estuary abundances in all flow years. The greatest total abundances in the Estuary were recorded in 2011/12, whilst in the North Lagoon they occurred in 2010/11. During 2012/13, a site in the South Lagoon was added to the gill net sites previously sampled. The abundances found in the South Lagoon are considerably lower than those in other subregions in 2012/13 and were comparable to those observed in the Estuary and North Lagoon during the drought years.

.

Table 4. Fish species and numbers collected using gill nets during 2006/07, 2010/11, 2011/12 and 2012/13 barrage release intervention monitoring in the Coorong. 2006/07 fish data for relevant months are also presented for comparison. LCD = Life-cycle designation, MM = Murray Estuary, NL = North Lagoon and SL = South Lagoon

			2006/07			2010/11			2011/12			2012/13			
Common_Name	**Scientific Name**	**LCD**	**ME**	**NL**	**Total**	**ME**	**NL**	**Total**	**ME**	**NL**	**Total**	**ME**	**NL**	**SL**	**Total**
Congolli	*Pseudaphritis urvilli*	C	3	4	7	2		2	3	33	36		4		4
Black bream	*Acanthopagrus butcheri*	E	1		1	5	3	8				1			1
River garfish	*Hyporhamphus regularis*	E	1		1					6	6		2		2
Greenback flounder	*Rhombosolea tapirina*	E&M	6	2	8	1		1		7	7		7		7
Goldspot mullet	*Liza argentea*	E&M							25	4	29	9	2		11
Carp	*Cyprinus carpio*	FE				21	22	43	119	2	121	69			69
Goldfish	*Carassius auratus*	FE				1		1	1		1	3			3
Redfin perch	*Perca fluviatilis*	FE				12	9	21	32	12	44	3			3
Bony herring	*Nematolosa erebi*	FN	20	1	21	336	4,109	4,445	2,742	2,889	5,631	1,183	1,927	14	3,124
Golden perch	*Macquaria ambigua*	FN				1		1	3	1	4	2	1		3
Australian herring	*Arripis georgianus*	O	11		11		2	2					2		2
Mulloway	*Argyrosomus japonicus*	O	135	54	189	16	11	27	53	275	328	208	135		343
Sea mullet	*Mugil cephalus*	O	1	2	3	2		2				2	1		3
Toadfishes	Family Tetraodontidae	O		2	2										
Australian salmon	*Arripis truttaceus*	O	209	5	214	2	207	209	620	189	809	310	10		320
Western striped grunter	*Pelates octolineatus*	O	4		4										
Yelloweye mullet	*Aldrichetta forsteri*	O	104	153	257	24	627	651	190	627	817	450	1,425	137	2,012
Soldier	*Gymnapistes marmoratus*	O											1		1
Yellowfin whiting	*Sillago schomburgkii*	O				1		1							
Total			**495**	**223**	**718**	**424**	**4,990**	**5,414**	**3,788**	**4,045**	**7,833**	**2,240**	**3,517**	**151**	**5,908**
% catch			**69**	**31**		**8**	**92**		**48**	**52**		**38**	**59**	**3**	

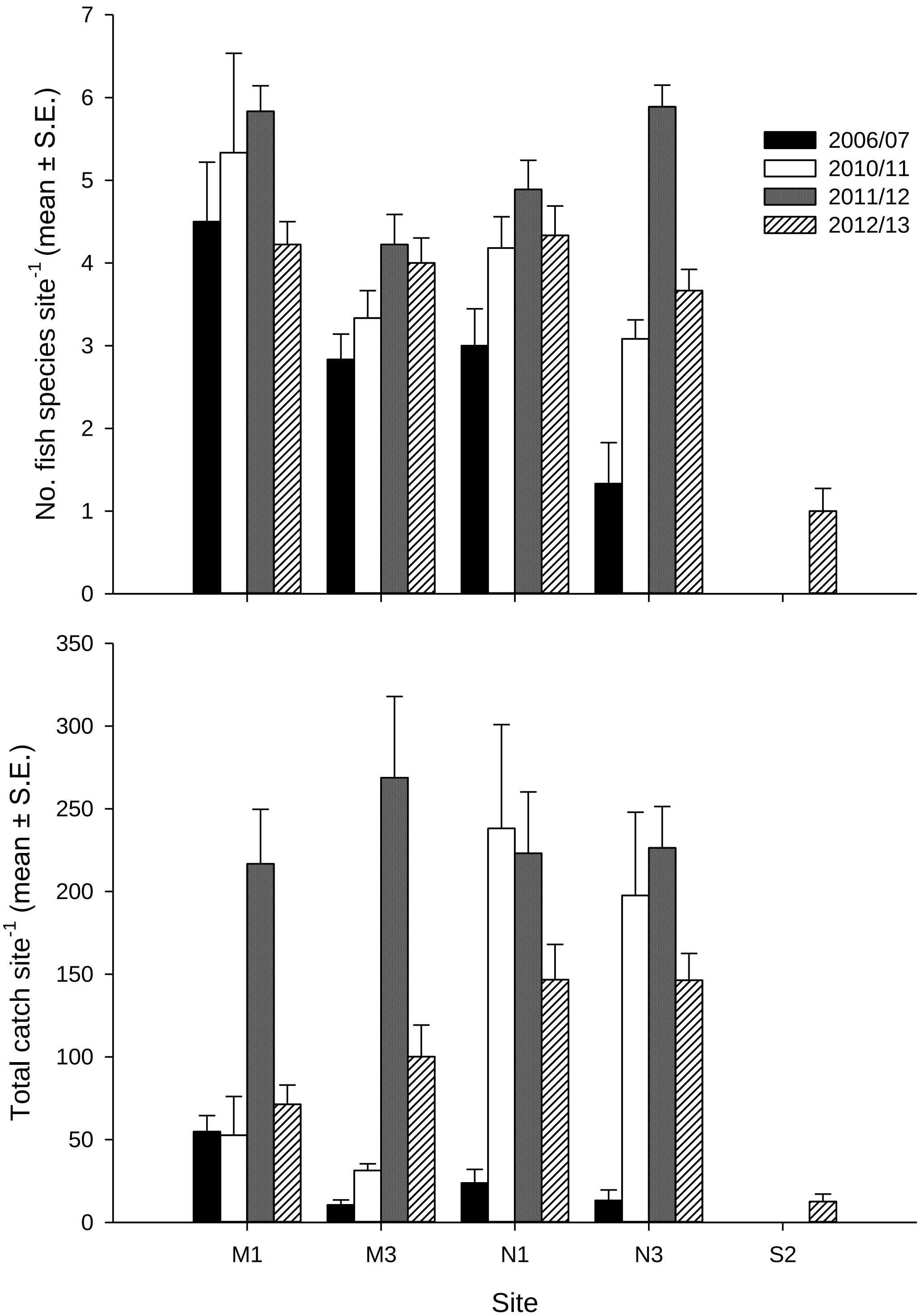


Figure 5. Mean ± (S.E.) species richness (top) and total fish abundance (bottom) sampled by gill net at different sites in the Estuary and North Lagoon of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13.

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 and 2012/13) and Subregion (i.e. Estuary, North Lagoon and South Lagoon) (Table 5), suggesting different inter-annual patterns among subregions. Pairwise comparisons revealed a significant difference in fish assemblage between all years (P<0.003) in each subregion. Similarly, a significant spatial difference was detected between all subregions (P=0.001) in each year.

Table 5. PERMANOVA results for fish assemblage comparison based on seine net data (4th root transformed data) between years and subregions of the Coorong. Bold p values are significant.

Source	df	MS	Pseudo-F	P(perm)
Year	3	29,268	27.244	**0.001**
Subregion	2	148,920	8.044	**0.001**
Year x Subregion	6	19,361	18.022	**0.001**
Residuals	522	1,074		

For the Estuary, SIMPER analysis indicated that the greatest dissimilarity (69%) in fish assemblage structure occurred between 2012/13 and 2006/07 (Table 6). This was largely driven by an increase in abundance of sandy sprat, and a decrease in smallmouthed hardyhead, Australian salmon and yelloweye mullet in 2012/13 (Table 6). For the Estuary, dissimilarity was lowest between 2012/13 and 2011/12 (64%).

Table 6. SIMPER analysis for fish assemblage pairwise comparisons between 2012/13 and 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 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

	Mean abundance		**CR**	**Contrib%**	**Cum.%**
Species	**2012/13**	**2011/12**		Mean dissimilarity = 64.42	
Sandy sprat	2.78	2.67	1.19	17.89	17.89
Bony herring	0.62	1.72	1.32	10.97	28.86
Yelloweye mullet	1.43	0.78	1.26	9.78	38.63
Smallmouthed hardyhead	0.75	0.56	0.87	7.52	46.15
Australian salmon	0.53	0.76	1	7.03	53.18
Australian smelt	0.47	0.74	0.93	6.51	59.69
Congolli	0.72	0.30	0.85	5.69	65.38
Greenback flounder	0.32	0.57	0.92	4.95	70.33
Redfin perch	0.37	0.47	0.69	4.94	75.27
Species	**2012/13**	**2010/11**		Mean dissimilarity = 67.37	
Sandy sprat	2.78	2.87	1.2	10.5	10.5
Bony herring	0.62	2.51	1.57	9.98	20.48
Redfin perch	0.37	2.18	1.77	9.29	29.77
Australian smelt	0.47	2.16	1.82	9.06	38.83
Flat-headed gudgeon	0.09	1.60	1.76	7.63	46.46
Smallmouthed hardyhead	0.75	1.67	1.5	7.33	53.79
Yelloweye mullet	1.43	0.63	1.19	6.52	60.31
Tamar goby	0.53	1.64	1.49	6.44	66.75
Congolli	0.72	0.60	1	4.23	70.98
Carp	0.15	0.85	1.02	4.05	75.03
Species	**2012/13**	**2006/07**		Mean dissimilarity = 69.02	
Sandy sprat	2.78	1.58	1.18	17.01	17.01
Smallmouthed hardyhead	0.75	1.19	1.15	9.01	26.02
Australian salmon	0.53	1.23	1.13	8.68	34.7
Yelloweye mullet	1.43	1.70	1.21	8.34	43.04
Greenback flounder	0.32	0.87	1.17	6.24	49.28
River Garfish	0.23	0.80	1.03	5.67	54.95
Tetraodontidae	0	0.72	0.95	5.64	60.59
Congolli	0.72	0.02	0.71	4.74	65.33
Bony herring	0.62	0.05	0.72	4.65	69.98
Tamar goby	0.53	0.39	0.93	4.53	74.51
Scary's Tasman goby	0.6	0.12	0.87	4.35	78.86

For the North Lagoon, this year's fish assemblage was most dissimilar to 2006/07 (65%) and was driven by increase in abundances of sandy sprat and congolli and a decrease in abundance of smallmouthed hardyhead; whilst the least dissimilar year was 2011/12 (56%) driven by changes in the same direction in abundances of the same three species.

Table 7. SIMPER analysis for fish assemblage pairwise comparisons between 2012/13 and 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 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

	Mean abundance		**CR**	**Contrib%**	**Cum.%**
Species	**2012/13**	**2011/12**		Mean dissimilarity = 56.54	
Sandy sprat	2.99	2.31	1.28	19.04	19.04
Smallmouthed hardyhead	3.33	3.63	1.08	17.38	36.42
Congolli	1.37	0.32	1.4	9.26	45.68
Yelloweye mullet	1.16	0.76	1.12	8.31	53.99
Scary's Tasman goby	1.00	0.27	0.97	7.76	61.75
Greenback flounder	0.96	0.32	1.07	7.09	68.84
Bluespot goby	0.62	0.07	0.78	4.76	73.61
Tamar goby	0.66	0.03	0.8	4.62	78.23
Species	**2012/13**	**2010/11**		Mean dissimilarity = 62.23	
Sandy sprat	2.99	0.28	1.51	19.56	19.56
Smallmouthed hardyhead	3.33	4.31	1.13	15.68	35.24
Congolli	1.37	0.34	1.37	8.46	43.7
Bony herring	0.35	1.24	1.22	7.61	51.31
Yelloweye mullet	1.16	0.76	1.11	7.53	58.84
Scary's Tasman goby	1.00	0.23	0.94	7.08	65.92
Greenback flounder	0.96	0.41	1.04	6.49	72.41
Australian smelt	0.32	0.6	0.75	4.81	77.21
Species	**2012/13**	**2006/07**		Mean dissimilarity = 65.24	
Sandy sprat	2.99	0.34	1.51	21.39	21.39
Smallmouthed hardyhead	3.33	3.59	0.98	17.57	38.96
Congolli	1.37	0.11	1.47	9.9	48.87
Yelloweye mullet	1.16	0.50	1.04	8.32	57.18
Scary's Tasman goby	1.00	0.04	0.9	7.66	64.85
Greenback flounder	0.96	0.68	1.07	7.54	72.39
Tamar goby	0.66	0.29	0.87	5.27	77.66

In the South Lagoon, the greatest dissimilarity in assemblage structure occurred between 2006/2007 and 2012/13 (84%). This was mainly driven by the increase in abundance of smallmouthed hardyhead in the current sampling year. The least dissimilar years were 2011/12 and 2012/13 (22%) and it was mainly explained by the decrease in abundance of smallmouthed hardyhead and increase in abundance of yelloweye mullet.

Table 8. SIMPER analysis for fish assemblage pairwise comparison between 2012/13 and 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		**CR**	**Contrib%**	**Cum.%**
Species	**2012/13**	**2011/12**		Mean dissimilarity = 22.40	
Smallmouthed hardyhead	4.23	5.07	1.34	66.97	66.97
Yelloweye mullet	0.43	0.03	0.75	18.95	85.92
Species	**2012/13**	**2010/11**		Mean dissimilarity = 42.18	
Smallmouthed hardyhead	4.23	3.19	1.18	78.04	78.04
Species	**2012/13**	**2006/07**		Mean dissimilarity = 84.57	
Smallmouthed hardyhead	4.23	0.48	2.75	84.67	84.67

In 2012/13, the difference in fish assemblage between the Estuary and North Lagoon was mainly attributed to a higher abundance of smallmouthed hardyhead, sandy sprat and congolli, and lower abundance of yelloweye mullet in the North Lagoon (Table 9). Differences between the Estuary and South Lagoon were driven by a higher abundance of smallmouthed hardyhead and lower abundance of yelloweye mullet and congolli and absence of sandy sprat in the South Lagoon. The difference between fish assemblages between the North and South Lagoon was driven by the absence of sandy sprat, greater abundance of smallmouthed hardyhead and decreased abundance of yelloweye mullet and congolli in the South Lagoon.

Table 9. SIMPER analysis for fish assemblage pairwise comparisons between the Estuary, North and South Lagoons of the Coorong for seine net samples during 2012/13. Results are based on log transformed data. Mean abundance is number of fish per seine net shot. CR (consistency ratio) indicates the consistency of differences in abundance between years, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between regions (shown by PERMANOVA) attributable to individual species. A cumulative cut-off of 90% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar). ME = Murray Estuary and NL = North Lagoon.

	Mean abundance		**CR**	**Contrib%**	**Cum.%**
Species	**ME**	**NL**		Mean dissimilarity = 64.62	
Smallmouthed hardyhead	0.75	3.33	1.3	19.48	19.48
Sandy sprat	2.78	2.99	1.19	14.54	34.01
Congolli	0.72	1.37	1.37	7.79	41.81
Yelloweye mullet	1.43	1.16	1.17	7.79	49.6
Scary's Tasman goby	0.6	1	1.07	6.58	56.18
Greenback flounder	0.32	0.96	1.07	5.97	62.15
Tamar goby	0.53	0.66	0.99	4.87	67.02
Bony herring	0.62	0.35	0.85	4.51	71.52
Bridled goby	0.1	0.66	0.89	3.91	75.43
Species	**ME**	**SL**		Mean dissimilarity = 85.59	
Smallmouthed hardyhead	0.75	4.23	1.97	28.74	28.74
Sandy sprat	2.78	0	1.34	21.05	49.78
Yelloweye mullet	1.43	0.43	1.25	10.02	59.8
Congolli	0.72	0.13	0.78	5.12	64.92
Bony herring	0.62	0.06	0.72	4.91	69.83
Scary's Tasman goby	0.6	0.09	0.87	4.46	74.28
Australian salmon	0.53	0	0.68	4.28	78.56
Species	**NL**	**SL**		Mean dissimilarity = 63.98	
Sandy sprat	2.99	0	1.7	23.59	23.59
Smallmouthed hardyhead	3.33	4.23	1.14	16.58	40.18
Congolli	1.37	0.13	1.56	10.4	50.57
Yelloweye mullet	1.16	0.43	1.14	8.79	59.37
Scary's Tasman goby	1	0.09	0.94	8.12	67.49
Greenback flounder	0.96	0	1.02	7.64	75.14

The PCO of fish assemblage data for the Estuary subregion accounted for 49.2% of the total variation in the first two axes (Figure 6a). There was separation of samples from 2010/11 from 2006/07, mainly explained by high abundance of freshwater species such as Australian smelt, bony herring, carp, redfin perch and low abundance and absence of estuarine opportunistic species like yelloweye mullet and Australian salmon. Whilst 2011/12 and 2012/13 were interspersed between the drought and flood years, with a general reduction of freshwater species and an increase of opportunistic estuarine species. In the North Lagoon, 60.5% of the total variation was captured by PCO1 and PCO2 (Figure 6b). The distribution of the 2012/13 samples was separated from 2006/07 and 2010/11 samples, whilst 2011/12 appeared to be interspersed between groupings for the previous two years. High abundances of sandy sprat, congolli, Tamar goby and Scary's goby were associated to 2012/13.

In the South Lagoon, the two axes captured 93.3% of the fish assemblage differences between years, with a clear shift from 2006/07 to 2010/11, then to 2011/12 and 2012/13, which was mainly explained by the increase in abundance of smallmouthed hardyhead from the earlier years to the later (Figure 6c).

Applying PCO to the fish assemblage data collected during 2012/13 from the three subregions, 61.6% of the total variation was captured by PCO1 and PCO2 (Figure 7). There was separation of Estuary, North Lagoon and South Lagoon samples along the horizontal axis, which had a negative correlation with smallmouthed hardyhead and a positive correlation with Tamar goby abundances. The distribution of Estuary samples was associated to high abundances of yelloweye mullet and Australian salmon, whilst North Lagoon samples were associated to sandy sprat and Tamar goby. South Lagoon samples were attributable to high abundances of smallmouthed hardyhead.

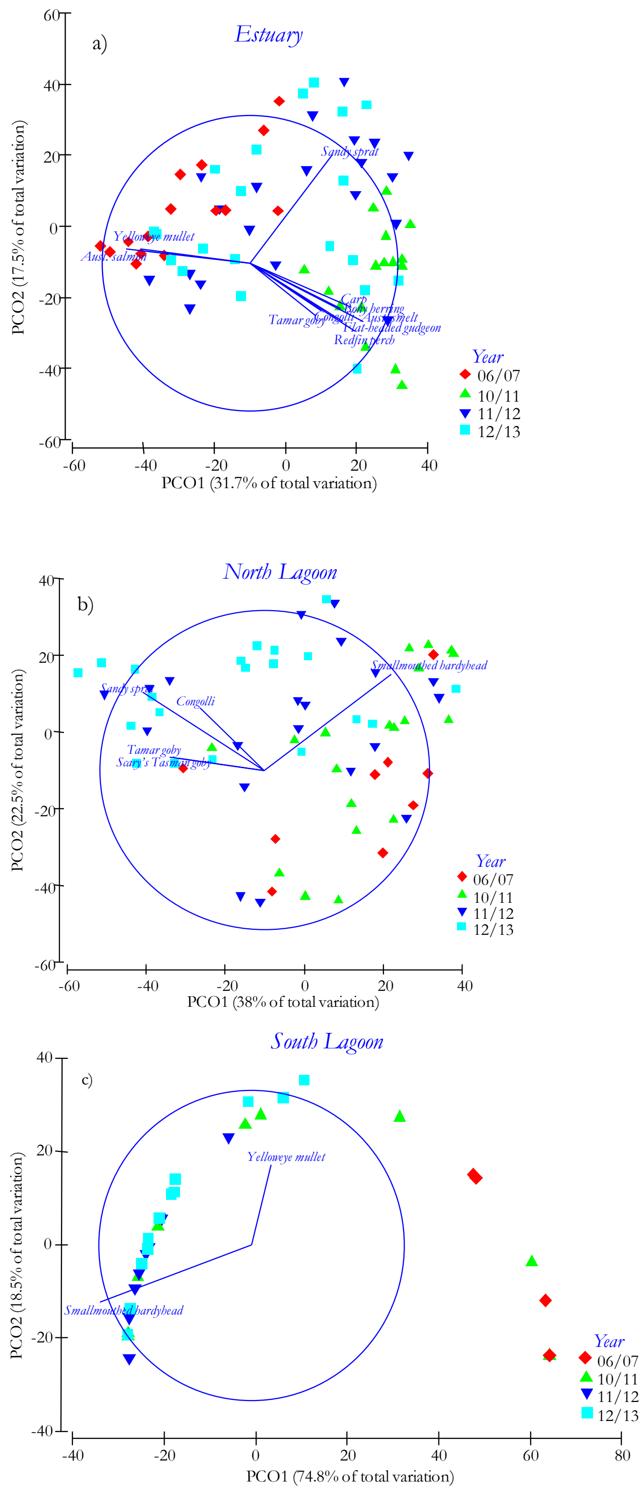


Figure 6. PCO of abundance samples of fish species collected by seine net in different years from a) Estuary, b) North Lagoon and c) South Lagoon subregions. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

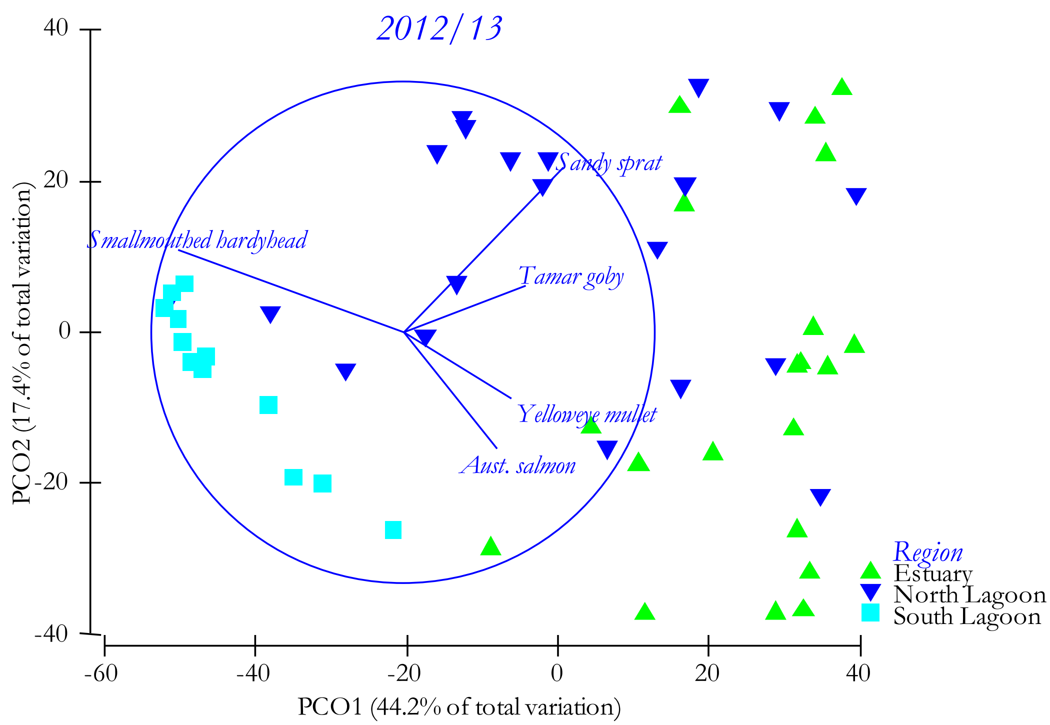


Figure 7. PCO of samples on the basis of the Bray-Curtis measure of squareroot transformed abundances of fish assemblages collected by seine net from different subregions during 2012/13. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species group with correlations >0.5, and with respect to a unit circle).

The best combination of environmental predictor variables for assemblage structure of seine net samples was salinity and transparency. Together these two variables explained 43.6% of the variation. The other two variables (i.e. temperature and pH) did not significantly contribute to explain the distribution of samples (Table 10). Salinity was the best environmental variable to explain the horizontal separation of the data cloud, whilst transparency best explained the vertical separation (Figure 8).

Table 10. DistLM sequential results indicating which environmental variable significantly contributed most to the relationship with the multivariate data could for 2012/13(seine net fish data). Proportion of the variation explained (Prop) and cumulative variation explained.

Variable	Pseudo-F	P	Prop.	Cumul.
Salinity	23.31	**0.001**	0.3315	0.3315
Transparency	8.54	**0.001**	0.1047	0.4362
pH	1.31	0.264	0.0159	0.4521
Temperature	1.21	0.232	0.0146	0.4667

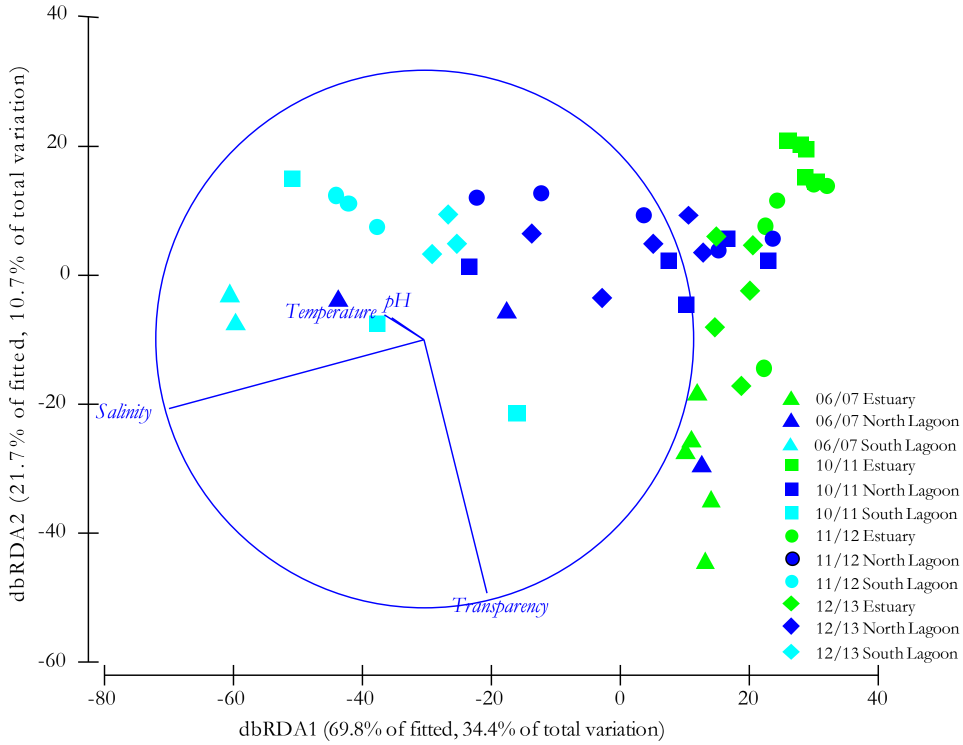


Figure 8. dbRDA ordination of the fitted model of species-abundance data collected by seine net (based on Bray-Curtis measure of squareroot transformed abundances) *versus* the predictor variables salinity, transparency, pH and temperature. The vector overlay indicates multiple partial correlations between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

3.4.2. *Gill net samples*

PERMANOVA detected a significant interaction when comparing large-bodied fish assemblages among four years (i.e. 2006/07, 2010/11, 2011/12 and 2012/13) and subregions (i.e. Estuary, North Lagoon and South Lagoon) (Table 11), suggesting inconsistent spatio-temporal variation among years and across subregions. Pairwise comparisons revealed a significant temporal difference in fish assemblage structure in each subregion ($P<0.01$), and a significant spatial difference in all years ($P<0.01$).

Table 11. PERMANOVA results for fish assemblage comparison based on gill net data (fourth root transformed) among years and subregions of the Coorong. Bold P values are significant.

Source	df	MS	Pseudo-F	P(perm)
Year	3	15237.0	24.67	**0.001**
Subregion	2	33315.0	8.88	**0.002**
Year x Subregion	4	4181.1	6.77	**0.001**
Res	142	617.7		

SIMPER analysis indicated that, in the Estuary, the greatest difference in fish assemblages occurred between 2012/13 and 2006/07 (dissimilarity = 58%), and was driven by the increased abundance of bony herring and yelloweye mullet and the decreased abundance of Australian salmon and mulloway in 2012/13 (Table 12). Changes in fish assemblage from 2011/12 to 2012/13 were driven by lower abundances of Australian salmon, bony herring and carp in 2012/13 and greater abundances of yelloweye mullet and mulloway (Table 12).

Table 12. SIMPER analysis for fish assemblage pairwise comparisons between 2012/13 and 2011/12, 2010/11 and 2006/07 for gill net samples from the Estuary subregion. 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		**CR**	**Contrib%**	**Cum.%**
Species	**2012/13**	**2011/12**		Mean dissimilarity = 45.38	
Australian salmon	1.36	1.94	1.28	17.01	17.01
Bony herring	2.37	3.57	1.68	16.38	33.39
Yelloweye mullet	1.38	0.9	1.33	16.1	49.49
Carp	0.73	1.07	1.21	12.62	62.12
Mulloway	0.99	0.75	1.25	11.75	73.86
Redfin perch	0.14	0.88	1.44	10.11	83.97
Goldspot mullet	0.19	0.47	0.79	6.34	90.32
Species	**2012/13**	**2010/11**		Mean dissimilarity = 53.36	
Yelloweye mullet	1.38	0.16	1.34	18.53	18.53
Australian salmon	1.36	0.13	1.39	18.08	36.6
Mulloway	0.99	0.47	1.16	13.19	49.79
Carp	0.73	0.89	1.44	11.77	61.56
Redfin perch	0.14	0.71	1.21	9.35	70.91
Bony herring	2.37	2.31	1.24	9.13	80.05
Goldfish	0.14	0.11	0.53	3.38	83.42
Black bream	0.05	0.24	0.57	3.36	86.79
Congolli	0	0.22	0.52	2.89	89.68
Golden perch	0.1	0.11	0.47	2.81	92.48
Species	**2012/13**	**2006/07**		Mean dissimilarity = 58.48	
Bony herring	2.37	0.27	2.04	29.59	29.59
Australian salmon	1.36	1.67	1.29	13.91	43.5
Mulloway	0.99	1.5	1.28	13.66	57.17
Yelloweye mullet	1.38	1.26	1.16	13.07	70.23
Carp	0.73	0	0.86	10.92	81.15
Australian herring	0	0.33	0.56	3.38	84.53
Congolli	0	0.25	0.56	2.94	87.47
Goldspot mullet	0.19	0	0.39	2.29	89.76
Redfin perch	0.14	0	0.4	2.16	91.92

For the North Lagoon, the greatest dissimilarity (63%) in fish assemblages occurred between 2006/07 and 2012/13, mostly driven by increased abundances of bony herring, yelloweye mullet and mulloway in the recent year (Table 13). The least dissimilarity was between 2011/12 and 2012/13 (29%) and was mainly driven by a decrease in abundances of Australian salmon, congolli and bony herring, and a slight increase in abundance of yelloweye mullet in 2012/13.

Table 13. SIMPER analysis for fish assemblage pairwise comparisons between 2012/13 and 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		**CR**	**Contrib%**	**Cum.%**
Species	**2012/13**	**2011/12**		Mean dissimilarity = 29.36	
Australian salmon	0.28	1.38	1.5	22.17	22.17
Yelloweye mullet	2.63	2.19	1.32	14.4	36.56
Congolli	0.13	0.77	1.17	13.64	50.21
Bony herring	2.9	3.46	1.35	12.95	63.16
Mulloway	1.42	1.83	1.16	9.8	72.96
Greenback flounder	0.29	0.3	0.83	7.76	80.72
River garfish	0.08	0.29	0.67	5.53	86.25
Redfin perch	0	0.22	0.43	3.87	90.12
Species	**2012/13**	**2010/11**		Mean dissimilarity = 36.99	
Australian salmon	0.28	1.32	1.45	20.38	20.38
Bony herring	2.9	3.09	1.35	20.24	40.62
Mulloway	1.42	0.41	1.64	19.51	60.13
Yelloweye mullet	2.63	1.96	1.27	15.64	75.77
Greenback flounder	0.29	0	0.63	5.16	80.92
Redfin perch	0	0.29	0.58	4.91	85.83
Carp	0	0.21	0.38	3.24	89.07
Australian herring	0.08	0.09	0.43	2.38	91.44
Species	**2012/13**	**2006/07**		Mean dissimilarity = 63.52	
Bony herring	2.9	0.08	3.37	41.32	41.32
Yelloweye mullet	2.63	1.23	1.17	23.78	65.1
Mulloway	1.42	1.02	1.02	11.65	76.74
Congolli	0.13	0.33	0.74	5.42	82.17
Australian salmon	0.28	0.21	0.7	5.18	87.35
Greenback flounder	0.29	0.1	0.69	4.74	92.09

The South Lagoon was only sampled in 2011/12 and 2012/13, with no fish caught in 2011/12. In 2012/13 the presence of yelloweye mullet and bony herring caused a dissimilarity of 100% (Table 14).

Table 14. SIMPER analysis for fish assemblage pairwise comparisons between 2012/13 and 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		CR	Contrib%	Cum.%
Species	**2012/13**	**2011/12**		Mean dissimilarity = 100	
Yelloweye mullet	1.11	0	4.48	74.77	74.77
Bony herring	0.52	0	1.51	25.23	100

When comparing between regions in 2012/13, the greatest dissimilarity (78.20%) occurred between the Estuary and South Lagoon, and was mainly due to greater abundances of bony herring and yelloweye mullet in the Estuary, as well as the absence of Australian salmon, mulloway and carp in the South Lagoon (Table 15).

Table 15. SIMPER analysis for fish assemblage comparison between Estuary, North Lagoon and South Lagoon for gill net samples during 2012/13. 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		CR	Contrib%	Cum.%
Species	**ME**	**NL**		Mean dissimilarity = 42.43	
Yelloweye mullet	1.38	2.63	1.28	21.47	21.47
Australian salmon	1.36	0.28	1.41	18.46	39.92
Mulloway	0.99	1.42	1.33	14.1	54.03
Bony herring	2.37	2.9	1.5	12.68	66.7
Carp	0.73	0	0.89	12.07	78.77
Greenback flounder	0	0.29	0.64	4.45	83.22
Goldspot mullet	0.19	0.08	0.49	3.47	86.7
Redfin perch	0.14	0	0.4	2.38	89.08
Goldfish	0.14	0	0.41	2.29	91.37
Species	**ME**	**SL**		Mean dissimilarity = 78.20	
Bony herring	2.37	0.52	1.57	29.6	29.6
Australian salmon	1.36	0	1.4	18.3	47.9
Yelloweye mullet	1.38	1.11	1.24	17.2	65.1
Mulloway	0.99	0	1.08	12.77	77.87
Carp	0.73	0	0.83	12.35	90.22
Species	**NL**	**SL**		Mean dissimilarity = 71.21	
Bony herring	2.9	0.52	2.21	37.69	37.69
Yelloweye mullet	2.63	1.11	1.34	26.5	64.19
Mulloway	1.42	0	2.99	21.4	85.59
Greenback flounder	0.29	0	0.63	4.32	89.91
Australian salmon	0.28	0	0.56	3.67	93.58

Variation in the fish assemblages across all sampled years in the Estuary was well captured by the first two axes of the PCO, which accounted for 83.9% of the variation (Figure 9a). There was a good separation of samples between 2006/07, 2010/11, 2011/12; whilst samples for 2012/13 were spread across the horizontal axis in two groups. Samples from 2006/07 were mainly associated with high abundances of mulloway. Whilst 2010/11 and 2011/12 were more attributable to the freshwater species bony herring, carp and redfin perch.

For the North Lagoon, PCO1 and PCO2 captured 66.1% of the total variation in the fish assemblage data (Figure 9b). There was a more distinct separation of 2006/07 samples from all other years mainly due to high abundances of yelloweye mullet and to a lesser extent sea mullet. Fish assemblages in 2010/11 and 2011/12, showed a positive association with bony herring, Australian salmon and redfin perch abundance; whilst 2012/13 samples were closely grouped and linked to an increase in yelloweye mullet and a decrease in bony herring abundances (Figure 9b).

The PCO of the 2012/13 gill net fish assemblage data captured 77.6% of the variation in the first two axes (Figure 10). There was a distinct separation of the South Lagoon from the other two subregions. The North Lagoon data were grouped closely whilst the Estuary data were sparsely distributed. The vertical distribution of data is associated with the abundance of freshwater species bony herring and carp.

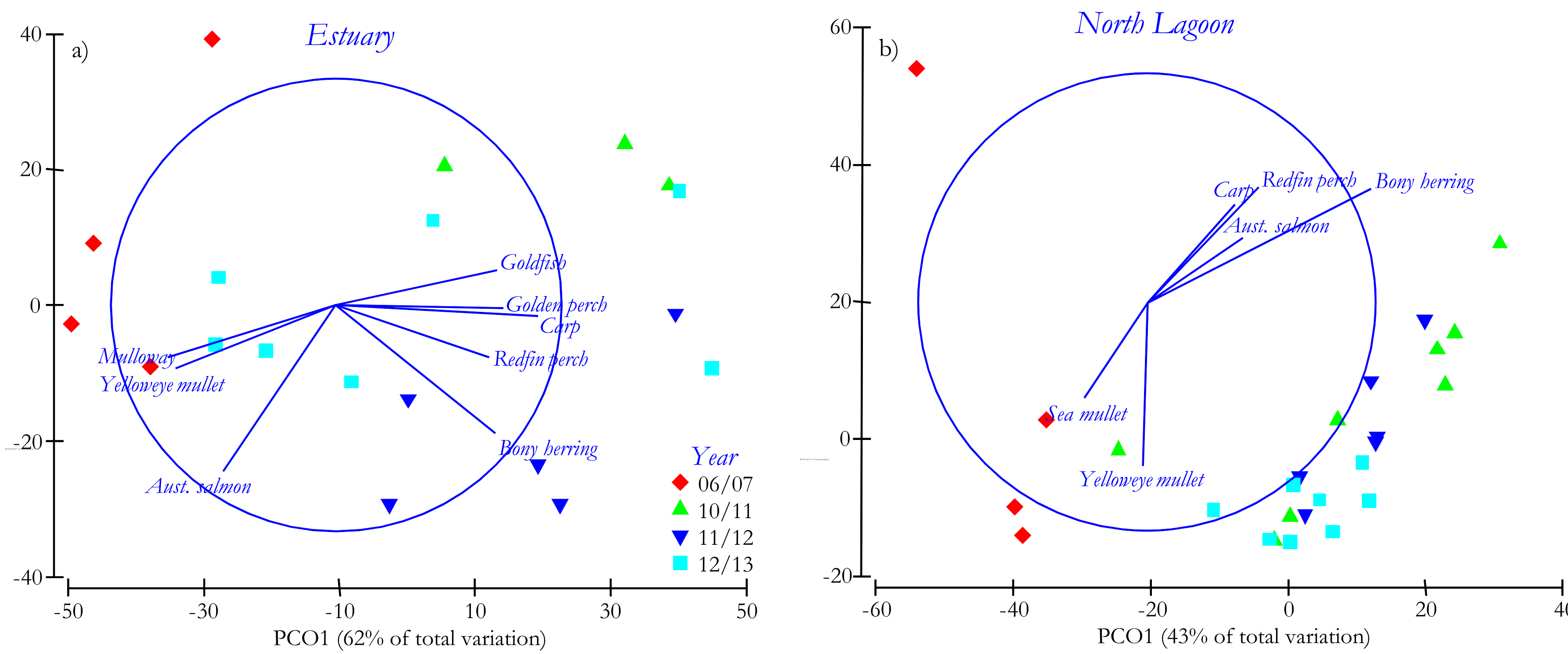


Figure 9. PCO of samples on the basis of the Bray-Curtis measure of square root transformed abundances of fish species collected by gill net in different years from each subregion a) Estuary and b) North Lagoon. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

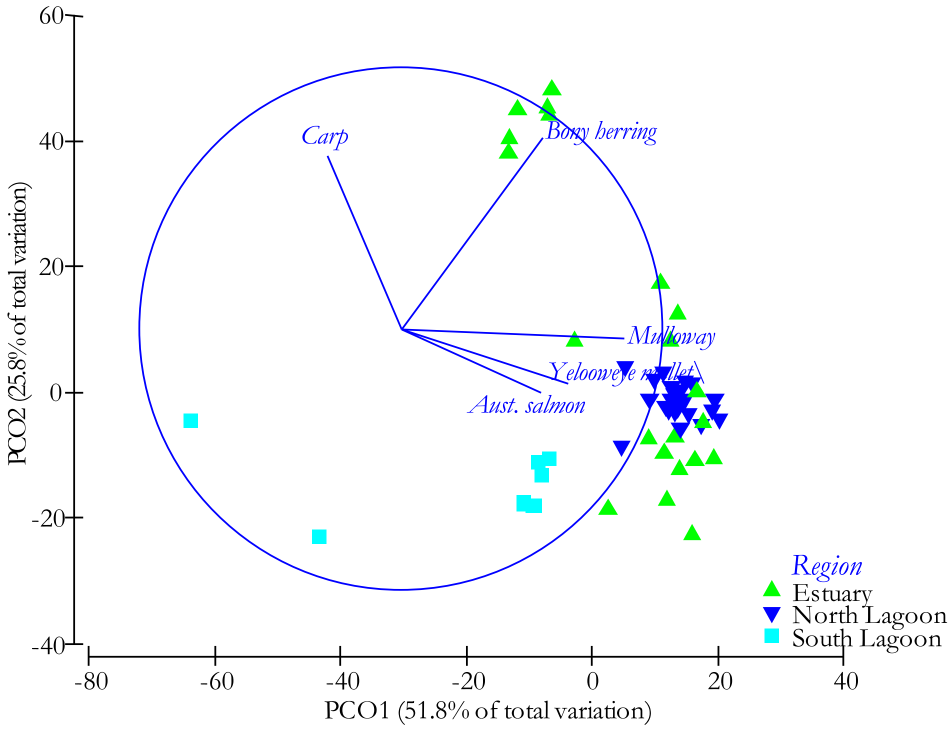


Figure 10. PCO of samples on the basis of the Bray-Curtis measure of 4th root transformed abundances of fish species collected by gill net from the three subregions during 2012/13. The vector overlay indicates Spearman rank correlations between species and PCO axes 1 and 2 (restricted to species with correlations >0.5, and with respect to a unit circle).

The DistLM analysis showed that salinity, transparency and pH were the three environmental variables that significantly contributed to explaining fish assemblages across the three regions. Together they explained 44% of the variation, with salinity strongly correlated to the horizontal axis, whilst transparency (positively) and pH (negatively) correlated with the vertical axis (Figure 11 and Table 16).

Table 16. DistLM sequential results indicating which environmental variable significantly contributed most to the relationship with the multivariate data cloud (gill net fish data). Proportion of the variation explained (Prop) and cumulative variation explained (Cumul).

Variable	Pseudo-F	P	Prop.	Cumul.
Salinity	21.17	**0.001**	0.3017	0.3017
Transparency	7.25	**0.001**	0.0872	0.3889
pH	3.79	**0.003**	0.0511	0.4400
Temperature	0.50	0.753	0.0068	0.4468

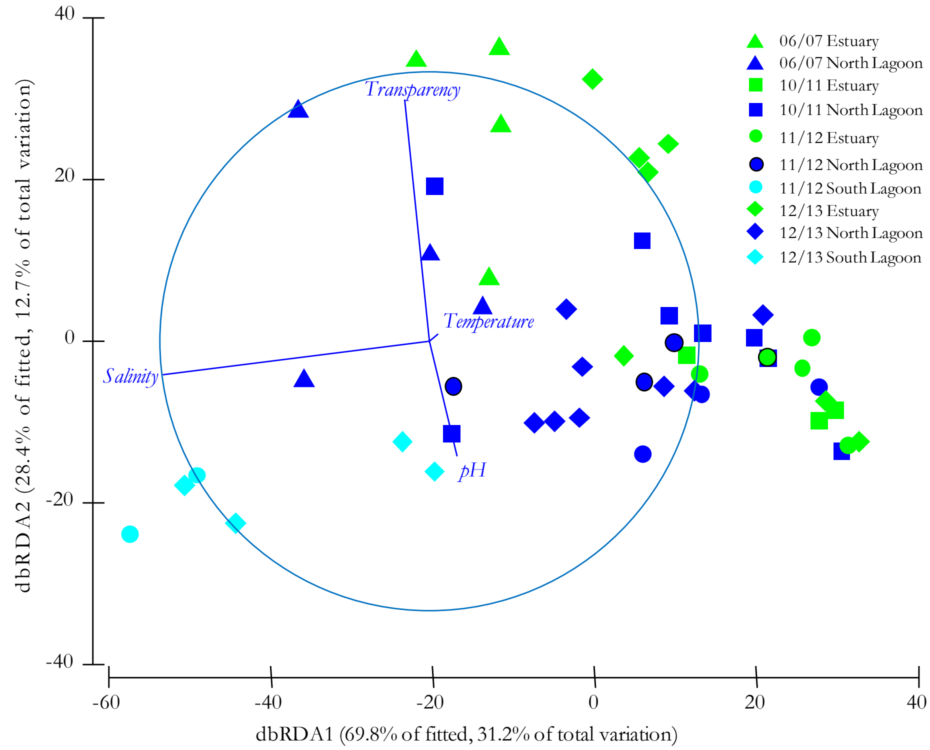


Figure 11. dbRDA ordination of the fitted model of species-abundance data collected by gill net (based on Bray-Curtis measure of square root transformed abundances) *versus* the predictor variables salinity, pH, temperature and transparency. The vector overlay indicates multiple partial correlations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

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

3.5.1. *Small-bodied estuarine species*

In 2012/13, the abundance and distribution of smallmouthed hardyhead and sandy sprat was similar to 2011/12. The small-bodied estuarine species responded well to the freshwater inflows from 2010/11 to 2012/13. Smallmouthed hardyhead and sandy sprat showed a substantial increase in abundance in the flow years compared to 2006/07 (Figures 12 a, b) with sandy sprat also extending its distribution range. The abundance of Tamar goby also increased in 2010/11 in the Estuary and the northern part of the North Lagoon. In the following two years, this species continued to show southward range extension to the southern part of the North Lagoon (Figure 13). Nevertheless, both sandy sprat and Tamar goby were absent in samples in the South Lagoon in all years.

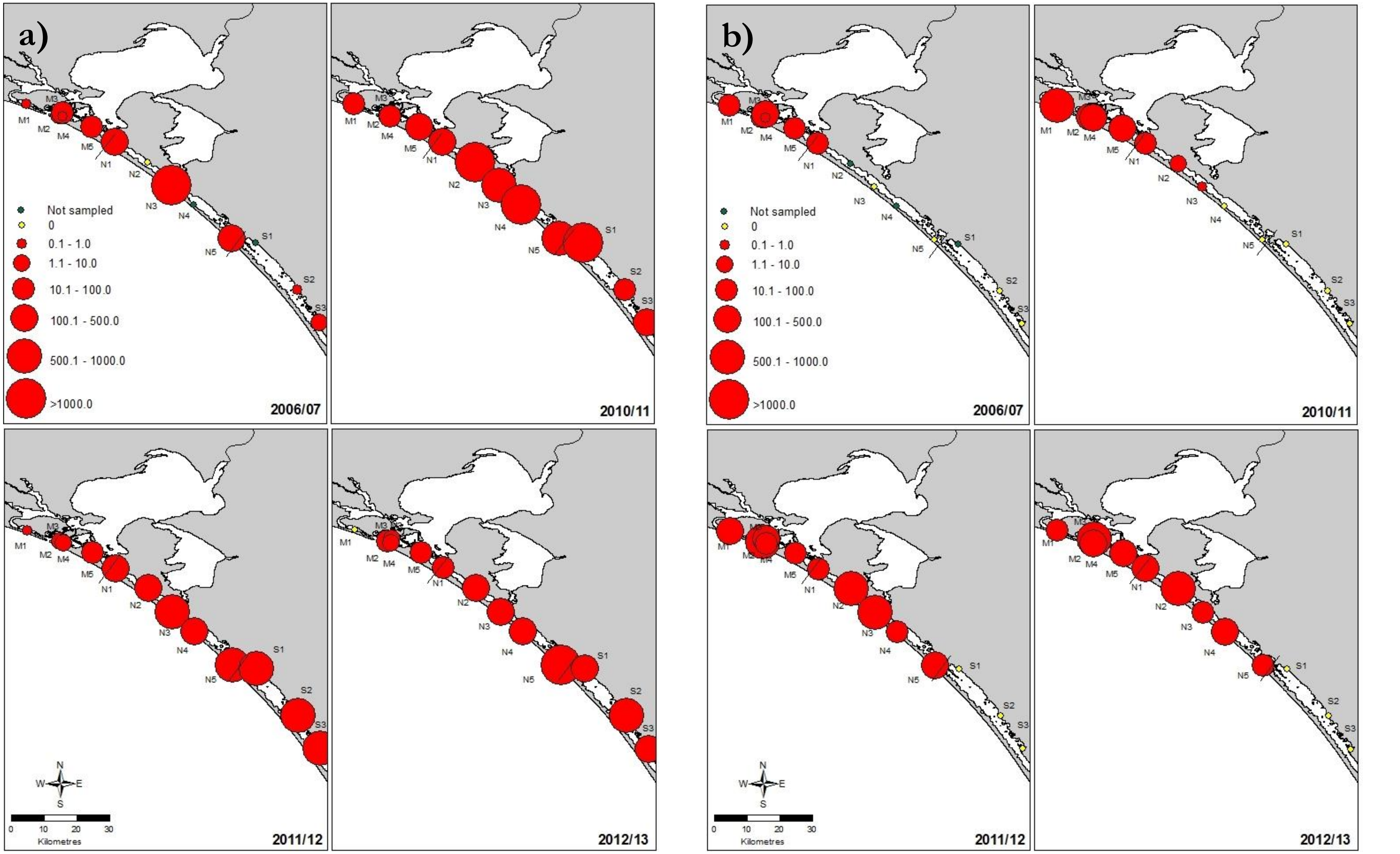


Figure 12. a) Smallmouthed hardyhead and b) sandy sprat relative abundance and distribution in 2006/07-2012/13 for the Coorong.

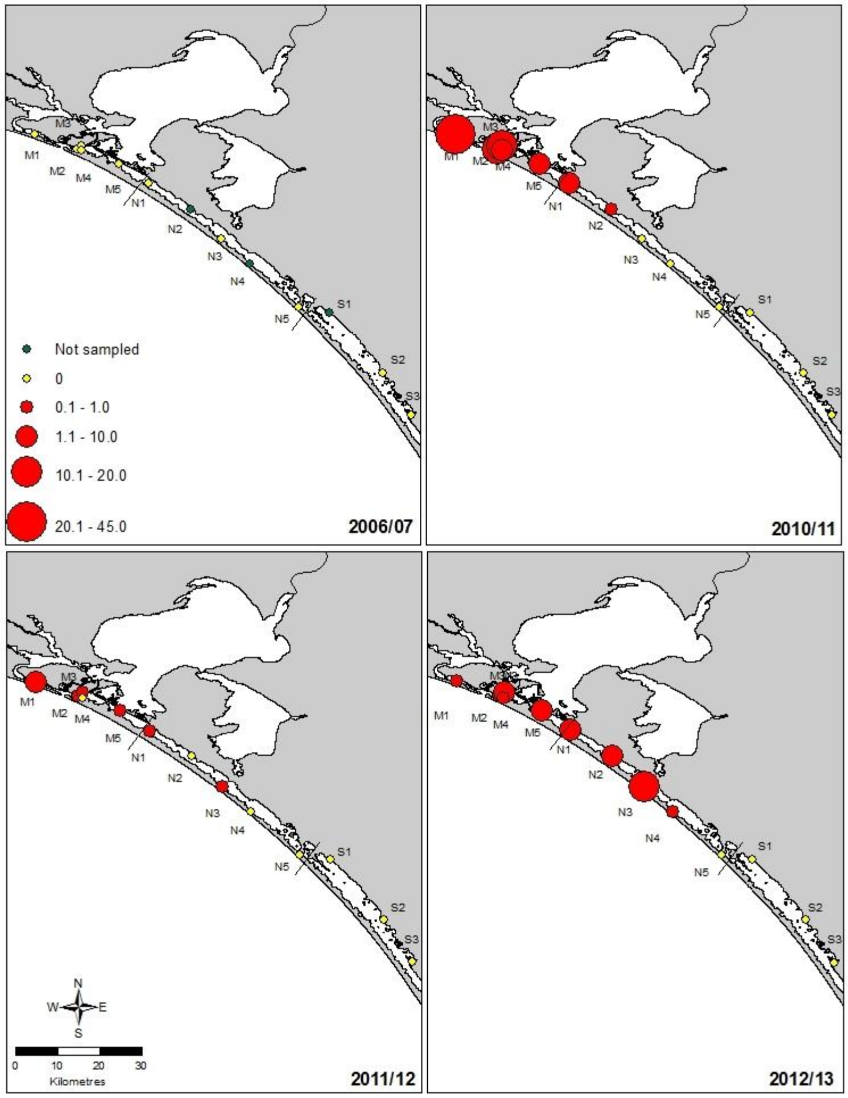


Figure 13. Tamar goby relative abundance and distribution in 2006/07 -2012/13 for the Coorong.

3.5.2. *Catadromous species*

Juvenile congolli showed a positive response in 2010/11 and 2011/12; in 2012/13 abundance in the Estuary and North Lagoon increased substantially (Figure 14a). A southward extension in distribution was observed consistently throughout the flow years. In 2012/13, congolli was sampled in the South Lagoon for the first time, although in low numbers compared to the North Lagoon and Estuary. There was a general increase in abundance of adult congolli in 2011/12, however in 2012/13, it decreased in abundance, but maintained its spatial distribution (Figure14b).

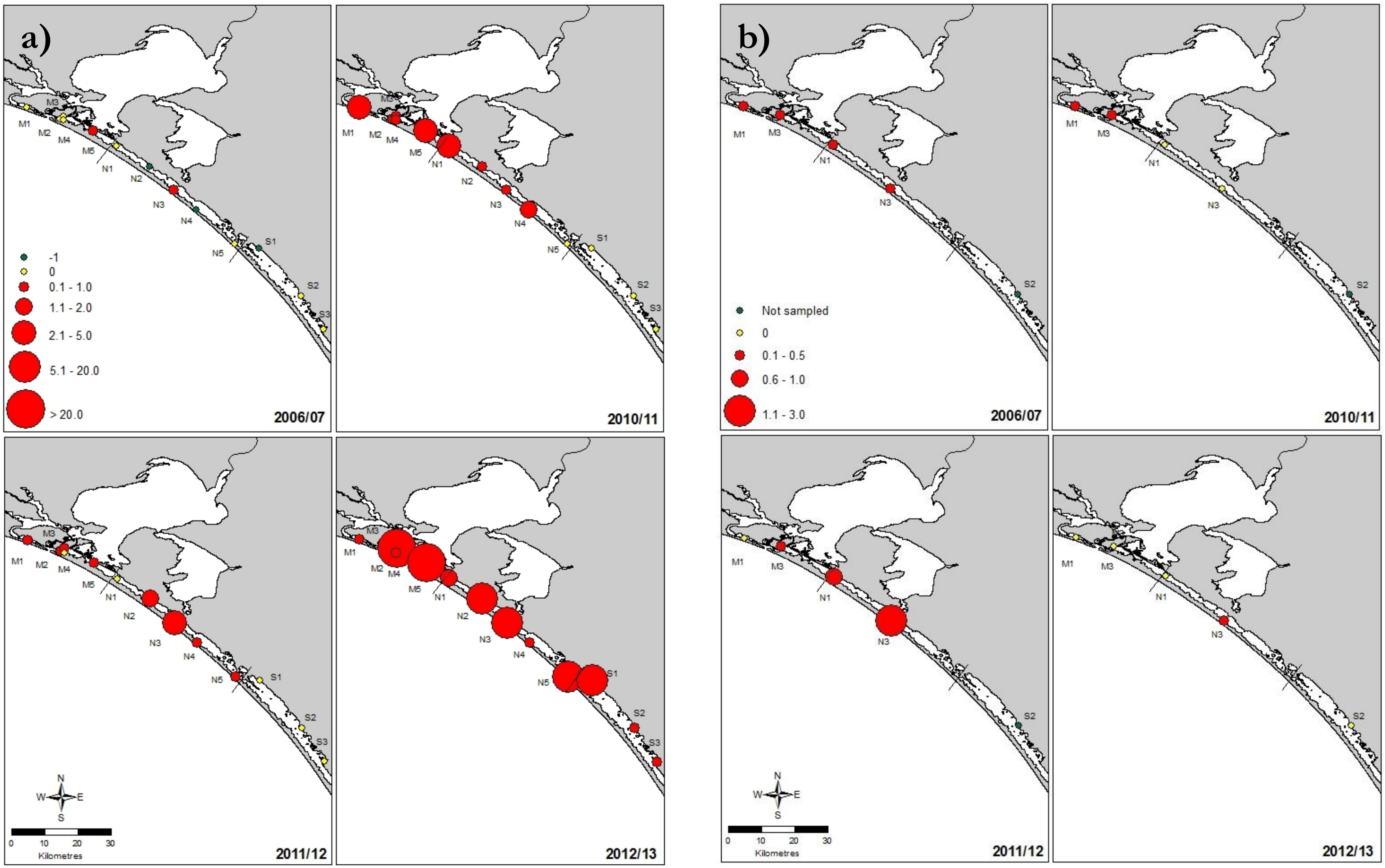


Figure 14. Congolli relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong.

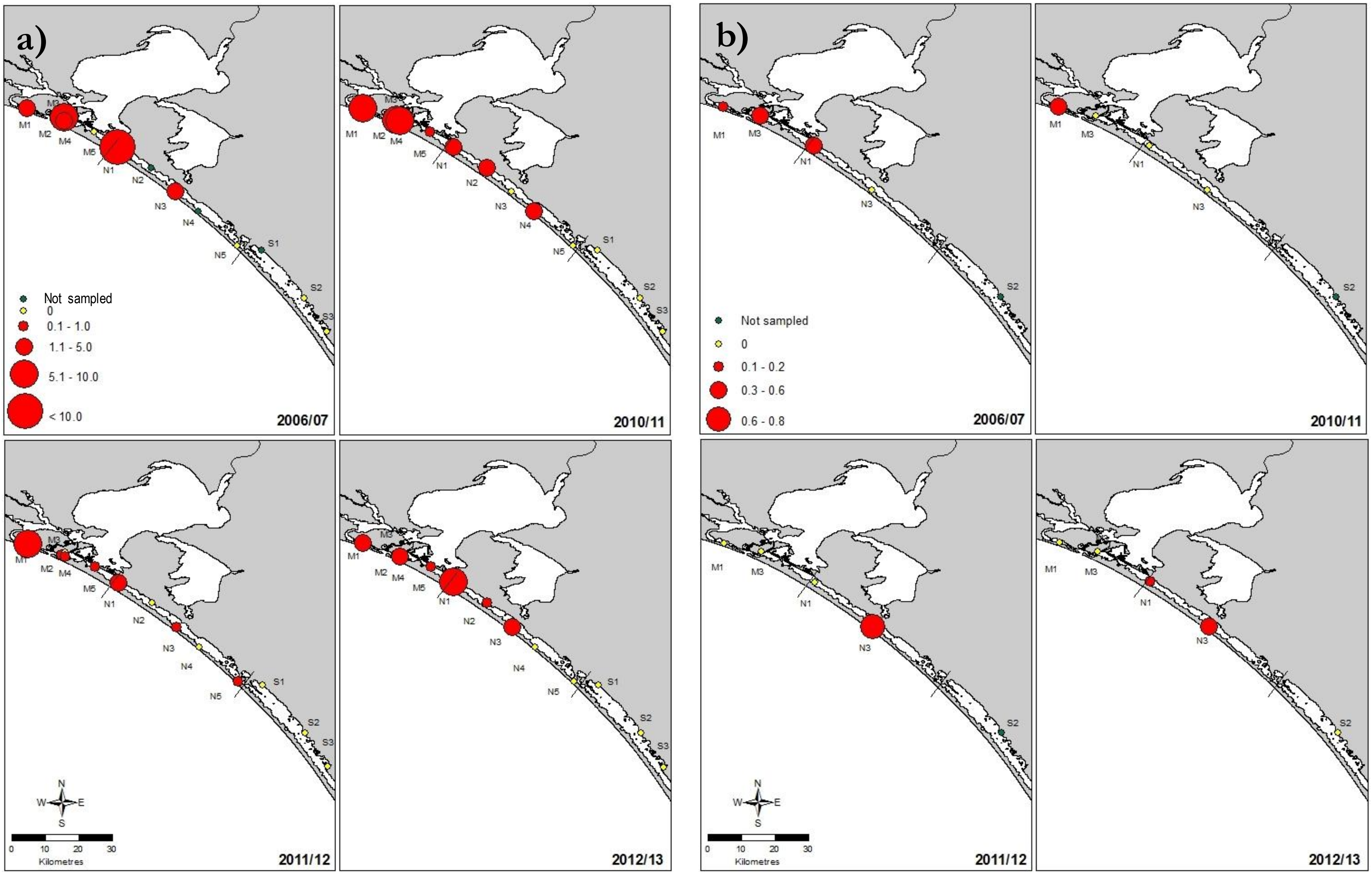
3.5.3. *Large-bodied estuarine species*

Juvenile greenback flounder showed a slight increase in abundance in the North Lagoon in 2012/13 relative to all other years (Figure 15b). Its distribution range, however, slightly contracted in a northward direction only reaching Noonameena (N3) in 2012/13, compared to the extended range southward to Hells Gate (N5) in 2011/12 (Figure 15a). Abundance of large greenback flounder seems to have declined in the Estuary since 2010/11 but increased in the North Lagoon since 2011/12.

For yelloweye mullet, there was a clear southward range extension particularly in 2011/12 compared to 2006/07 seine net samples; remarkably, juveniles were found in the southern part of the South Lagoon in 2011/12. That trend continued in 2012/13 with larger abundances of juveniles caught at more sites in the South Lagoon (Figure 16a). Furthermore, adult fish were caught in gill nets in the South Lagoon as well as the North Lagoon and Estuary in 2012/13 (Figure 16b).

The data indicated a low abundance of black bream in the Coorong in all four years. In 2006/07, both seine net and gill net catches were limited to the Estuary subregion (Figure 17). In 2010/11, no juvenile fish were sampled by seine net, however, there was an increase in gill net catch of adults, with their range extending into the North Lagoon. In 2011/12, two black bream were collected by seine net (one juvenile in the Estuary and one adult in the South Lagoon); no black bream were caught by gill net. In 2012/13, black bream were only present in seine nets in Salt Creek in the South Lagoon and in gill nets at one site in the Estuary (Figure 17 a, b).

In 2012/13, mulloway catch by seine net occurred at one site in the Estuary and one site in the North Lagoon. Catch by seine net was restricted to the Estuary in 2006/07, however, extended to the North Lagoon in 2012/13 (Figure 18a). There was a general decline in gill net catch of mulloway in 2010/11, followed by a considerable increase in 2011/12, particularly in the North Lagoon. In 2012/13, gill net catch in the Estuary increased and some fish were also obtained in the North Lagoon (Figure 18b).



.

Figure 15. Greenback flounder relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong

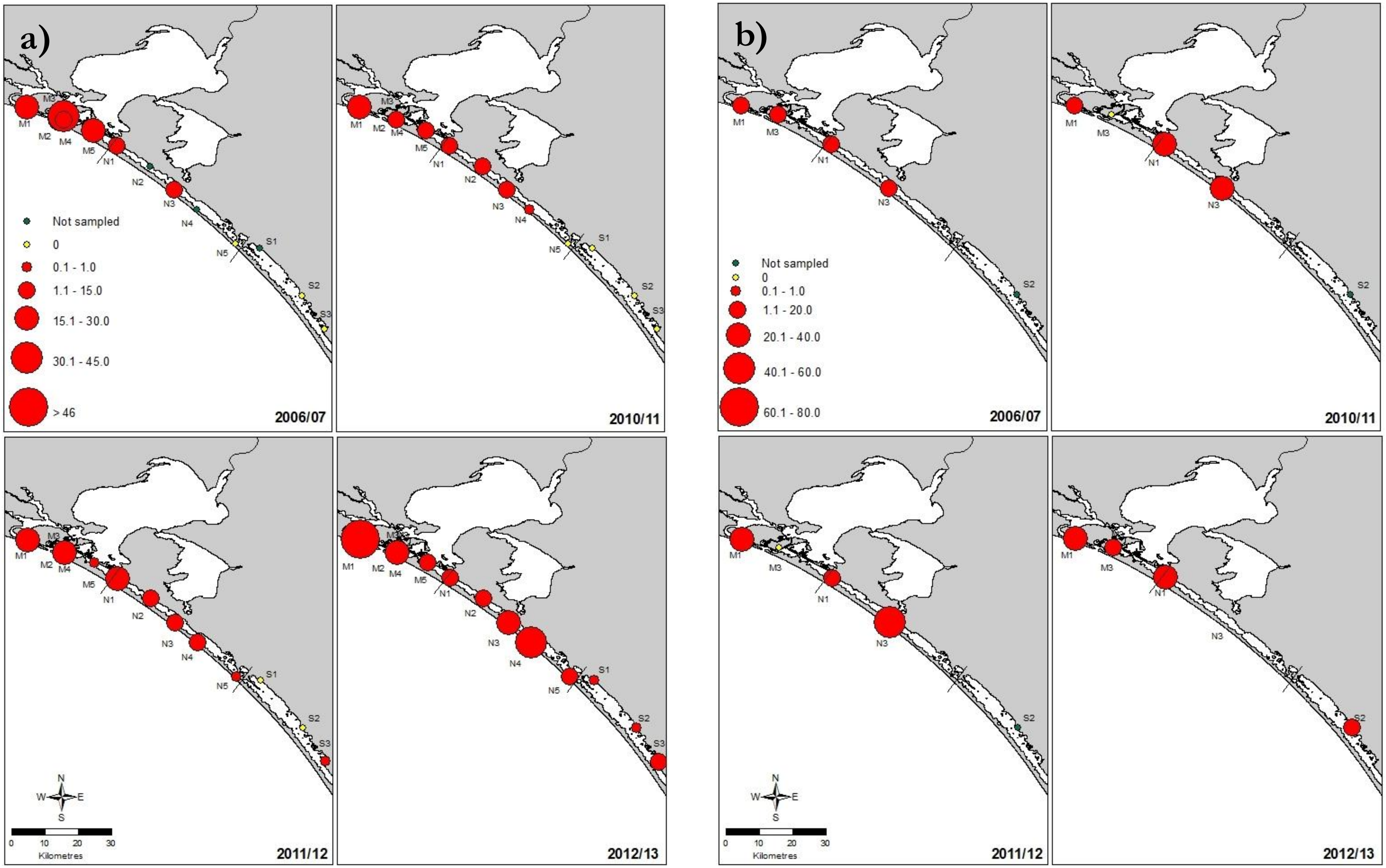


Figure 16. Yelloweye mullet relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong.

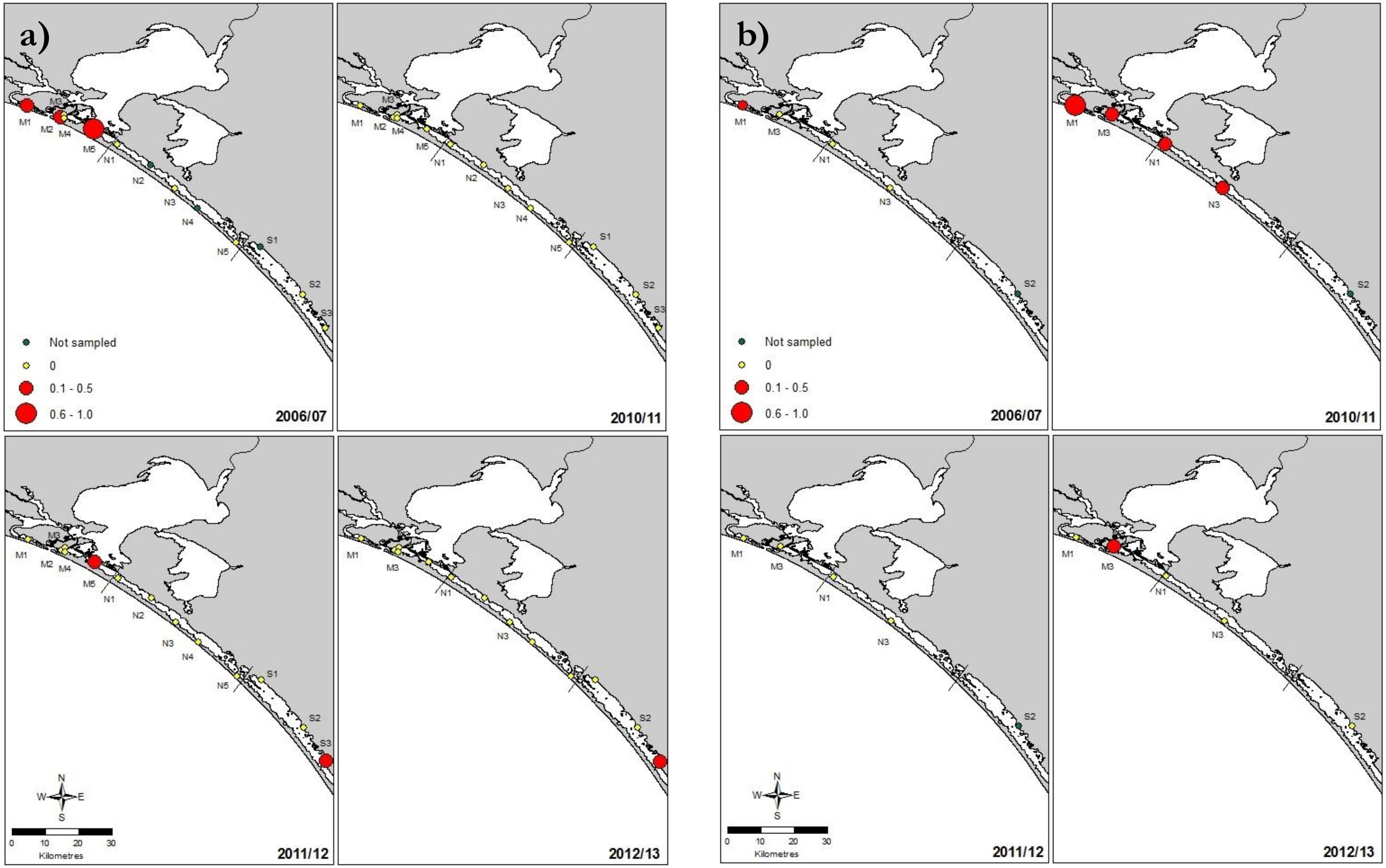
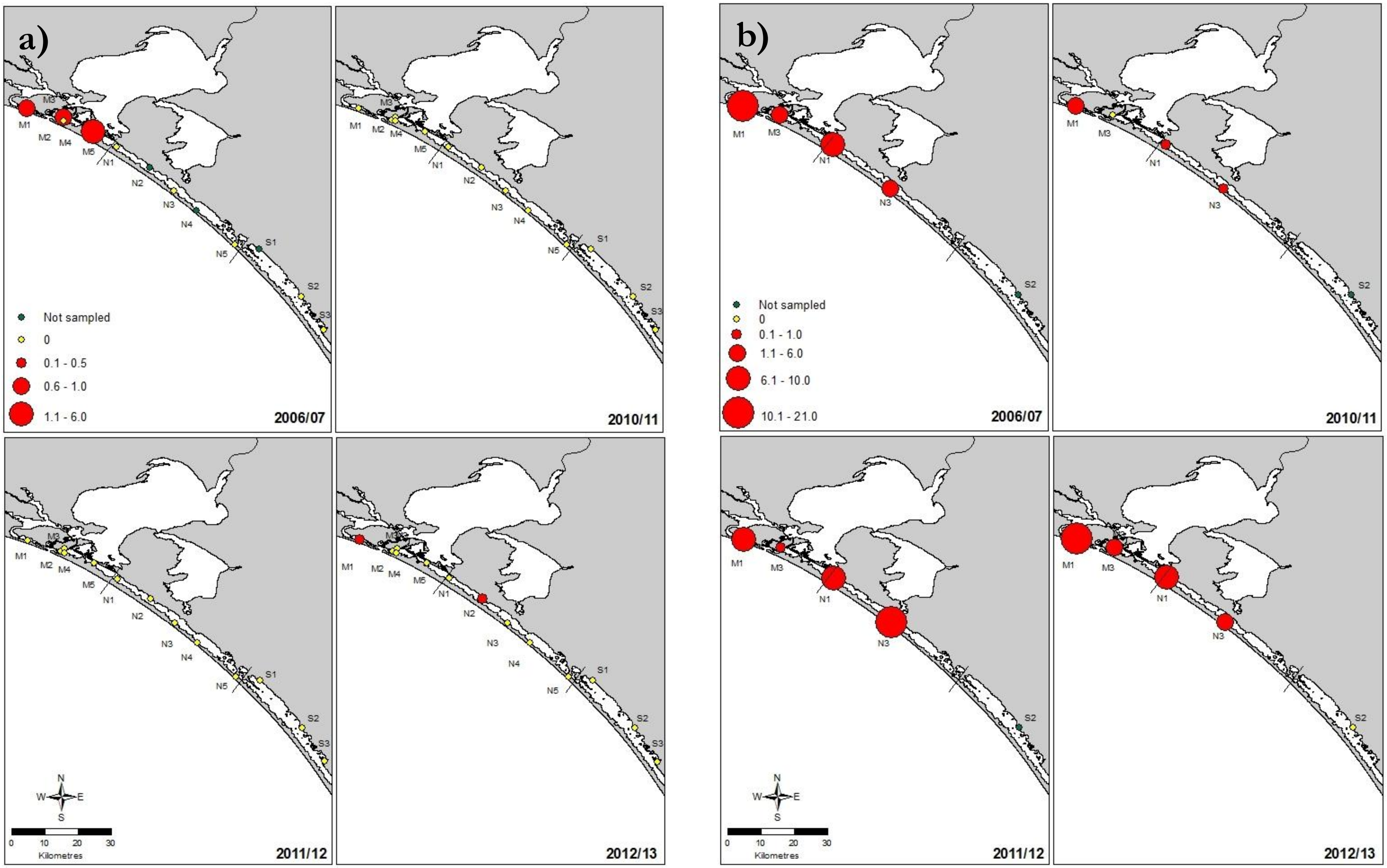


Figure 17. Black bream relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong



.

Figure 18. Mulloway relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong.

3.5.4. *Freshwater native species*

In 2012/13, bony herring maintained a similar abundance to 2011/12 but its distribution extended further into the South Lagoon. For the first time in the sampled years bony herring was sampled by both gear types in the South Lagoon in 2012/13 (Figure 19a, b).

3.5.5. *Freshwater exotic species*

Carp and redfin perch, previously absent in the Coorong in the drought years (Noell *et al.* 2009), were sampled in large numbers by both gear types in 2010/11, particularly in the Estuary and northern part of the North Lagoon (Figures 20 and 21). In 2011/12, seine net samples showed a decline in both abundance and distribution of carp, with catches restricted to the Estuary (Figure 20a), whilst gill net data indicated variable abundance in adult carp between sites with a similar range to the previous year's (Figure 20b). In 2012/13, carp distribution was limited to the Estuary for both gear types, with very low abundances observed in seine net catches.

Similarly, for redfin perch, seine net samples showed a decline in both abundance and distribution from 2010/11 to 2011/12. In 2012/13, both seine and gill net sampled fish abundances declined and distributions were limited to the Estuary (Figure 21a, b).

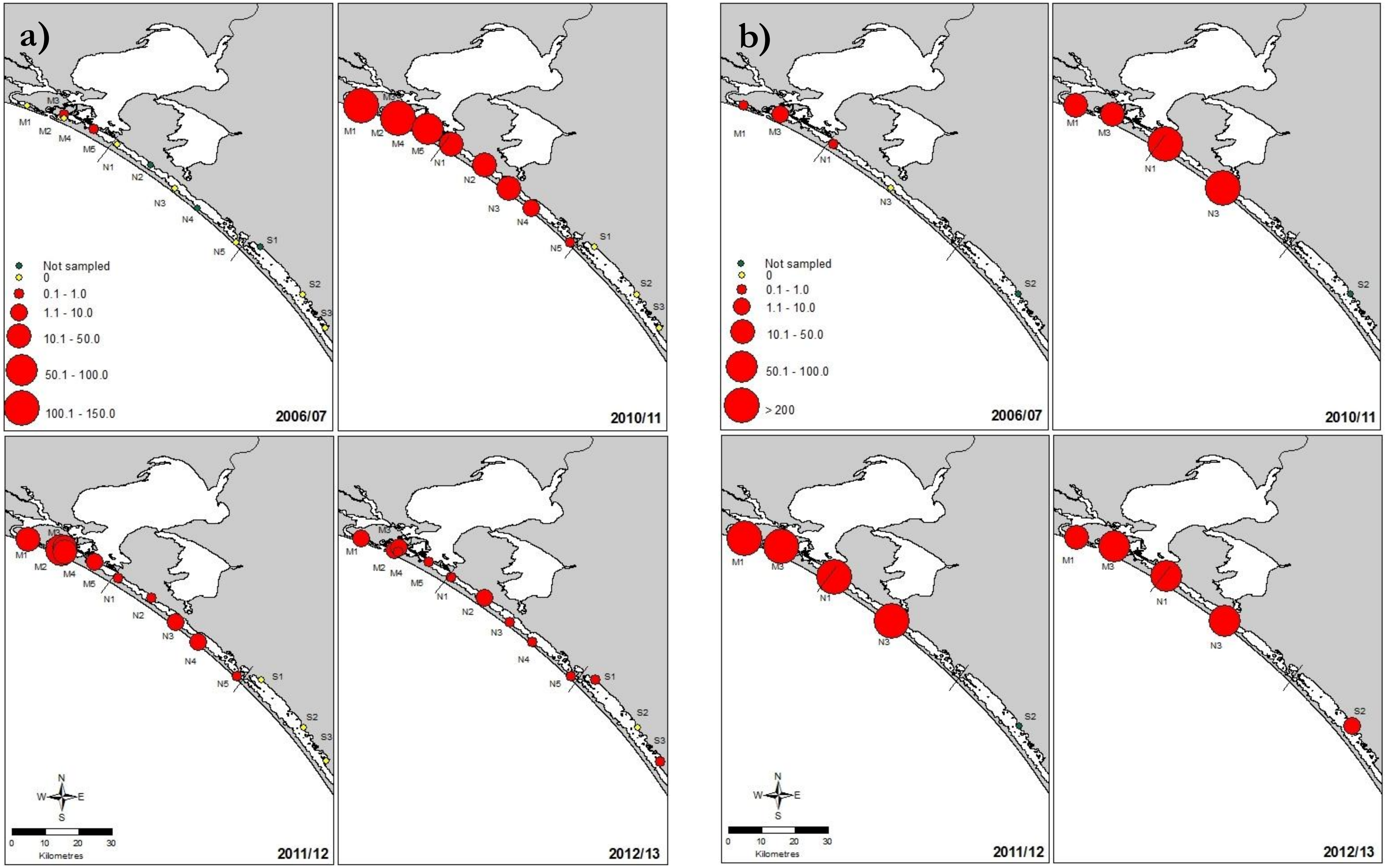


Figure 19. Bony herring relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong

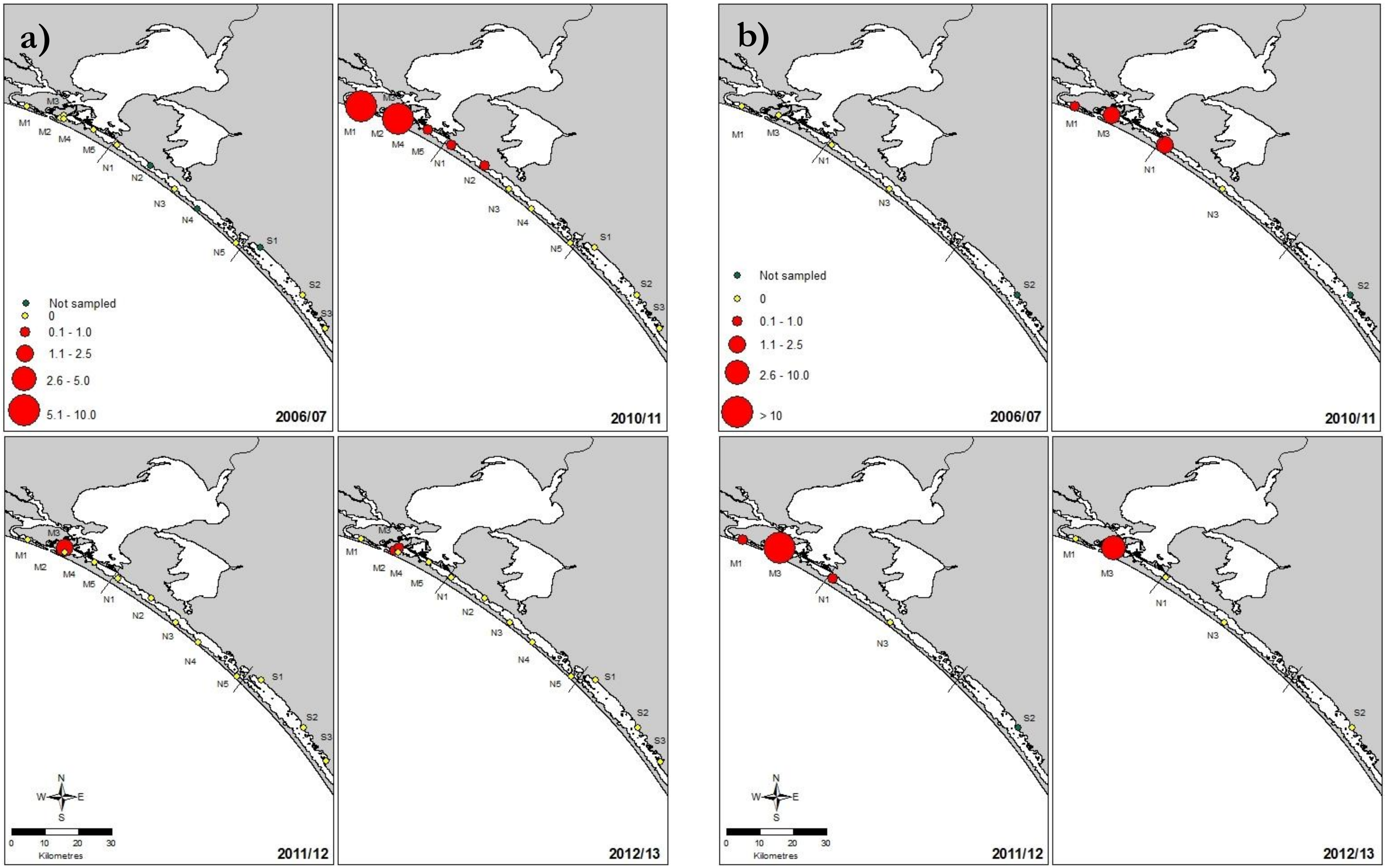


Figure 20. Carp relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong

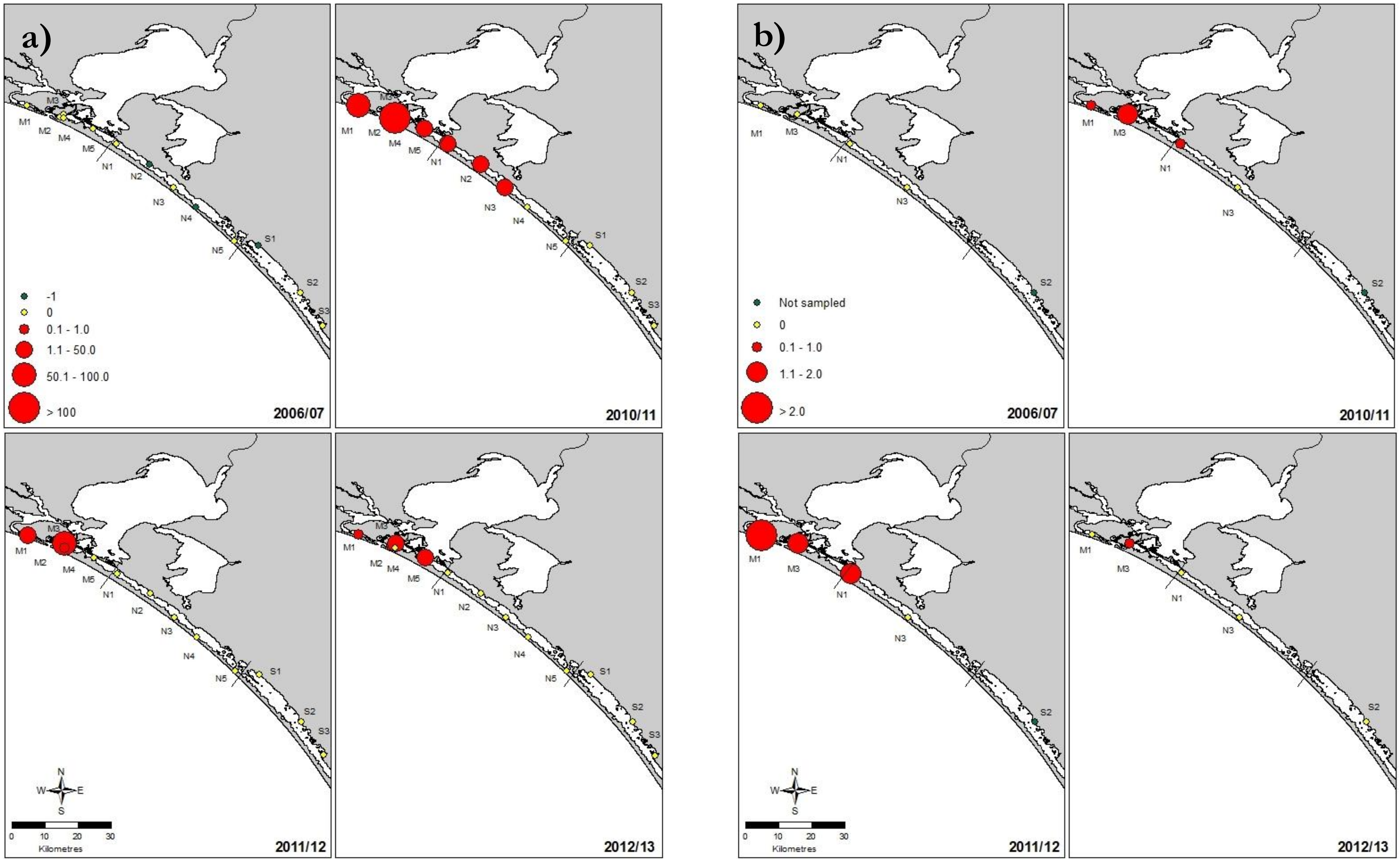


Figure 21. Redfin perch relative abundance and distribution for a) seine net and b) gill net in 2006/07-2012/13 for the Coorong

3.6. Length frequency distributions of key species

Length measurement data were obtained from fish collected using both seine nets and gill nets. Seine netting from the shore was most effective for sampling small-bodied species and juveniles of large-bodied species, whilst gill nets were set near the main channel, targeting adults of large-bodied species. It is assumed that both methods collectively sampled most size classes of the fish populations. Length frequency data can enable the identification of cohorts that can sometimes be inferred as year classes, to identify recruitment events for key species.

3.6.1. *Small-bodied estuarine species*

The length frequency distributions for smallmouthed hardyhead and Tamar goby generally showed broad ranges in size distribution (Figure 22 and 24, respectively). Several size classes were also present for sandy sprat (Figure 23). These size structures, in conjunction with occasional samples of very small fish, indicated successful recruitment for these species (Figures 22, 23 and 24). Most significantly for smallmouthed hardyhead, many new recruits were collected in the North and South Lagoons in 2010/11, 2011/12 and 2012/13 (Figure 22). Sandy sprat in 2012/13 showed a larger proportion of recruits from the North Lagoon than the Estuary with no fish sampled in the South Lagoon (Figure 23). The recruitment of Tamar goby was strong in the Estuary and North Lagoon in 2012/13, in contrast with the previous two years where it had occurred mainly in the Estuary. Furthermore Tamar goby was observed in the South Lagoon for the first time in the sampled years (Figure 24).

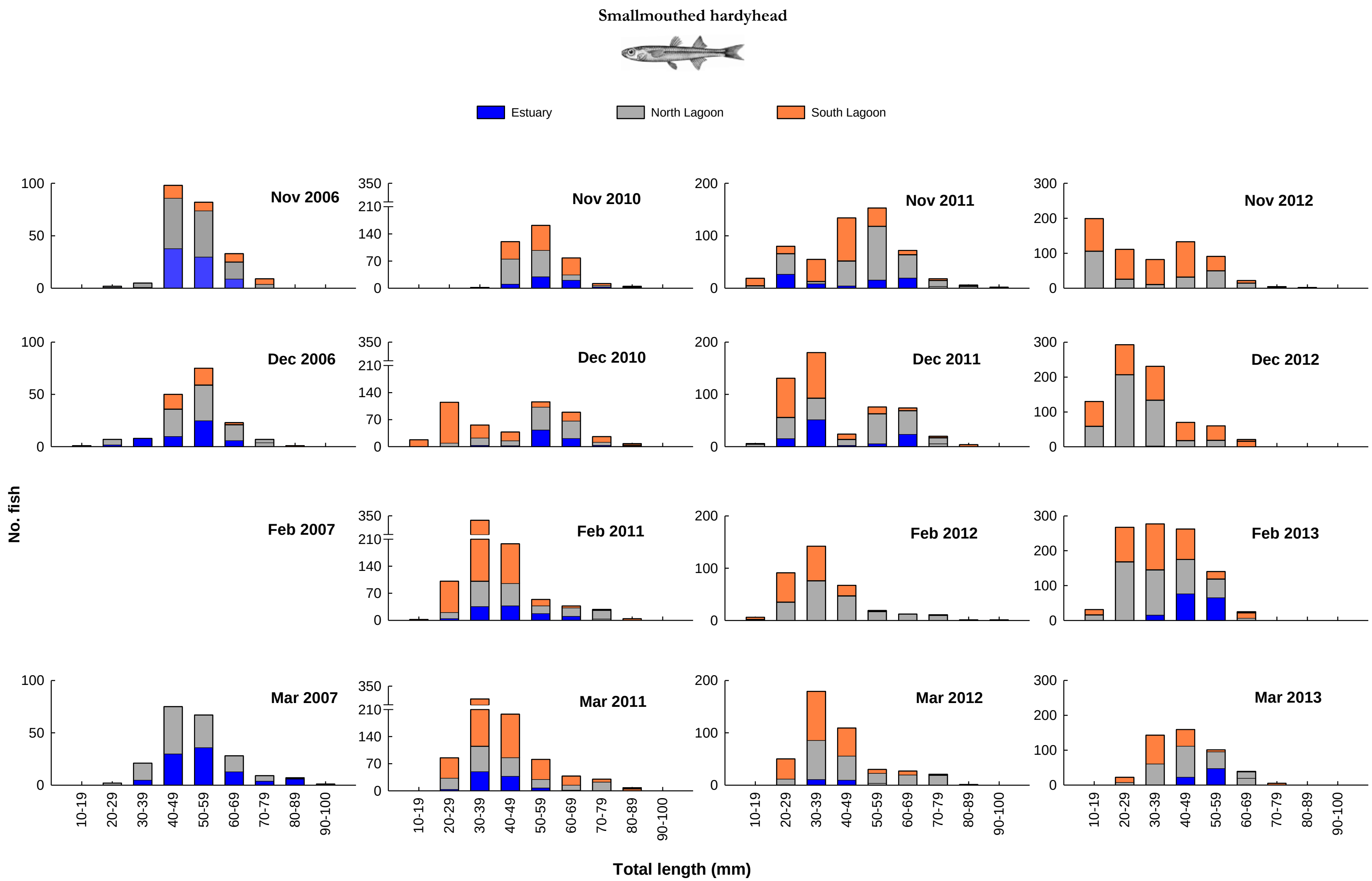


Figure 22. Length frequency distributions of smallmouthed hardyhead from seine net samples in the Estuary, North Lagoon and South Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis

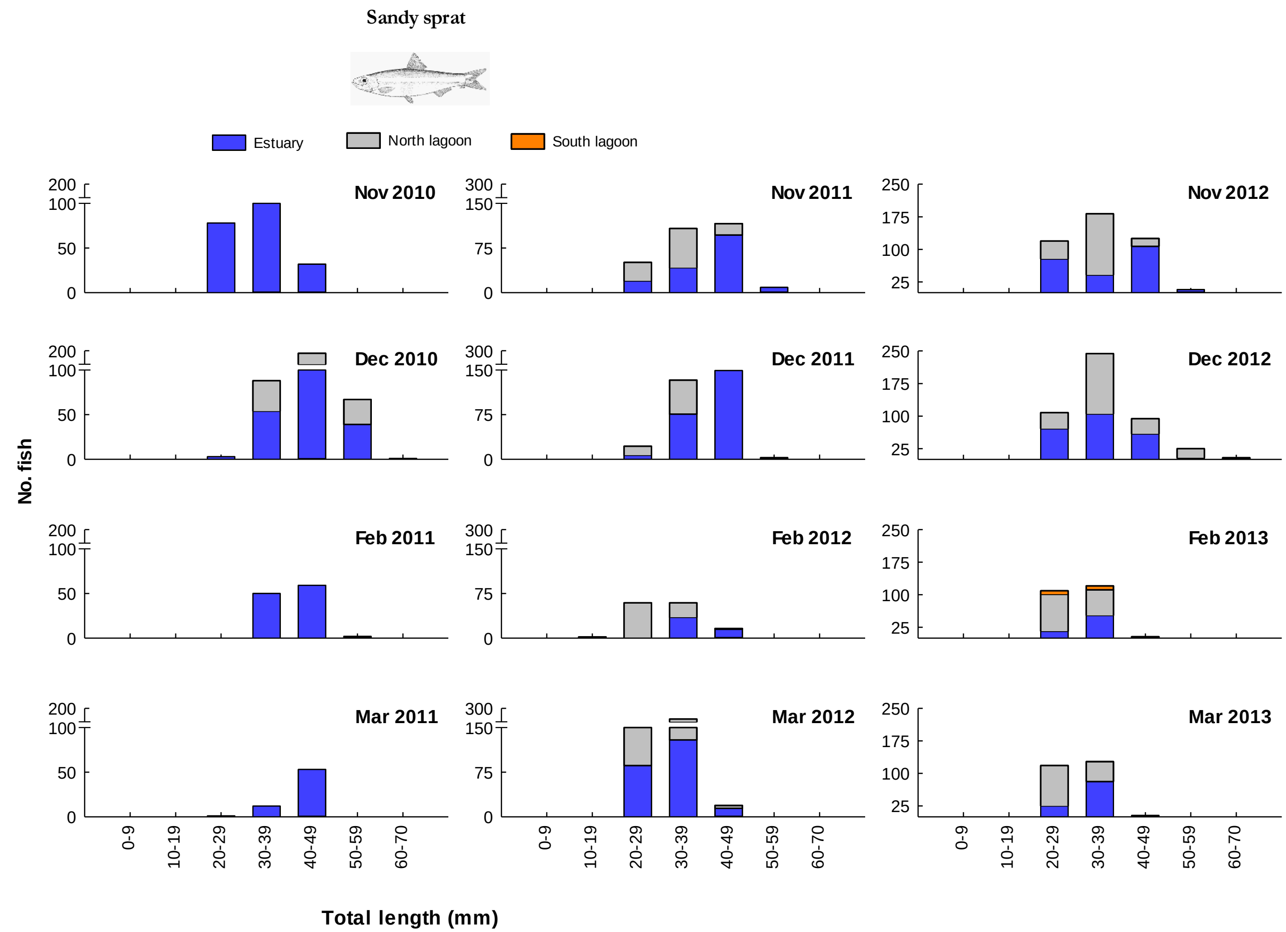


Figure 23. Length frequency distributions of sandy sprat from seine net samples in the Estuary and North Lagoon subregions of the Coorong in 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

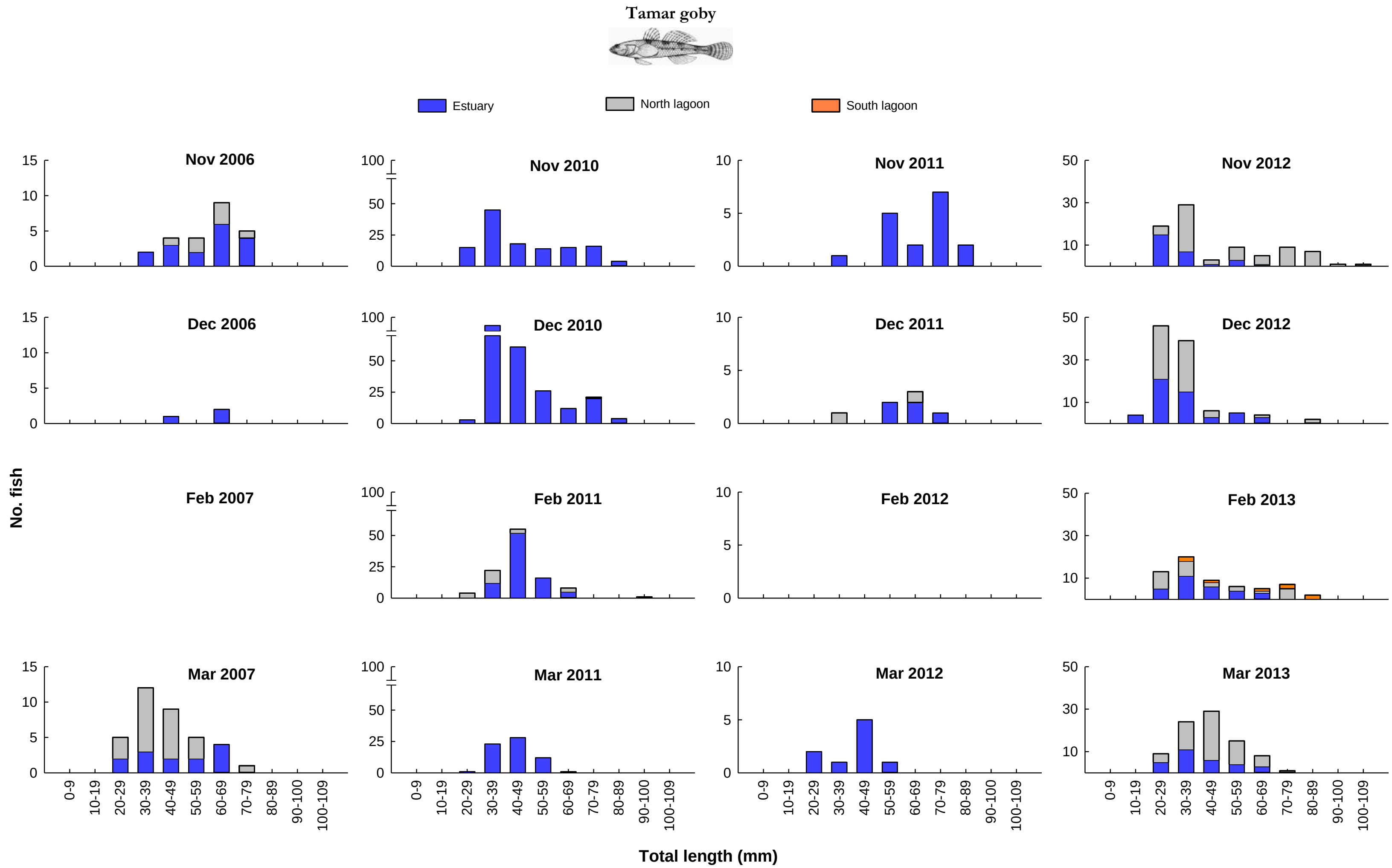


Figure 24. Length frequency distributions of Tamar goby from seine net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

3.6.2. *Catadromous species*

Congolli, as a medium-bodied species, were successfully collected by both gear types in all years. However, in 2012/13 the abundance of recruits was more than tenfold that of any of the previous years sampled. The length frequency distributions indicated strong cohorts coming through from the Estuary and North Lagoon and there was even presence of recruits in the South Lagoon; albeit in much smaller abundances. Whilst in 2010/11, fish numbers increased compared to the drought years, those abundances remained similar in 2011/12. The current year shows an increase in recruits across all regions (Figure 25).

Congolli

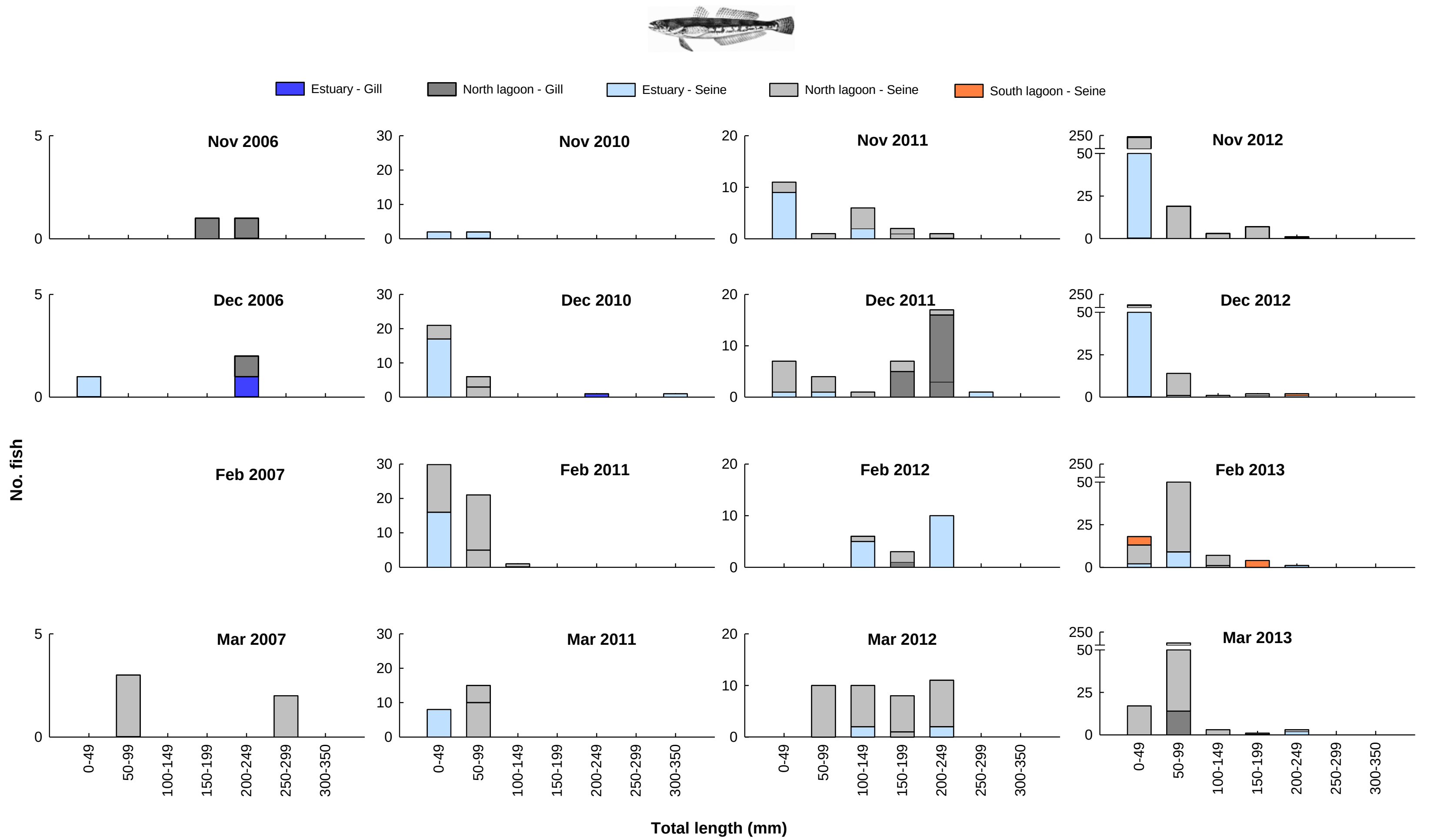


Figure 25. Length frequency distributions of juvenile and adult congolli from seine and gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

3.6.3. *Large-bodied estuarine species*

The length frequency distribution of greenback flounder was unimodal in all years. The size compositions of juvenile greenback flounder in 2012/13 were similar to those in the previous year, with a strong mode in the 50-99 mm TL. This modal size appeared to be larger than fish sampled in corresponding months in 2006/07 and 2010/11 (i.e. 0-49 mm TL) (Figure 26). Seine netting appeared to be effective for sampling juvenile greenback flounder. 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 distribution. In 2012/13, there was a clear bimodal size distribution in the first two sampled months (November and December). The larger cohort did not appear from February onwards, however, the smaller cohort could be followed throughout the entire sampling regime showing a good modal progression. This smaller cohort was mainly found in the Estuary with a small contribution from the North and South Lagoons, whilst the larger cohort was found throughout the three regions (Figure 27).

Mulloway were present in both the Estuary and North Lagoon in all years. In 2012/13, mulloway were mainly collected in the Estuary by gill net, with a broad size range from 80 to 560 mm. A distinct modal progression could be observed from December 2012 to March 2013 (Figure 28). In all years, there was a high number of 160-239 cm size class, suggesting that new recruits entered the Coorong at this size around December.

Black bream were collected in very low numbers throughout the study period. Length frequency data were patchy; hence it was not clear whether recruitment success occurred (Figure 29).

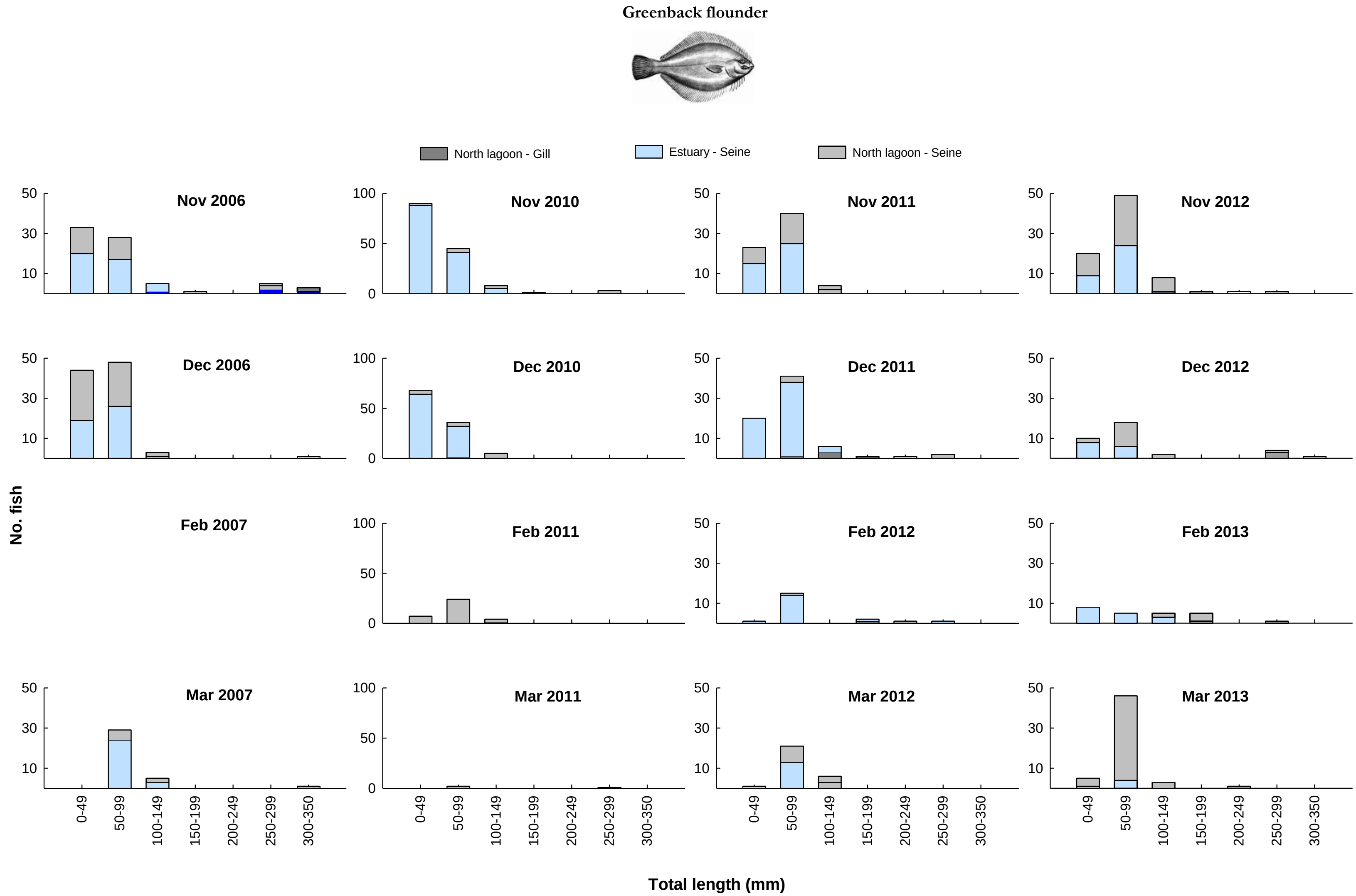


Figure 26. Length frequency distributions of juvenile and adult greenback flounder from seine and multipanel gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

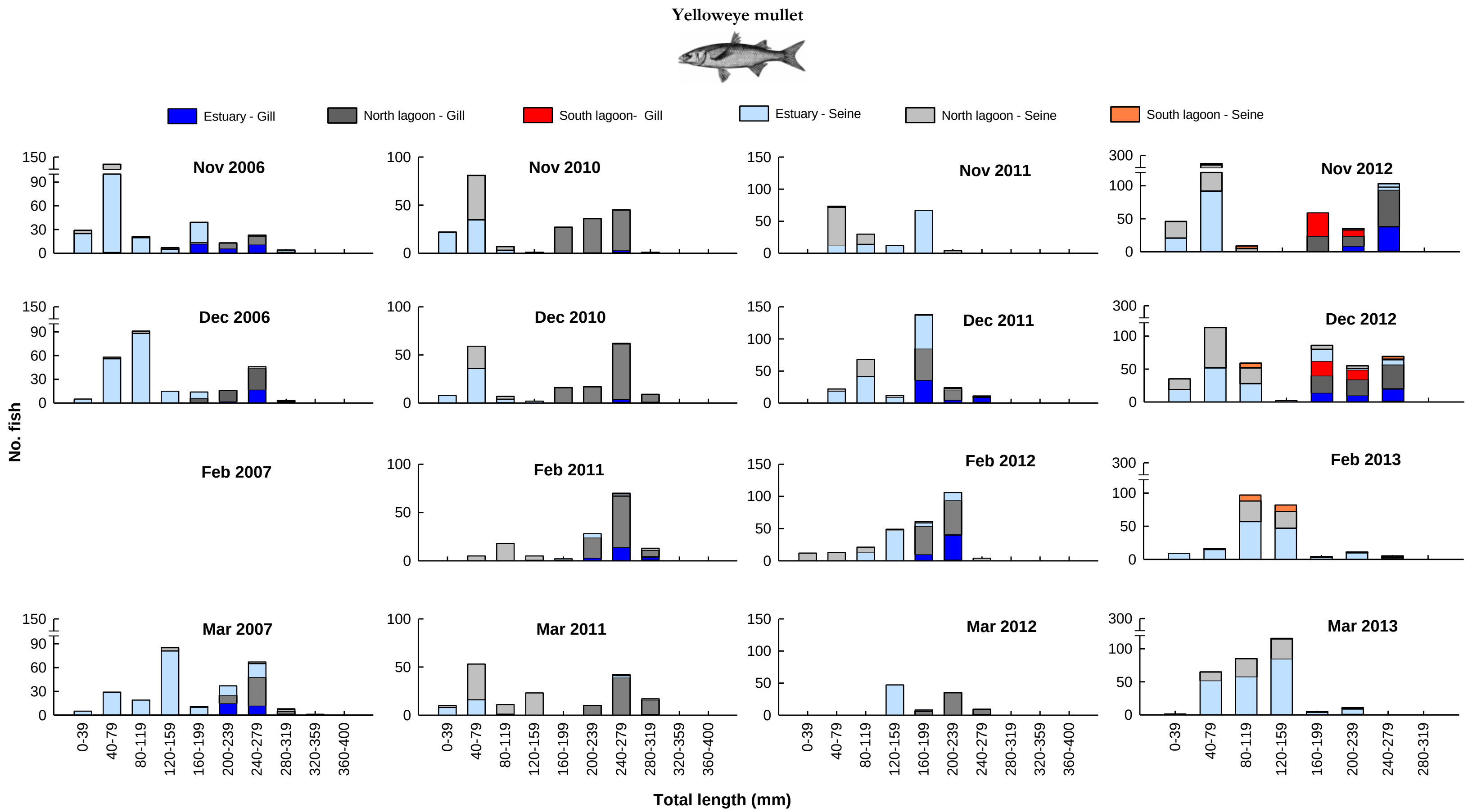


Figure 27. Length frequency distributions of juvenile and adult yelloweye mullet from seine and multipanel gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

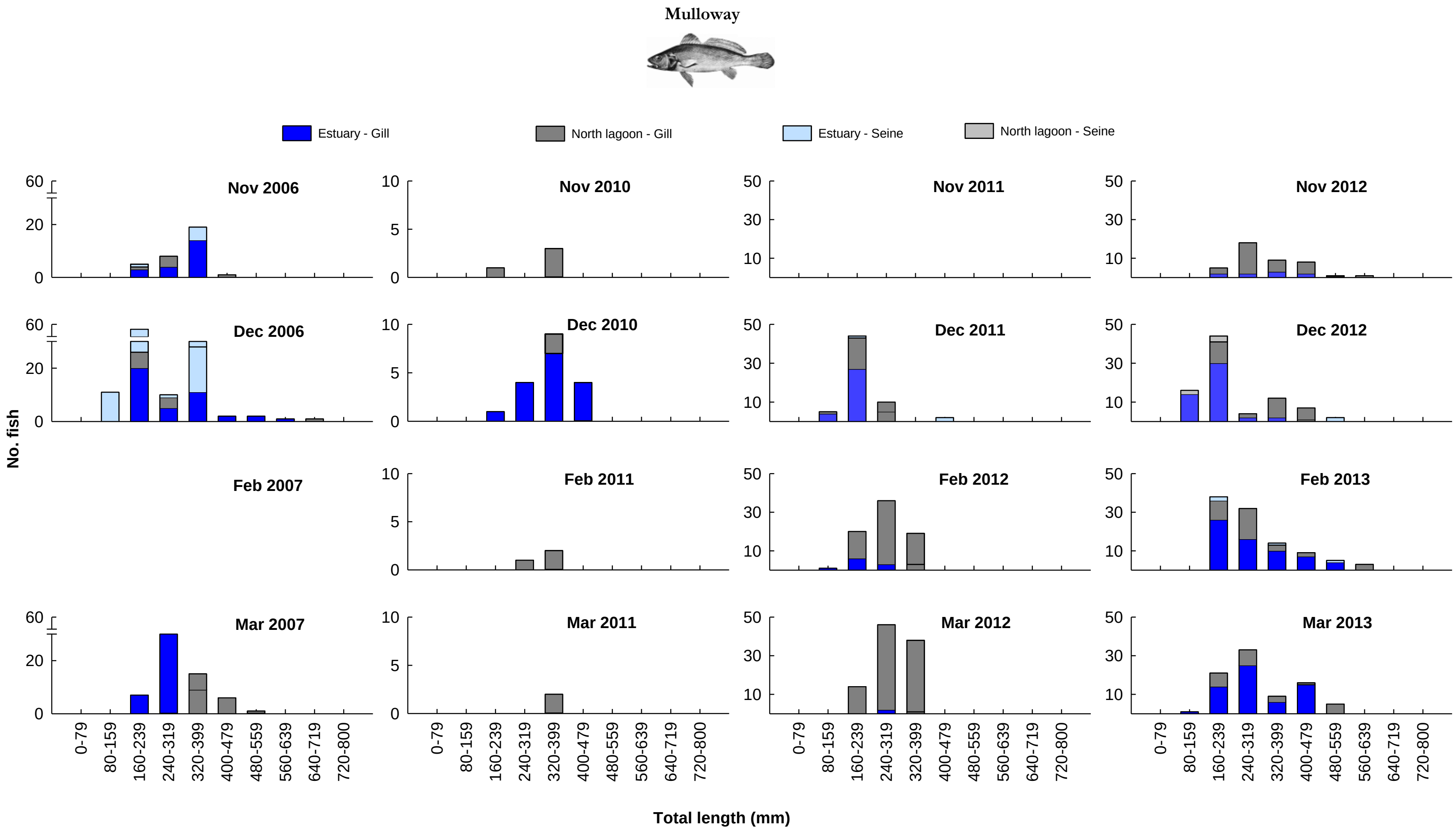


Figure 28. Length frequency distributions of juvenile and adult mulloway from seine and multipanel gill net samples in the Estuary and North Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

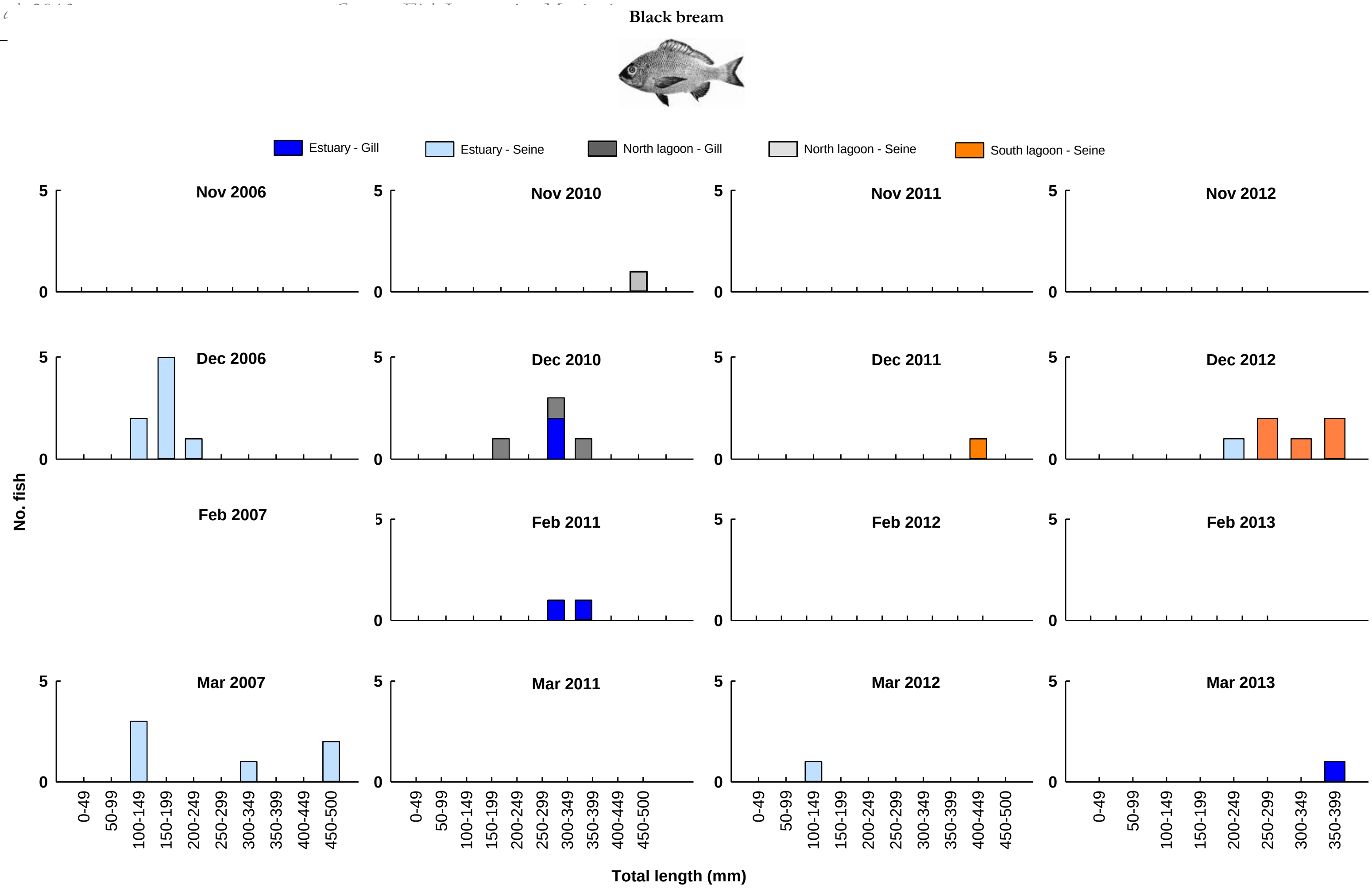


Figure 29. Length frequency distributions of juvenile and adult black bream from seine and multipanel gill net samples in the Estuary, North Lagoon and South Lagoon subregions of the Coorong in 2006/07, 2010/11, 2011/12 and 2012/13. Note the scale differences on the y-axis.

4. DISCUSSION

4.1. Barrage flow

The extensive and well documented drought that affected the MDB during the first decade of the 21st century significantly reduced freshwater flows to the Coorong. Annual discharge during this period was <1000 GL y^{-1}, including a period of zero discharge between 2007/08 and 2009/10. One of the most obvious impacts the drought had on water quality in the Coorong was the increase in salinity. The Estuary subregion remained at typically marine salinities, whilst the entire North Lagoon and South Lagoon reached hypersaline conditions. The drought scenario drastically changed in 2010 due to high rainfall in the MDB which increased flow in the River Murray, Lower Lakes and finally 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.

The flow to the Coorong in 2012/13 was lower than that observed in the previous two flow years. The effects of the reduction in flow to salinity were evident in the Estuary and North Lagoon subregions. This could potentially be caused by the intrusion of sea water when there is not enough freshwater flow through the mouth of the River Murray. In the South Lagoon, salinity was comparable to previous flow years suggesting that there may be a lag in the response time in this region due to its distance to the mouth. If low flows into the Coorong continue salinity in all the subregions is expected to increase, albeit at differential rates.

The other important water characteristic that significantly changed with the return of freshwater flows to the Coorong in 2010/11 was transparency. During the years of drought, water transparency was relatively high but was reduced by more than 1 m in 2010/11 following barrage releases. In 2012/13, transparency increased in the Estuary subregion whilst not yet reaching drought levels. Transparency may affect individual species behaviour, predator/prey interactions between species, as well as the habitat structure and water column productivity, which may influence fish communities.

Both salinity and transparency were strongly associated to changes in fish assemblages in the Coorong. The return of flow to the Coorong caused changes in water conditions that affected 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 may take several years. This was the case of the iconic diadramous species congolli that showed significantly enhanced recruitment for the third consecutive flow year, 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, 29 species were recorded from both seine and gill net samples during the monitoring for barrage releases in 2012/2013. The total number of species increased slightly compared to 2006/07 (26 species) under drought conditions. In particular, there was a substantial increase in the number of freshwater species (from two to six species) and a small decline in the number of marine estuarine opportunistic species (from twelve to ten) in this study. When compared to 2011/12, the number of opportunistic species increased by two, but more importantly the abundances of some of these opportunistic species that are important to commercial and recreational fisheries like yelloweye mullet, significantly increased. The two catadromous species, common galaxias and congolli also showed a more than tenfold increase from the previous year and in the case of congolli, a >250 fold increase from 2006/07. Concurrently the six estuarine resident species either maintained similar abundances to 2011/12 or increased such was the case for Tamar goby and Scary's Tasman goby. 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 2010-2013, 32 species were sampled by seine netting a total area of ~78144 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 150000 m^2 (Noell *et al.* 2009), noting that the total number of fish collected was 4-5 times higher during the post flow study in 2010-2013. 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. In addition, there was an overall increase in the number of freshwater species (e.g. bony herring, redfin perch, Australian smelt) in flow years, particularly in 2010/11. In 2012/13, abundances of freshwater species generally declined, including the non-native species redfin perch and carp.

The greater species richness at most North Lagoon sites in 2012/2013 was due to the presence of estuarine and freshwater native fish species that were not present at these sites in the previous sampling year. A similar trend was observed for the South Lagoon where marine estuarine opportunistic, catadromous and freshwater native species all contributed to the increase in species richness.

In previous studies in the Coorong, a general decline in species richness and diversity with increasing distance from the Murray Mouth was observed, likely related to a salinity gradient (Noell *et al.* 2009). 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 have broader access to food resources, habitat and space, and expand their ecological niche (Colburn 1988). In this study however, the subregion with greatest species richness was the North Lagoon, followed by the Estuary and South Lagoon. Our study found that most of the decrease in species richness in 2006/07 occurred in the northern part of the North Lagoon. In 2012/13, these same sites in the North Lagoon are the ones that showed the greatest increase and 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, estuarine/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 abundant fish in seine net samples consistently in every sampled year except 2012/13 when it was the second most abundant. It comprised ~55% of the total number of fish collected in 2006-2013, and continued to dominate (almost 100% by number) the South Lagoon even after salinities decreased to ~76-79 psu. The dominance of smallmouthed hardyhead was also reported in previous fish studies in the Coorong (Molsher *et al.* 1994; Noell *et al.* 2009; Zampatti *et al.* 2010). 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 over all years and the most abundant in 2012/13. This small-bodied clupeid, a marine estuarine opportunist species that regularly enters estuaries in large numbers (Potter and Hyndes 1999; Whitfield 1999), comprised 35% of the catch throughout the study (i.e. 2006-13). Sandy sprat constituted 20%, 38% and 49% of the total catch in 2010/11, 2011/12 and 2012/13, respectively. This 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 2010-2013 was probably due to the barrage flows and subsequent enhanced productivity in the Coorong.

The next two most abundant species were the estuarine Scary's Tasman goby and the estuarine opportunistic yelloweye mullet. Scary's Tasman goby increased its abundance more than 10 fold of any of the previously sampled years; in 2006/07 only 9 individuals were found mainly in the Estuary subregion, whilst in 2012/13 a total of 1,330 fish were recorded with more than 90% of the catch coming from the North Lagoon. This suggests that the prolonged estuarine conditions have favoured its recruitment and re-establishment 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 Lagoon during 2012/13 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 Lagoon, and even in the Estuary their numbers were extremely low. With the high flow of 2010/11, abundance of common galaxias increased in the Estuary, although there was a sharp drop in 2011/12, the abundance increased substantially in 2012/13 to more than double those observed in 2010/11. Congolli showed a similar pattern in the Estuary and sustained abundance in the North Lagoon following barrage releases in 2010/11. Particularly in 2012/13 with continued barrage flows, the abundance of congollis increased by 5 and 12 times those of 2010/11 in the Estuary and North Lagoon, respectively.

The changes in abundance of the catadromous species are likely related not only to the reduced salinities but also to the sustained connectivity of the estuary with the upper reaches of the river through barrages opening and fishway operation. Zampatti *et al.* (2010) have shown that abundance of young-of-the-year congolli was drastically reduced with reduced flows, and they suggested that even small flows could enhance recruitment of these species.

The last two sampling years, 2011/12 and 2012/13, have shown a general decline in the presence of freshwater species which were abundant in the flood year (i.e. 2010/11). This is to be expected as estuarine conditions in the Coorong stabilise 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 it 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 (King *et al.* 1997). 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 thirteen sampling sites. Total catches from gill nets were much lower than seine net catches. The 15 species caught using gill nets during 2012/13 were also caught in the 2010-2012 period. As a general trend, all species declined or remained similar to the previous sampling year, except for yelloweye mullet which was almost three times greater than 2011/12 and extended its range to the South Lagoon, representing 90% of the total catch in that subregion. The other species present in the South Lagoon was the freshwater native bony herring, although at 1% of the abundance found in the Estuary or North Lagoon.

The most abundant species in gill net samples was the freshwater bony herring, numerically accounting for 82%, 72% and 53% of the total catch in 2010/11, 2011/12 and 2012/13, respectively. Although a common freshwater species, bony herring are known to tolerate high salinities (as well as high temperatures, high turbidities and low dissolved oxygen) (Briggs and McDowall 1996; Lintermans 2007). Nevertheless, their occurrence in the 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).

The second, third and fourth most abundant species in gill net catches were the marine estuarine opportunists yelloweye mullet, Australian salmon and mulloway, respectively. These species are also common in several south-western Australian estuaries (Potter and Hyndes 1999). For yelloweye mullet, despite an overall increased gill net catch (adult and sub-adult representatives), a reduction was observed in the Estuary in 2010/11, with 96% of the catch taken from the North Lagoon. This may reflect the short-term disturbance in the Estuary during a period of substantial barrage releases which led to broad-scale reductions in salinity along the Coorong and a subsequent southward movement of this species into the North Lagoon. During the second flow year (2011/12), yelloweye mullet numbers increased in the Estuary, and their abundance was maintained in the North Lagoon. In 2012/13, their abundance increased significantly in the Estuary and North Lagoon and was found for the first time in this study in the South Lagoon. It is clear that yelloweye mullet tolerate high salinities as this species had a noticeable presence in the South Lagoon (79 psu) in 2012/13.

A similar pattern was observed for Australian salmon, with a shift of catch from the Estuary to the North Lagoon in the first high flow year (2010/11) followed by an increase in numbers in the Estuary during the second flow year (2011/12). In 2012/13, however, abundance of Australian salmon reduced by 50% in the Estuary and 95% in the North Lagoon. In contrast, mulloway abundance significantly reduced in 2010/11 in both Estuary and North Lagoon subregions, followed by a significant and consistent increase in the Estuary during 2011/12 and 2012/13; whereas in the North Lagoon the abundance of mulloway was reduced by 51% from 2011/12 to 2012/13.

For gill net samples, the increase in species richness from drought to flow years was most apparent at Noonameena (middle of the North Lagoon), which was probably driven by salinity reductions (73 psu in 2006/07 to ~37 psu in 2010-2012), and in the South Lagoon where no catch was recorded in 2006/07 and 2011/12. The total abundance of fish, as shown in gill net catches, increased in the North Lagoon during 2010/11 and throughout the three subregions during 2011/12, but generally decreased in 2012/13. 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

The extremely high salinities within the three subregions observed during the drought years were substantially diluted after the high flow of freshwater into the Coorong in 2010/11. This led to significant changes in fish assemblage structure in each subregion, with a shift from marine and estuarine species to freshwater species assemblages, particularly in the Estuary and North Lagoon regions. However the reduction in salinity in the South Lagoon did not immediately affect the assemblage in this subregion. It was only in 2012/13, two years after the return of flows to the Coorong, when a noticeable increase in species richness was observed in this subregion. Some species seem to respond more rapidly to the opening of the barrages and the decrease in salinity such as the freshwater species. However, other species show a less lineal response such as the catadromous species which showed an immediate increase in 2010/11, followed by a significant reduction in 2011/12 and a very large abundance in 2012/13 probably driven by successful recruitment.

Overall, the marked shift in assemblage structure after the high flow event in 2010/11 from marine/estuarine opportunistic species to freshwater species was 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, estuarine opportunistic and catadromous species occurred. In the last two years (i.e. 2011/12 and 2012/13) the changes in fish assemblages have been 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, often resulting in high species richness (Potter and Hyndes 1999; Whitfield *et al.* 2006)

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 hinder or intensify the effects of oxygen depletion (Rose *et al.* 2009).

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

Following the barrage releases and substantial salinity reductions in the Coorong from 2010/11 to 2011/12 all the key estuarine, opportunistic and catadromous species had a southward range extension, with several species expanding their distribution further south (sandy sprat, Tamar goby, yelloweye mullet and black bream). Black bream and yelloweye mullet were sampled for the first time in this study, although in low numbers, in the South Lagoon in 2011/12; whilst previous studies during the extended drought found no fish or only a single species, smallmouthed hardyhead, in low numbers in this subregion (Noell *et al.* 2009; Ye *et al.* 2011c, d). In 2012/13, three additional species (congolli, Scary's Tasman goby and bony herring) were found in the South Lagoon. Our findings support the hypothesis that fish populations would at least maintain the ranges observed in the Coorong in 2010/11 for key estuarine and catadromous species under continued flow. In fact, several species further extended their range southward in 2012/13. Black bream, yelloweye mullet and congolli were previously found in the northern part of the South Lagoon during 1983/84, when salinities reduced to 55 psu following above average barrage flows (Geddes 1987). In terms of freshwater species, bony herring (native fish) had a substantial increase in abundance and extended its distribution into the southern end of the North Lagoon 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 ranged was maintained (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 despite high salinities. The findings of this study also support the hypothesis that fish populations would at least maintain the ranges observed in the Coorong in 2010/11. 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, when they were only found in the Estuary in decreased abundance from all previous years since the high flows. Exotic freshwater species are less tolerant of high salinities compared to Australian native species of marine origin.

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 in 2010-2013 and subsequently their abundances increased in the Coorong, with many new recruits occurring in the North Lagoon. This pattern was markedly increased for sandy sprat, congolli, Scary's Tasman goby and Tamar goby in 2012/13. These results support the hypotheses that diadromous and estuarine fish would continue to recruit in 2012/13, and estuarine fish habitat would maintain in the North Lagoon and serve as a nursery ground for several species. An exponential increase in smallmouthed hardyhead abundance occurred in the South Lagoon after salinities reduced from 105-168 psu in 2006/07 to the current 76-79 psu. This was likely a combined result of local spawning events, a range extension in this species from the North Lagoon, and dispersion of the remnant population from Salt Creek into the South Lagoon. Importantly, the presence of many fish <30 mm TL in the South Lagoon in all flow years suggested recruitment success in this subregion. In the current study for the first time since the return of flows, smallmouthed hardyhead was the second most abundant species, behind sandy sprat which is known to be an important prey item for small coastal seabirds and inshore pelagic fishes (Hoedt and Dimmlich 1994; Hoedt *et al.* 1995). Such a response by this keystone species has high ecological significance, as smallmouthed hardyhead provide important ecological services, in particular as a major food item for various piscivorous fish and water birds (Paton 1982; Rogers and Paton 2009; Deegan *et al.* 2010).

Length frequency distribution and age structure for congolli indicated that strong cohorts of 0+ and 1+ year old fish recruited to the Estuary following the barrage opening and increased freshwater inflows to the Coorong during 2010-2012 (Ye *et al.* 2012). The length frequency distribution of the current year is unequivocal in showing a strong recruitment in the Estuary and North Lagoon, 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 (Zampatti *et al.* 2010). The importance of freshwater flows for the recruitment of congolli and other catadromous species (common galaxias) has been previously documented in the Murray Estuary (Bice *et al.* 2007; Jennings *et al.* 2008; Zampatti *et al.* 2010). The strongest cohort recorded in this study for both catadromous species support 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.

In terms of the large-bodied estuarine opportunistic species, yelloweye mullet showed a general decline in abundance (both juveniles and adults) in the Estuary but an increase in the North Lagoon following the barrage releases in 2010/2011; although there appeared to be a slight recovery in abundance in the Estuary during the second flow year. This recovery was significantly enhanced 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. This suggests that high freshwater inflows may represent a short-term disturbance in the Estuary for this opportunistic species. Given yelloweye mullet have a relatively high salinity tolerance (i.e. laboratory estimates of 50% lethal concentration (LC_{50}) range between 82-91 psu; Ye *et al.* 2012a), this species may have moved southward to explore more saline environments, particularly in the North Lagoon (8-76 psu) in 2011/12 and South Lagoon in 2012/13. This was supported by their southward range expansion in all flow years. For mulloway, gill net samples indicated a reduction in catch throughout the Coorong in 2010/11 compared to 2006/07; this was not unexpected given the very low salinities in the Murray Estuary following substantial freshwater inflows over a long period. Freshwater flows are believed to be important for the recruitment of mulloway (Ferguson *et al.* 2008). Freshwater attracts spawning aggregations of reproductively mature adults and sub adults at the interface of the River Murray plume with the Southern Ocean during the springsummer (November to March) period (Hall 1984; Ferguson *et al.* 2008). Larval development is thought to occur at sea, with juveniles entering the Murray Estuary several months later at 100-150 mm total length (Hall 1986). Therefore, sampling might have occurred too early to detect a flow related recruitment response in mulloway during the 2010/11 season, or the very high flows might have reduced their catchability. However, gill net sampling in 2011/12 identified the presence of a cohort of juvenile mulloway in the 1+ year class that originated from successful recruitment in 2010/11. In addition, the 2011/12 year class also appeared as a strong pulse of 0+ year old fish in the age structure. These two cohorts were the primary contributors (~80%) to the improved catch of mulloway in 2011/12. In 2012/13, another small cohort was found mainly in the Estuary but also in the North Lagoon. These results support the critical role of freshwater inflows in facilitating the recruitment of mulloway and the Coorong being an important nursery ground for mulloway (Ferguson *et al.* 2008).

Greenback flounder, an estuarine and marine species, responded positively to the barrage releases during 2010-2013 by extending their nursery grounds into the southern part of the North Lagoon (to Hells Gate in 2011/12), as evidenced by the increased range of juveniles. In contrast, juvenile abundance showed a general decline in the Coorong, which might partially relate to their dispersion throughout a much broader habitat. Targeted investigation on this species during fish condition monitoring indicated increased numbers of juveniles at specific sites (e.g. Mark Point) in the North Lagoon following the 2010-2012 barrage releases (Ye *et al.* 2012b). Greenback flounder recruitment is likely influenced by freshwater flows to estuaries (Robins and Ye 2007); as this species spawns during winter (Crawford 1984), before the typical high flow season, larval and juvenile growth may be enhanced by increased biological productivity (i.e. food availability) related to freshwater flows to estuaries, resulting in higher levels of recruitment success (Robins and Ye 2007). In addition, freshwater inflow is a key driver of the Coorong salinity regime (Geddes and Butler 1984; Geddes 1987; Brookes *et al.* 2009; Ye *et al.* 2011a). Salinity is known to play a key role in the reproductive biology of greenback flounder, with optimum 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 ~55-150 psu) 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 (salinities 8-76 psu), which likely benefited spawning and recruitment. Furthermore, juvenile greenback flounder are more tolerant of hypersaline conditions than eggs, with the laboratory estimates of LC_{50} for juveniles ranging from 79-88 psu (Ye *et al.* 2012a). Tolerance data, therefore, agree with the collection of juvenile greenback flounder in the northern to mid part of the North Lagoon during recent drought years (Noell *et al.* 2009; Ye *et al.* 2011b), as well as its distribution expansion to the southern end of the North Lagoon (Hells Gate) in 2011/12. During 2012/13, distribution of juvenile greenback flounder contracted from the south to the mid region of the North Lagoon. However, juvenile abundance in general increased suggesting enhanced recruitment. Increased fishery catch in the North Lagoon also suggests that this species is showing positive signs of recovery.

Many estuarine associated species, particularly small-bodied fish, have shown signs of a positive response to the barrage releases in 2010-2013. However black bream, an iconic large-bodied estuarine resident species showed very little signs of a population recovery. Black bream relative abundance remained low in the Coorong for both adults and juveniles. Whilst salinity reductions throughout the Coorong have allowed adult black bream to recolonise the North Lagoon (i.e. slight increase in gill net catch in 2010/11), no young of the year were collected in 2010/11 and only four juvenile fish was caught in 2011/12. In 2012/13 very few juveniles were found in this study and practically no adults suggesting that this species has not been able to successfully recover. However, recent data from a targeted study into juvenile black bream suggests that this may be changing with large numbers of juveniles caught in the Coorong during recent sampling (Ye, pers. comm.).

Many large-bodied fish (e.g. black bream, greenback flounder, mulloway, yelloweye mullet) that inhabit the Murray Estuary and Coorong are important species for the Lakes and Coorong fisheries (both commercial and recreational). Fish condition monitoring in the Coorong in 2013 found that after the significant barrage releases in 2010/11, the commercial fishery catch of black bream slightly increased although it remains below the past ten years' average. Concurrently, the commercial fishery catch of greenback flounder increased to the sixth highest ever recorded since 1984/85, indicating signs of population recovery. This occurs after relative abundances reached historical lows in 2008-2011. Nevertheless, the truncated population age structures for both species may imply a high exploitation rate by the fishery. Although for greenback flounder, this may partially be attributed to movement between the Coorong and marine system (Ye *et al.* 2012b). A recent stock assessment for mulloway 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. Given the uncertainty in population trajectory for some of these large-bodied long-lived species, monitoring will be required in subsequent years to continue to investigate the recruitment response and population recovery in these commercially important species and evaluate potential benefits of freshwater inflows to the Coorong on these species. Environmental water management should also consider small to moderate freshwater releases, which could potentially lead to recruitment success in black bream, as suggested by the presence of strong cohorts of 1997/98, 2003/04 and 2006/07 in the Coorong (Ye *et al.* 2012b). In addition, conservation management should seek to protect the remnant populations of these species and rebuild the age structures to improve capacity for egg production and therefore enhance population resilience. Further investigation is required into the dynamic movement patterns of the estuarine and marine estuarine opportunistic species in the Murray Estuary and Coorong, as well as between the Coorong, freshwater and marine environments under different flow conditions. Additional research is also required to determine the environmental factors and/or mechanisms, including flow regimes, critical habitat requirements and food resources that contribute to recruitment success of key estuarine species. Such knowledge will facilitate the development of well-informed ecologically sustainable management strategies for estuarine fish populations in the dynamic ecosystem in the Coorong.

5. CONCLUSIONS

Freshwater inflows play an important role in structuring fish assemblages in the Murray Estuary and Coorong, maintaining estuarine conditions and facilitating the recruitment of estuarine and catadromous species. Following the barrage releases in 2010/11, 2011/12 and 2012/13, salinities were reduced significantly from marine to extremely hypersaline (up to ~170 psu) to the current levels of 0-14 psu in the Estuary, 21-66 psu in the North Lagoon, and 76-79 psu in the South Lagoon. Broadly decreased salinities, coupled with other freshwater induced environmental changes (e.g. dissolved oxygen, transparency), elicited significant ecological responses in fish assemblages in the region. The fish assemblage composition has changed significantly compared to that of the drought years, mainly due to an increase in the diversity and increased abundances of small-bodied estuarine resident and opportunistic species (i.e. smallmouthed hardyhead, Tamar goby and sandy sprat) and catadromous species (i.e. congolli) following enhanced recruitment. It seems that changes in fish assemblages are still occurring after three years of flow, with abundances and recruitment of estuarine and catadromous species, as well as commercially important opportunistic species (i.e. yelloweye mullet) still increasing from year to year. Although large-bodied estuarine opportunistic species such as yelloweye mullet and Australian salmon declined in the first flow year in the Estuary, their abundance recovered in 2011/12 and 2012/13. The freshening of the Coorong also resulted in a southward range expansion for all key species, including black bream, yelloweye mullet, congolli, greenback flounder, Tamar goby, Scary's Tasman goby, sandy sprat and bony herring. Length frequency distributions indicate recruitment success at different levels in all key species (except for black bream) during the 2010-2013 flow events. Two species, namely congolli and yelloweye mullet, showed significantly improved recruitment success in 2012/13 compared to the previous two years, highlighting the importance of sustained estuarine conditions. 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 ten-fold increase in 2012/13. 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.

The following points are provided to address the key questions with reference to "fish response monitoring in the Coorong in 2012/13" (Appendix I):

- Salinity in the Estuary subregion increased compared to the previous two years, but was lower than those observed during the drought years. In the North Lagoon salinity was slightly higher but still within a similar range as the previous two years which was significantly lower than the drought years, whilst in the South Lagoon salinities were lower than 2011/12 and almost half that observed during the drought.

- Recruitment for most species that were seen to recruit in 2011/12 continued in 2012/13.
- Yelloweye mullet showed a noticeable increase in recruitment compared to 2011/12.
- Enhanced recruitment in diadromous species was particularly significant with juvenile congolli recorded in high abundances in the Estuary and North Lagoon subregions.
- Most key species were able to at least maintain their distribution ranges as observed in 2011/12, with some expanding further into the South Lagoon such as Scary's Tasman goby, congolli and bony herring.
- The non-native freshwater species, carp and redfin perch, declined with distribution ranges confined to the Estuary subregion.
- The fish assemblages observed in 2012/13 were generally similar to those observed in 2011/12, whilst they were vastly different to those present in the drought years.

Overall, the monitoring for barrage releases in 2010-2013 following years of minimal freshwater inflows into the Murray Estuary and Coorong demonstrated changes in estuarine fish assemblages. There is a dynamic response of the fish assemblages that is attributable to a species-specific response to freshwater flows. 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. Other aspects, beyond freshwater flow, 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 species (black bream and mulloway), long-term monitoring will be required to continue to investigate the biological performance of these commercially important species and evaluate potential benefits of freshwater inflows to the Coorong for these fish.

6. REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Hoedt, F. E.; Dimmlich, W. F., 1994: Diet of subadult Australian salmon, *Arripis truttaceus*, in Western Port, Victoria. *Australian Journal of Marine and Freshwater Research***.** **45**, 617–623.

Hoedt, F. E.; Dimmlich, W. F.; Dann, P., 1995: Seasonal variation in the species and size composition of the clupeoid assemblages in Western Port, Victoria. *Marine and Freshwater Research.* **45**, 1085–1091

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 2012-2013 following the significant flows of 2010-2011 and further flows in 2011-2012, 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 2012-2013 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) Has recruitment continued for fish species which underwent recruitment in 2011-2012 and is recruitment occurring for other species in 2012-2013?	- Diadromous and estuarine fish seen to recruit in 2011-2012 will continue to recruit in 2012-13; - Additional species will show recruitment events in 2012-13.
c) Can the recruitment of species in 2012-2013 be linked with the timing of differing flow scenarios to identify drivers of fish recruitment?	- The recruitment of key fish species will be linked to freshwater inflows and salinities, which will change subject to particular flow scenarios.
2. Will species be able to maintain any range increases observed in 2011-12?	Fish populations will maintain the ranges observed in the Coorong in 2010-11.
3. Are there similarities or differences in the community structure of fish across differing flow scenarios (drought/flood)? - How do 2012-2013 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.