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Water for a Healthy Country

Fish assemblages of the Murray Mouth and Coorong region, South Australia, during an extended drought period

C. J. Noell, Q. Ye, D. A. Short, L. B. Bucater and
N. R. Wellman

April 2009

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Foreword

The environmental assets of the Coorong, Lower Lakes and Murray Mouth (CLLAMM) region in South Australia are currently under threat as a result of ongoing changes in the hydrological regime of the River Murray, at the end of the Murray-Darling Basin. In particular, a number of fish species of commercial, recreational or conservation significance have experienced dramatic declines in biomass in recent years across the region. While a number of initiatives are underway to halt or reverse this environmental decline, rehabilitation efforts are hampered by the lack of knowledge about the links between flows and ecological responses in the system.

The CLLAMM program is a collaborative research effort that aims to produce a decision-support framework for environmental flow management for the CLLAMM region. The framework aims to evaluate the environmental trade-offs for different scenarios of manipulation of management levers, as well as different future climate scenarios for the Murray-Darling Basin.

One of the most challenging tasks in the development of the framework is predicting the response of ecological communities to future changes in environmental conditions in the CLLAMM region. Of special interest is the composition of fish assemblages, and establishing potential links between these assemblages and environmental variables, the topic of the research presented in this report.

This study is a collaboration between the Fisheries Research & Development Corporation (FRDC), the Murray-Darling Basin Commission (now Murray-Darling Basin Authority), SA Murray-Darling Basin Natural Resources Management Board and the CLLAMMecology Research Cluster. CLLAMMecology is a partnership between CSIRO, the University of Adelaide, Flinders University and SARDI Aquatic Sciences to study ecological responses to environmental change in the region, supported through the CSIRO Flagship Collaboration Fund.

Additional reports relevant from the CLLAMM program and the CLLAMMecology Research Cluster can be found can be found at
http://www.csiro.au/partnerships/CLLAMMecologyCluster.html

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We also acknowledge the contribution of several other funding agencies to other aspects of the CLLAMM program and the CLLAMMecology Research Cluster, including Land & Water Australia and SA Water. Other research partners include Geoscience Australia and the Flinders Research Centre for Coastal and Catchment Environments. The objectives of this program have been endorsed by the SA Department of Environment and Heritage, SA Department of Water, Land and Biodiversity Conservation, SA Murray-Darling Basin NRM Board and Murray-Darling Basin Commission.

This report was reviewed by M. Geddes, M. Steer and J. Tanner. We thank these reviewers for their helpful comments that improved the manuscript.

Executive Summary

The original aims of this study were to investigate flow-related effects on the fish and fisheries ecology of the Murray Mouth and Coorong region. However, with no freshwater inflows to the region since October 2006 and continuation of a drought that has lasted more than five years, the aims were revised to instead: 1) quantitatively describe the fish assemblages of the region; 2) determine whether there were any spatial or temporal differences in assemblages; and 3) explore potential relationships between environmental variables and assemblages.

In addressing these aims, particular attention was given to seven key species: black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*), yelloweye mullet (*Aldrichetta forsteri*), mulloway (*Argyrosomus hololepidotus*), smallmouth hardyhead (*Atherinosoma microstoma*), Tamar goby (*Afurcagobius tamarensis*), and congolli (*Pseudaphrites urvillii*).

A fine-mesh seine net was used to collect fish from ten sites located in the Murray Mouth subregion (five sites) and the Northern (three) and Southern Lagoons (two) of the Coorong approximately every three months between October 2006 and September 2008, while a sinking composite gill net was used to catch fish at four of these sites (two each within the Murray Mouth and Northern Lagoon).

Using the seine net, a total of 66,515 fish representing 26 species were collected, many of which were either small-bodied fish or juveniles of larger species. A general decline in species diversity occurred with increasing distance from the mouth; all 26 species were found in the Murray Mouth subregion, 13 in the Northern Lagoon and only 1 species, *Atherinosoma microstoma*, was found in the Southern Lagoon. As in the fish fauna of many temperate Australian estuaries, where atherinids are particularly important and often the most dominant species, the estuarine species *At. microstoma* was by far the most abundant species in the current study, contributing 61% to the total number of fish collected. The next two abundant species were *Aldrichetta forsteri* (17%) and *Hyperlophus vittatus* (16%). In the Murray Mouth subregion, *Hype. vittatus* (38%) and *Al. forsteri* (35%) were the most abundant species, followed by *At. microstoma* (10%), *Arripis truttaceus* (7%), and *Galaxias maculatus* (3%), whereas in the Northern Lagoon, the vast majority of fish were *At. microstoma* (92%), with relatively small contributions by *Al. forsteri* (5%) and *Hype. vittatus* (2%). Most *At. microstoma* (89%) were collected from the Northern Lagoon and, although the Murray Mouth had greater species diversity, more fish were caught in the Northern Lagoon, mainly due to the very high abundance of *At. microstoma*. For *Hype. vittatus* and *Arr. truttaceus*, the Murray Mouth and Coorong is likely an important nursery area. *Galaxias maculatus*, which is often considered to be catadromous, has an adaptable life-history strategy, which may be important in drought conditions where there is a lack of inflows and migratory options.

With respect to the life cycle classification of these 26 species, 12 complete their life cycle within estuaries and are thus referred to as estuarine species (comprising 6 solely-estuarine, e.g. *At. microstoma*, and 6 ‘estuarine and marine’ species), 10 are marine species (9 marine estuarine-opportunist species, e.g. *Al. forsteri*, *Hype. vittatus*, *Arr. truttaceus*, and 1 marine straggler), 2 are freshwater species, and 2 are catadromous (i.e. mostly live in freshwater but spawn in the sea, e.g. *Ga. maculatus*). In terms of number of fish, most (62%) are solely-estuarine species (again, mostly owing to the dominance of *At. microstoma*), with a significant contribution also made by marine estuarine-opportunist species (35%).

The gill net method yielded a total catch of 2,679 fish representing 16 species; 13 species were found in each of the Murray Mouth and Northern Lagoon subregions. The three most abundant species (overall and in each subregion) using this method were *Arr. truttaceus* (42% of total number), *Al. forsteri* (37%), and *Argyrosomus hololepidotus* (15%), making up 94% of the total catch from both subregions. *Arripis truttaceus* made a significant contribution to the number of fish in the Murray Mouth (61%), whereas *Al. forsteri* was common in the Northern Lagoon (68%).

Of the 16 species caught with a gill net, 3 are estuarine species (2 solely-estuarine and 1 ‘estuarine and marine’ species), 11 are marine species (9 estuarine-opportunists, e.g. the three ‘abundant’ species, and 2 stragglers), 1 is a freshwater species, and 1 is catadromous.

All 12 species that were known before this study to complete their life cycle within the region (i.e. estuarine species) were collected among the grand total of 31 species from both seine and gill net samples combined. Of these 31 species, 6 had not been recorded in previous inventories for the region. Each of these additional species is believed to be of marine origin, either marine estuarine-opportunists or stragglers.

Length-frequency distributions from seine and gill net samples were obtained for key species of commercial (*Acanthopagrus butcheri*, *Rhombosolea tapirina*, *Al. forsteri*, *Arg. hololepidotus*), ecological (*At. microstoma*, *Afurcagobius tamarensis*), and conservation importance (*Pseudaphrites urvillii*) to gain an understanding of the utilisation of the Murray Mouth and Coorong region by these species and particular life stages. These distributions support the literature or provide new information concerning aspects of the respective species’ life histories, such as the identification of cohorts, estimation of spawning season, and estimation of the duration and growth of these cohorts.

Classification and ordination of the 100 seine net samples (10 sites × 10 sampling occasions) by multivariate analysis demonstrated that fish assemblages tended to be more similar between sites that were either within the same subregion or proximate to one another. Further, the greatest dissimilarity occurred between the typically multi-species assemblages of the Murray Mouth subregion and the zero or single-species samples of the Southern Lagoon, while assemblages of the Northern Lagoon were intermediate, usually comprising more than one species but fewer species than in the Murray Mouth assemblages. Significant differences found between assemblages of different subregions were generally attributed to dissimilarities in abundances of *At. microstoma*, *Al. forsteri*, *Arr. truttaceus* and *Hype. vittatus*. A smaller, yet still significant difference was also found between assemblages of the Murray Mouth and Northern Lagoon from gill net samples, and this attributed to relatively fewer *Arr. truttaceus* and *Arg. hololepidotus* and greater numbers of *Al. forsteri* in the Northern Lagoon. No temporal differences (by year or season) were found between assemblages for either seine or gill net samples, possibly indicating stability of the fish fauna of the region during the current drought.

Hydrodynamic processes suggest that the lack of freshwater input, along with drought conditions, has resulted in higher salinities throughout the region (probably the highest ever), with some parts extremely hypersaline. A strong north-south salinity gradient that increases with distance from the mouth persisted throughout the study, with mean salinities of 30-40‰ in the Murray Mouth subregion, 61-86‰ in the Northern Lagoon, and 105-164‰ in the Southern Lagoon recorded on each sampling occasion. When all salinity measurements at each site were pooled, the greatest between-site variation occurred among the Northern Lagoon sites (45-108‰), accounting for >70% of the range of mean site salinities throughout the region (36-125‰). Looking at the change that has occurred since years with a normal flow regime (e.g. 1983-84), effectively there has been a shift of Northern Lagoon-like salinities towards the Murray Mouth and Southern Lagoon-like salinities in the Northern Lagoon, while the salinity of the Southern Lagoon has become virtually intolerable to almost all fish species.

Among several water quality variables, salinity alone was the best explanatory variable for the observed fish assemblages in this study, with highly significant correlations found for both seine and gill net species abundance data. A general decline in species diversity with distance from the mouth is probably a response to the greater osmoregulatory stress and diminishing food resources with the increasing salinity gradient, thus providing limited opportunities for only the few highly salt-tolerant species to extend their ecological niche. This is best exemplified by the dominance of *At. microstoma* in the hypersaline Northern Lagoon and its occurrence as the only species that could tolerate the extremely hypersaline Southern Lagoon, where it was found in salinities up to 134‰. As a result, the structuring of fish assemblages in the Murray Mouth and Coorong region (which can be considered typical of assemblages of the region during a drought) is primarily attributed to the distribution and abundance of this keystone species, with secondary influences of *Al. forsteri*, *Hype. vittatus*, and *Arr. truttaceus* also important.

With respect to key species, the continuation of the drought and an ongoing lack of freshwater inflows to the Murray Mouth and Coorong region are believed to have negative implications for *Rh. tapirina*, *Arg. hololepidotus*, *Ac. butcheri* and *Pseuda. urvillii* based on knowledge of these species' life histories (these are discussed) and low densities recorded in the current study, while it is unknown if or how the remaining three species (*Al. forsteri*, *At. microstoma* and *Af. tamarensis*) are affected.

There is a high likelihood that the extended drought conditions and the subsequent lack of freshwater input and increases in salinity throughout the Murray Mouth and Coorong have influenced the composition of fish assemblages observed in this study. We recommend that the results of this study be treated as a baseline by which future quantitative assessments are made, and that if a normal flow regime were to return to the region, this type of study be repeated in order to understand whether and how the composition of fish assemblages of this region responds to non-drought conditions.

1. Introduction

1.1. Estuarine and coastal lagoon ecosystems

Estuaries and coastal lagoons lie at the interface between marine, freshwater, terrestrial and atmospheric systems, and are thus among the most dynamic ecosystems (Edgar *et al.*, 1999). They are often described in terms of their physico-chemical environment, biota, and habitat, all of which are determined by natural drivers (geomorphology, hydrology and climate) and anthropogenic activities (e.g. water extraction, hydraulic engineering, urban development) (Phillips & Muller, 2006; Pérez-Ruzafa *et al.*, 2007*a*, 2007*b*). Whilst these coastal and transitional waters are regarded as stressed systems subject to frequent environmental disturbances and fluctuations (Barnes, 1980; Kjerfve, 1994; UNESCO, 1980, 1981) and human-induced impacts (Webster & Harris, 2004; Viaroli *et al.*, 2007), it is the relative magnitude and complex interaction of these factors that condition the biotic component and general functioning of the ecosystem (Mariani, 2001; Gamito *et al.*, 2005; Franco *et al.*, 2007).

It is widely recognised that estuaries and coastal lagoons play an important role in providing breeding grounds, nursery areas and spawning migratory pathways for a variety of higher trophic level organisms (e.g. birds and fish) (Blaber & Blaber, 1980; Potter et al, 1990; Pollard, 1994; Whitfield, 1999; Paton, 2002). However, when the variability of estuaries and coastal lagoons imposed by environmental factors is further confounded by increasing extraction of freshwater upstream, for example, some of these ecosystems can degrade into extreme states (Edgar *et al.*, 1999; Whitfield, 2005; Viaroli *et al.*, 2007). The fish assemblages of estuaries and coastal lagoons respond to these pressures in a variety of ways. When freshwater inflows to these ecosystems are considerably reduced or eliminated altogether as a result of drought conditions caused by climate and/or water extraction, the system effectively ceases to be an estuary, even if the mouth remains open and sea water penetrates upstream to replace the estuary water (Whitfield, 2005). As a consequence, fish populations may suffer from poor recruitment and, particularly when hypersaline conditions occur, species diversity and abundance may also decline (Vega-Cendejas & Hernández de Santillana, 2004; Whitfield, 2005).

Fundamental to understanding the impact that environmental and anthropogenic factors have on estuarine and lagoonal fish assemblages is knowledge of the spatial and/or temporal changes in species composition of these assemblages and their respective distribution and abundance within the system. In Australia, many detailed quantitative studies on fish assemblages have been carried out in temperate estuaries and lagoons (e.g. Pollard, 1994; Young *et al.*, 1997; Edgar *et al.*, 1999; Griffiths & West, 1999; Potter & Hyndes, 1999; Griffiths, 2001; Kanandjembo *et al.*, 2001; Young & Potter, 2002; Hoeksema *et al.*, 2006; Hoeksema & Potter, 2006), yet surprisingly, there is a lack of these types of studies on fish assemblages of the Murray Mouth and Coorong, South Australia, at the terminus of Australia's longest river, the River Murray. Much of the work that has been done in this region by Geddes and co-workers has generally involved the assessment of the overall ecological health of the region through adaptive sampling in response to flow regimes and subsequent changes in the physico-chemical environment (Geddes & Butler, 1984; Geddes, 1987, 2003, 2005), however, information in these studies concerning fish is mostly qualitative and on just a few representative species (usually atherinids and gobiids). Nevertheless, this work constitutes a benchmark for providing a comprehensive and quantitative account of the fish assemblages of the region, which the current study aims to do.

1.2. Study region

The Murray Mouth and Coorong region comprises a modified estuary and lagoon system situated between the River Murray and Lower Lakes (Lakes Alexandrina and Albert) of the Murray-Darling Basin and its opening to the sea (**Fig. 1**). A series of five barrages (Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere Barrages), with a combined length of almost 8 km, separate the fresh water of the Lower Lakes from the saline waters of the Coorong lagoons that exchange water with the sea through the Murray Mouth.

These barrages were constructed in the 1930s to maintain a freshwater reservoir in the Lower Lakes and to prevent entry of saltwater. Through regulation of these barrages, the Murray Mouth and Coorong periodically receive freshwater inflows when the water level of Lake Alexandrina exceeds its full supply level at 0.75 m above sea level. However, over the past decade or so, the volume of fresh water discharged across the barrages has substantially reduced to a fraction of previous volumes (**Fig. 2**), mainly due to water extraction (predominantly used for irrigation purposes) and an extended drought in the Murray-Darling Basin. Along with a reduction in discharge across the barrages is an increase in the likelihood of closure of the Murray Mouth (Webster, 2005). Ongoing dredging has been necessary to keep the mouth open to the sea, and so over the recent low-flow period, the Murray Mouth can be regarded as permanently open.

The long (>100 km), narrow (<4 km wide) and shallow (mean depth ≈2 m) Coorong lagoons extend south-eastward from the Murray Mouth, running parallel to the South Australian coastline, and isolated from the Southern Ocean by Younghusband Peninsula. The Coorong is divided into the Northern and Southern Lagoons, which are connected by a very narrow channel at Parnka Point with adjacent shallow sand bars.

The Murray Mouth and Coorong region has an estuarine influence, but it is not a typical estuary (Geddes, 2003). With construction of the barrages, the 'estuary' has been reduced to 11% of its original size (Ferguson *et al.*, 2008). The dredging of the mouth and lack of freshwater input means the Murray Mouth and Coorong is now effectively a tidal marine inlet with a reverse estuary influence. Salinity increases with distance from the mouth, generally ranging between saline in the Murray Mouth and hypersaline in the Northern and Southern Lagoons.

The region (including the Lower Lakes) is a Ramsar-listed Wetland of International Importance, provides important habitat for several migratory waterbirds, is listed as one of six Significant Ecological Assets in the Living Murray Initiative, and supports the multi-species Lakes and Coorong Fishery.

1.3. Background

In 2006, a CSIRO Research Cluster under the Water for a Healthy Country Flagship, CLLAMMecology, was formed to 'support government policy and management by developing a decision-support framework for assessing the likely effectiveness of interventions to improve the ecological function of the Coorong, Lower Lakes and Murray Mouth (CLLAMM) ecosystems.' Within CLLAMMecology, the 'key species response theme' (one of four linked themes) was responsible for documenting, through experimental and/or monitoring studies, the responses of key species to changes in aquatic environments likely under different water management regimes in the River Murray (essentially quantities and timing of releases of freshwater over the barrages). The fish ecology component of this theme, proposed to study the freshwater flow-related effects on fish and fisheries ecology of fish populations inhabiting the Murray Mouth and Coorong region below the barrages.

For the duration of this study (October 2006 to September 2008), the Murray-Darling Basin, including the Lower Lakes, Murray Mouth and Coorong, has experienced particularly dry weather and high evaporative losses. As a result of these drought conditions, as well as ongoing water extraction along the length of the River Murray, the water level of Lake Alexandrina has steadily declined and remained well below sea level (freshwater discharge occurs at 0.75 m above sea level) (**Fig. 2**). At such low lake levels it is not possible to release freshwater and, consequently, the Murray Mouth and Coorong region has received no freshwater inflows since August 2006. The mean annual freshwater discharge at the barrages of the Lower Lakes during 2004-2008 was only 176 GL yr^{-1}, a small fraction of the previous five-year mean during 1999-2003 of ~1,500 GL yr^{-1} and the long-term mean during 1979-2003 of ~4,400 GL yr^{-1}.

1.4. Objectives

Given the lack of freshwater flows to the Murray Mouth and Coorong during the entire study, our objective was revised to provide a comprehensive and quantitative account of the fish assemblages of the region over a two-year drought period. Specifically, the objectives of this study were to: 1) describe the fish assemblages of the Murray Mouth and Coorong region in terms of species' composition, distribution and abundance, including the size composition of key species (see below); 2) determine whether there are any spatial and/or temporal differences between assemblages; and 3) investigate potential relationships between environmental variables (water quality) and assemblages.

In addition to quantifying the total number of species and fish throughout the region, the size composition was determined for several key species. These included: 1) four commercially-important species, black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*), yelloweye mullet (*Aldrichetta forsteri*), and mulloway (*Argyrosomus hololepidotus* (= *Arg. japonicus*)); 2) two common small-bodied estuarine species, smallmouth hardyhead (*Atherinosoma microstoma*) and Tamar goby (*Afurcagobius tamarensis*); and 3) a species of conservation significance, congolli (*Pseudaphrites urvillii*) (Hammer *et al.*, 2007, recommended that *Pseuda. urvillii* be listed as 'rare' under South Australian legislation).

2. Methods

2.1. Sampling regime

Fish were collected from ten sites in the Murray Mouth and Coorong region on ten sampling occasions at approximately three-monthly intervals between October 2006 and September 2008. Of these sites, five were located near (within 15 km) the Murray Mouth, three in the Northern Lagoon, and two in the Southern Lagoon (**Fig. 1**, **Table 1**). Each site was sampled during the day with a seine net, with four of these sites also sampled overnight using sinking composite gill nets. Three replicate samples were conducted on each sampling occasion for each gear type (**Table 2** and **Table 3**). The seine net was 61 m long and consisted of two 29-m-long wings (22 mm mesh) and a 3-m-long bunt (8 mm mesh). It was deployed in a semi-circle, which sampled to a maximum depth of 2.0 m and swept an area of ~592 m^2. The composite gill nets comprised five 9-m-long panels with stretched mesh size of 38, 50, 75, 115 or 155 mm. They were set in the afternoon or night (at 1500-2000 hours), and retrieved the next day 11-19 hours later. The gill nets had a drop of 2 m and were generally set in water depths less than 2 m and so often sampled the entire water column. Note that gill net sampling was not conducted at Beacon 19 (Site M1) or Noonameena (N2) in October 2006 as site selection had not been finalised at that time, and adverse weather conditions made it impractical to sample using this gear at N2 in December 2006 and at Mark Point (N1) in March 2007 (**Table 3**).

All fish collected using seine and gill nets were identified to species and the total number of individuals of each species recorded (raw species abundance data in **Appendix A** and **Appendix B**). The scientific and common names for all fish species follow the standard names of Australian fishes (Yearsley *et al*., 2006) (**Table 4**). Due to some uncertainty in field identification, *Contusus brevicaudus*, *Contusus richei* and *Tetractenos glaber* were identified to the family Tetraodontidae and treated as a single taxon. For the key species, the total length (L_T) of each fish was measured to the nearest 1 mm, except when the number of individuals of a species was large, in which case the lengths of a random subsample of up to 100 fish were recorded. The total number of each fish species caught at each site by seine net was adjusted to a density, i.e. number of fish 500 m^{-2}, while those caught using a gill net were not adjusted, and were simply expressed as the number of fish net set^{-1}.

On each sampling occasion, the water temperature, salinity, dissolved oxygen and pH were measured at 30 cm beneath the water surface using a TPS water quality meter (model 90FL), and a measure of transparency was obtained from a secchi disk depth measurement (water quality measurements in **Appendix C** and **Appendix D**). The TPS meter was calibrated prior to each sampling occasion. According to the manufacturer, salinity measurements are accurate between 0 and 100‰ using the recommended standard solution of 36‰, however, we obtained an accuracy of -1.2% with a known solution of 150‰.

2.2. Life-cycle designations

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

2.3. Multivariate analyses

All multivariate analyses were performed using the PRIMER v6 package (Clarke & Warwick, 2001).

For each gear type used, the mean densities of fish at each site on each sampling occasion were classified by hierarchical agglomerative clustering (CLUSTER), using group average linking and similarity profiles (SIMPROF), and ordinated using non-metric multidimensional scaling (MDS). Prior to classification and ordination, the densities of fish in seine net and gill net samples were fourth-root and square-root transformed, respectively, to downweight high-abundance species, a dummy species was added to adjust for blank samples, and the Bray-Curtis similarity measure used to construct the association matrix. Analysis of similarities (ANOSIM) was used to test whether the species abundance data differed between subregions, years and austral seasons, then similarity percentages (SIMPER) was used to determine which species contributed most to any dissimilarities between groups (Clarke, 1993). Multivariate dispersion (MVDISP) was used to ascertain the degree to which the samples were dispersed (Somerfield & Clarke, 1997).

Note that, for the seine net method, samples collected during October and November 2006 were omitted from ANOSIM as these were not part of the regular three-monthly sampling regime. For comparisons between seasons, samples collected during the same month over consecutive years were pooled (i.e. December 2006 and 2007, March 2007 and 2008, June 2007 and 2008, and September 2007 and 2008), whereas the comparison between years was done by pooling samples collected from December 2006 to June 2007 and from December 2007 to June 2008. For the gill net method, missing samples at some sites during October and December 2006 and March 2007 produced an uneven distribution of samples between seasons and years, thus precluding any temporal comparison. Although these missing samples did not preclude ANOSIM between subregions for gill net samples, the spatial comparison was nevertheless restricted to the remaining seven sampling occasions.

As with species-abundance data, an association matrix was constructed for water quality variables, except Euclidean distance was used as the similarity measure. Prior to constructing the association matrix, missing pH and secchi disk measurements were replaced using an expectation maximum likelihood algorithm, salinity values for seine net samples were log-transformed (following inspection of draftsman plots), and all water quality variables were normalised. For each gear type, the extent of potential relationships between the composition of fish assemblages and any combination of water quality variables was explored by comparing the two association matrices using the BIOENV subroutine of PRIMER (Clarke & Ainsworth, 1993).

3. Results

3.1. Environmental (water quality) measurements

3.1.1. Water temperature

A seasonal cycle was clearly evident for water temperature across the region, with similar mean temperatures recorded in each subregion in most months (**Fig. 3**). Mean monthly water temperatures fell from a maximum of ~23°C in December 2006 to a minimum of ~11°C in June 2007, and then rose to at least 25°C in December 2007 before dropping again to ~14°C in June 2008. The lowest and highest mean monthly water temperatures of 11.2 and 27.2°C were recorded in the Southern Lagoon in June and December 2007, respectively.

3.1.2. Salinity

Mean salinities for each subregion differed on each sampling occasion; salinities were always lowest in the Murray Mouth and highest in the Southern Lagoon (**Fig. 3**). Mean monthly salinities ranged between ~30 and ~43‰ in the Murray Mouth, 61 and ~86‰ in the Northern Lagoon, and ~105 and ~164‰ in the Southern Lagoon. No obvious temporal pattern in mean monthly salinities occurred for either the Murray Mouth or Northern Lagoon, but sharp peaks in salinity occurred in the Southern Lagoon around March. Relatively high variation in mean monthly salinities was recorded between sites in the Northern Lagoon, as indicated by the relatively large error bars (**Fig. 3**). Mean salinities at each site generally increased with increasing distance from the mouth, from 35.5‰ at M1 to 125.1‰ at Jack Point in the Southern Lagoon (S1). Most of this increase in salinity occurred within the Northern Lagoon itself, where mean salinities ranged from 44.5‰ at N1 to 107.8‰ at Hell's Gate (N3) (**Fig. 3**).

3.1.3. Dissolved oxygen

Dissolved oxygen concentrations generally followed similar trends in the Murray Mouth and Northern Lagoon, with higher concentrations recorded in the Northern Lagoon on most occasions (**Fig. 3**). Thus, mean monthly dissolved oxygen concentrations in these two subregions rose from 6.4-7.6 ppM in December 2006 to 9.8-13.1 ppM in June 2007, and then declined to 6.0-7.5 ppM in March 2008 before rising again to 12.4-13.2 ppM in September 2008. In the Southern Lagoon, mean monthly dissolved oxygen concentrations appeared to peak between September and December, however, measurements were highly variable in this subregion.

3.1.4. pH

Mean monthly pH values were lower in the Southern Lagoon than in the other two subregions except on two occasions (in December 2006 and September 2008), when the trend was reversed (**Fig. 3**). Both the lowest and highest pH of 7.8 and 8.5 were recorded in the Southern Lagoon, in October 2006 and September 2007, respectively, while pH values in the Murray Mouth and Northern Lagoon usually fluctuated between ~8.2 and 8.4.

3.1.5. Turbidity

In most months, water transparency generally decreased (= increase in turbidity) with distance from the mouth, as indicated by secchi disk depth measurements (**Fig. 3**). Examination of mean secchi disk depth measurements at each site shows that a steep decline in water transparency occurs between Pelican Point in the Murray Mouth subregion (M5, 1.45 m) and N3, at the southern end of the Northern Lagoon (0.44 m).

3.2. Composition of fish assemblages

3.2.1. Seine net samples

A total of 78,754 fish representing 26 species was caught using the 61-m seine net throughout the Murray Mouth and Coorong region between October 2006 and September 2008. The abundance rank, number per 500 m2, and percentage contribution for each species is shown in **Table 5**. The atherinid *At. microstoma*, which is a solely-estuarine species, was by far the most abundant species, occurring in 73% of seine net samples, and contributing 60.5% to the total number of fish collected using this method. The second most abundant species, the mugilid *Al. forsteri*, which is a marine estuarine-opportunist, occurred in 64% of samples and contributed 16.5% to the total number, while the third most abundant, the clupeid *Hyperlophus vittatus*, which is also an estuarine-opportunist, appeared in 36% of samples and contributed 15.6% to the total number. These three species were the only species to contribute more than 3% to the total number of fish collected using the seine net, collectively accounting for 92.5% of that total catch. The only other species that contributed >1.0% were the arripid *Arripis truttaceus* (2.7%), another estuarine opportunist, and the galaxiid *Galaxias maculatus* (1.3%), which is considered to be a catadromous species.

All 26 fish species collected using this method were recorded from the Murray Mouth subregion, while 13 were recorded in the Northern Lagoon, and only 1 species, *At. microstoma*, was found in the Southern Lagoon (**Table 5**). The five most abundant species in the Murray Mouth were *Hype. vittatus* (38.0%), *Al. forsteri* (34.5%), *At. microstoma* (10.1%), *Arr. truttaceus* (6.6%), and *Ga. maculatus* (3.4%), while the Northern Lagoon was dominated by *At. microstoma* (91.8%), with relatively small contributions by *Al. forsteri* (5.3%) and *Hype. vittatus* (1.6%), and minor contributions by the pleuronectid *Rh. tapirina* (0.5%), an 'estuarine and marine' species, and the solely-estuarine gobiid *Af. tamarensis* (0.3%) (**Table 5**).

Although the species diversity in the Northern Lagoon was only half that of the Murray Mouth, a greater total number of fish were collected from the Northern Lagoon (despite the smaller number of samples) as a result of the numerical dominance of *At. microstoma* (~92%) in that subregion. Of the 40,216 *At. microstoma* collected, 89.4% were from the Northern Lagoon, 6.4% from the Murray Mouth, and 4.1% from the Southern Lagoon (**Table 5**). The importance of the Northern Lagoon to *At. microstoma* is further highlighted by the observation that it is the only species that was more abundant in this subregion compared to the Murray Mouth despite the fewer samples collected. Even though only 6.4% were collected from the Murray Mouth, *At. microstoma* was still the third most abundant species in that subregion.

The 26 species collected from the Murray Mouth and Coorong region using a seine net comprised 12 species that complete their life cycles within estuaries (6 solely estuarine and 6 'estuarine and marine' species), 10 marine species (9 estuarine-opportunists and 1 marine straggler), 2 catadromous species and 2 freshwater species (**Table 6**). Of these 26 species, all were found in the Murray Mouth, 7 estuarine species (4 solely estuarine and 3 'estuarine and marine' species), 5 marine estuarine-opportunists and 1 catadromous species were collected in the Northern Lagoon, while only 1 species was found in the Southern Lagoon (the solely-estuarine species, *At. microstoma*).

The vast majority of the total number of fish across the region was made up by solely-estuarine (61.8%) and estuarine-opportunist species (35.4%) (**Table 6**). The estuarine-opportunists were more abundant in the Murray Mouth (80.4%), while solely-estuarine species were dominant in the Northern (92.1%) and Southern Lagoons (100%).

The mean number of species collected at each site showed a general decline in species richness with distance from the mouth, ranging from 8.4 species at Boundary Creek Lower in the Murray Mouth (M2) to 0.6 species at S1 (**Fig. 4**).

The mean number of fish collected at N2 was 1,072 fish 500-m^{-2}, which is 3.9 times more than the second most abundant site, M1 (275 fish 500-m^{-2}) (**Fig. 4**). The high abundance at N2 relates to the very high numbers of *At. microstoma* collected (~1,040 fish 500-m^{-2}). Densities of this species fell away in either direction from N2, but substantial numbers were still collected from N1 and N3 (78 fish 500-m^{-2}), and from Salt Creek in the Southern Lagoon (S2, 54 fish 500-m^{-2}). *Aldrichetta forsteri* was commonly found at all sites located within the Murray Mouth and N1 and N2 in the Northern Lagoon. *Hyperlophus vittatus* showed a clear preference for the Murray Mouth subregion, particularly M1 (158 fish 500 m^{-2}), Boundary Creek Structure (M3, 79 fish 500 m^{-2}) and M5 (65 fish 500-m^{-2}). *Arripis truttaceus* showed modest abundance between M1 and Camp Site (M4), with densities of ~14 fish 500-m^{-2}.

3.2.2. Gill net samples

A total of 2,679 fish representing 16 species was caught from the sites within the Murray Mouth (M1 and M3, 1,457 fish) and Northern Lagoon subregions (N1 and N2, 1,222 fish) using the composite gill net (**Table 7**). The three most abundant species were *Arr. truttaceus* (75% occurrence in all gill net samples; 41.6% of total number of fish), *Al. forsteri* (72% occurrence; 37.3% of total number), and the sciaenid, *Arg. hololepidotus* (69% occurrence; 14.8% of total number), all of which are marine estuarine-opportunistic species. Collectively, these species contributed 93.7% to the total catch. The only other species that contributed >1.0% to the total catch was another mugilid, *Mugil cephalus*, also an estuarine-opportunist.

Of the 16 species, 13 were caught from each subregion (**Table 7**). *Arripis truttaceus* made the major contribution in catches from the Murray Mouth (61.2%), while *A. fosteri* was common in the Northern Lagoon (68.2%). Other noteworthy contributions towards the total catch from a subregion (≥1.0%) were the freshwater clupeid, *Nematolosa erebi* (1.4% of the catch from the Murray Mouth), and the catadromous pseudaphritid, *Pseuda. urvillii* (1.0% of the catch from the Northern Lagoon).

The fish collected by gill net comprised 11 marine species (9 estuarine-opportunists and 2 marine stragglers), 3 estuarine species (2 solely estuarine and 1 ‘estuarine and marine’ species), 1 catadromous species and 1 freshwater species (**Table 8**). Of the 11 marine species, 9 species were caught in each subregion, while the five remaining ‘non-marine’ species were found in both subregions. The vast majority of the total number of fish across the two subregions was made up by marine estuarine-opportunistic species (97.5%).

Approximately 4 species were caught on average with a gill net at M1, M3 and N1 on each sampling occasion (range: 3.7-4.7 species), while N2 was less diverse, with a mean of only 1.5 species (**Fig. 5**). Site N2 also yielded fewer fish (13 fish net set^{-1}) than the three more northern sites (M1, M3 and N1, range: 24-34 fish net set^{-1}). Both *Arr. truttaceus* and *Al. forsteri* were caught at all four sites, however, catches of *Arr. truttaceus* were greater at sites within the Murray Mouth, and more *Al. forsteri* were caught in the Northern Lagoon (**Fig. 5**). Small to moderate catches of *Arg. hololepidotus* contributed to the total gill net catches at the four sites (Murray Mouth: 2.5-7.0 fish net set^{-1}; Northern Lagoon: 0.7-4.2 fish net set^{-1}), while *Mu. cephalus* was found in appreciable numbers only at M3 (2.3 fish net set^{-1}).

3.3. Length-frequency distributions of key species

Length data was obtained from both seine and gill net samples. Seine nets set from the shore were efficient for sampling small-bodied species and juvenile fish, while the gill nets were set near the main channel to catch larger more mobile fish. If it is assumed that for a particular species, both methods collectively sampled most size classes of its population, then length-frequency data for that species can enable the identification of cohorts (that can sometimes be inferred as year classes), an estimation of the timing and duration of these cohorts in the region, and the modal progression (or growth) of cohorts to be traced with successive samples.

3.3.1. *Atherinosoma microstoma*

Atherinosoma microstoma was highly abundant, appeared in seine net hauls only, occurred in 73% of samples (73 of 100), and had a total length (L_T) range of 17-91 mm. In October 2006, samples generally comprised most of the 5-mm length classes within this range, and appeared as a single wide cohort. There is evidence of a second cohort emerging in November/December 2006 to produce the cohort in March, June, September and December 2006. In December 2007, the smallest length classes (15-20 and 20-25 mm) began to appear again and grow through March, June and September 2008 (**Fig. 6**).

3.3.2. *Aldrichetta forsteri*

Aldrichetta forsteri was abundant, collected using both gear types, occurred in 64% of seine net samples and 72% of gill net samples, and had length ranges of 26-308 mm L_T in seine net samples and 145-375 mm L_T in gill net samples. Composite samples for both gear types demonstrated that three or four cohorts were clearly identifiable in most months (**Fig. 7**). It appears that *Al. forsteri* spawn between February and early April, consistent with Harris (1968). The modal progression of these cohorts (year classes) to March 2007 and March 2008 suggests that this species attains growth of approximately 120-130, 240, and 290 mm L_T in its first, second and third years of life, respectively. Examination of differences in length-frequency distributions between subregions show that since March 2007, fewer small fish <170 mm L_T (mostly seine net samples) and more larger fish >170 mm L_T (mostly gill net samples) were caught in the Northern Lagoon than in the Murray Mouth (**Fig. 8**).

3.3.3. *Rhombosolea tapirina*

Rhombosolea tapirina was moderately abundant, mainly collected using a seine net, occurred in 56% of seine net samples and 31% of gill net samples, and had length ranges of 18-355 mm L_T in seine net samples and 105-340 mm L_T in gill net samples. Most length frequencies derived from samples collected between October 2006 and March 2007 were dominated by a single cohort, with a length range of 18 to ~110 mm L_T. It is assumed that most, if not all, of these fish originated from the most recent spawning season during the winter months June to August 2006 (unpublished gonadosomatic data). The growth of this winter cohort is evident in consecutive samples of December and March, with a modal progression from 40-50 to ~70-80 mm L_T during these months. Catches of *Rh. tapirina* larger than 150 mm L_T were small and sporadic, which suggests these larger fish have low catchability using either seine or gill nets (**Fig. 9**).

3.3.4. *Afurcagobius tamarensis*

Afurcagobius tamarensis was moderately abundant within the Murray Mouth and Northern Lagoon, was collected by seine net only, occurred in 26% of samples, and had a total length range of 20-77 mm. Following an estimated spawning period of October to January (based on unpublished gonadosomatic data), the smallest size class of 20-25 mm L_T began to appear in March and June 2007 and again in June 2008 (**Fig. 10**). Although somewhat unclear, there is evidence of modal progression of three different cohorts between October and November 2006, March and September 2007, and June and September 2008.

3.3.5. *Argyrosomus hololepidotus*

Argyrosomus hololepidotus was caught almost exclusively by gill net (except for seine net samples collected in December 2006 from the Murray Mouth subregion), occurred in 69% of gill net samples and only 5% of seine net samples, and had length ranges of 128-380 mm L_T in seine net samples and 155-710 mm L_T in gill net samples. Similar numbers of this species were caught from the Murray Mouth and Northern Lagoon using the gill net. Although a few of these fish reached up to 710 mm L_T, most were within the length range of 180-500 mm L_T. The progression of a single mode can be traced from December 2006 (modal length class of 180-200 mm L_T) through to March 2008 (~400 mm L_T) (**Fig. 11**). This cohort represents the 2005/06 year class from the November-March spawning period (Ferguson *et al.*, 2008). On either side of this cohort there is evidence of an older (2004/05) year class, between November 2006 and March 2007, and younger (2006/07) year class, between December 2007 and June 2008.

3.3.6. *Acanthopagrus butcheri* and *Pseudaphrites urvillii*

Small juveniles (100-150 mm L_T) of the sparid, *Ac. butcheri*, were found each year, i.e. December 2006, September 2007 and September 2008, which indicates that recruitment of this species occurred each year. However, the wide length ranges for *Ac. butcheri* and *Pseuda. urvillii* in this study (105-484 and 40-265 mm L_T, respectively) and the small numbers collected using either gear type (**Fig. 12** and **Fig. 13**) meant that few conclusions can be drawn for either species with respect to relative success in spawning or recruitment.

3.4. Fish assemblage structure

3.4.1. Classification of seine net samples

Classification of the mean densities of each fish species collected using a seine net at each site (10) on each sampling occasion (10) demonstrates evidence of structure among the 100 samples. Using the SIMPROF procedure, each sample (made up of three replicate samples) was allocated to one of six ‘similar profile’ groups on the basis that it had significant internal structure, i.e. samples within the same group share a similar fish assemblage pattern (accounting for both the component species of the sample and the density of each of those species) (**Fig. 14**). These groupings are significant ($P < 0.05$) at a similarity of at least 48%.

In general, these similarity profile groups were dominated (>77%) by samples collected from sites within the same subregion, which suggests that some overall fish assemblage pattern exists throughout the Murray Mouth and Coorong region (**Fig. 14**). The only exception is Group V_S, which was made up of 13 samples from the Southern Lagoon and 12 samples from the Northern Lagoon, although 9 of the 12 Northern Lagoon samples were collected from N3, which is located at the southernmost part of the Northern Lagoon. Groups I_S and II_S comprised samples that were primarily collected from the Murray Mouth and which shared a similarity profile of at least 49.0 and 51.7%, respectively, while Group III_S comprised a single sample collected from M5. Group IV_S comprised samples that were similar at 53.6% and greater, which were predominantly taken from the Northern Lagoon, while samples in Group VI_S were similar at a level of at least 60.4%, most of which were collected from the Southern Lagoon. Group V_S appeared to be a transition group between the two predominantly-lagoon groups; samples contained within this group had a similarity of at least 65.3%. No groups contained samples from both the Murray Mouth and the Southern Lagoon. It should also be noted that 8 of the 9 samples within Group VI_S show 100% similarity with one another as a consequence of these samples containing no fish.

ANOSIM demonstrated that highly significant differences were found in the composition of samples between subregions (Global R-statistic = 0.626, $P < 0.001$) (**Table 9**). All three subregions were highly significantly different from one another (Murray Mouth *vs* Southern

Lagoon: R-statistic = 0.958; Murray Mouth *vs* Northern Lagoon: 0.520; Northern Lagoon *vs* Southern Lagoon: 0.315). No significant differences were found between years or seasons.

3.4.2. Ordination of seine net samples

The ordination of all 100 samples, which depicts the similarities between samples in two-dimensional space, is comparable to the results of classification and ANOSIM (**Fig. 15**). Thus, all samples collected from the Murray Mouth occupy the left side of the plot and are clearly separate from all samples taken from the Southern Lagoon, which occupy the right side. The bottom left corner of the plot is dominated by Murray Mouth samples, the bottom right corner mainly made up by Southern Lagoon samples (many of those in Group VI_S are overlapping), while Northern Lagoon samples are either interspersed with samples from one of the other subregions or occupy an intermediate position at the top centre of the plot. Also shown are the groups of samples with similar assemblage structure (at similarity boundaries of 48%).

Samples collected from the Northern Lagoon were more widely dispersed than those in the Murray Mouth and Southern Lagoon, which is reflected by a higher dispersion value, i.e. 1.159 *vs* 1.002 and 0.626, respectively. At the site level, dispersion was particularly high at N1 (1.407).

The fish assemblages of the Murray Mouth subregion were identified using SIMPER as containing relatively lower numbers of *At. microstoma* and greater numbers of *Al. forsteri* and *Arr. truttaceus* than the Northern Lagoon, which collectively account for almost half (48.6%) of the dissimilarity between the two subregions (**Table 10**). With respect to assemblages of the two lagoons, although only *At. microstoma* was found in the Southern Lagoon and other species were collected in the Northern Lagoon, these other species generally occurred in relatively low numbers, and so most of the dissimilarity (57.0%) is attributed to *At. microstoma* being present at much higher densities in the Northern Lagoon. The dissimilarity between the Murray Mouth and Southern Lagoon assemblages can be attributed to all species present having a relatively greater abundance in the Murray Mouth, including *At. microstoma*, although *Al. forsteri* and *Arr. truttaceus* were the most discriminating species.

3.4.3. Classification of gill net samples

Classification of the mean catches of each fish species using a gill net at four sites on at least eight sampling occasions resulted in the division of 36 samples into two similar profile groups: Group I_G, which comprised most of the samples (18 samples from the two Murray Mouth sites and 13 from the two Northern Lagoon sites), with at least 36.7% similarity; and Group II_G, which was made up by the remaining samples (4 Northern Lagoon samples and 1 Murray Mouth sample) and had a similarity profile of at least 58.4% (**Fig. 16**). It should be noted that for 3 of the 5 samples in Group II_G, no fish were caught; all of these ‘zero’ samples were recorded at N1. ANOSIM demonstrated that the difference in sample composition was significant between the Murray Mouth and Northern Lagoon (R-statistic = 0.148, $P < 0.05$) and (**Table 11**).

3.4.4. Ordination of gill net samples

The ordination of all 36 gill net samples shows that most of the samples from the Murray Mouth occupied the top left corner of the plot, while Northern Lagoon samples tended to occupy the bottom left corner, although considerable overlap occurred between these two subregions (**Fig. 17**). Also shown are the boundaries of the two similarity profile groups (at 36% similarity). The ordination also reflects the greater dispersion of samples collected from the Northern Lagoon compared to those from the Murray Mouth subregion (dispersion value: 1.178 *vs* 0.858).

The catches of fish from the Murray Mouth subregion were identified using SIMPER as containing relatively more *Arr. truttaceus* and *Arg. hololepidotus*, but fewer *Al. forsteri* than the Northern Lagoon, which collectively account for most (~78%) of the dissimilarity between the two subregions (**Table 12**).

3.5. Link between salinity and fish assemblages

BIOENV demonstrated that, despite the availability of up to five water quality variables to potentially explain the observed fish assemblages across the region, salinity alone was the best explanatory variable of all possible combinations of variables for either seine net or gill net samples. The correlations (rho-statistic, ρ) between the salinity data and seine and gill net species abundance data were 0.676 and 0.478, respectively, both of which are highly significant ($P < 0.001$).

The salinity ranges of abundant and key species were examined based on water quality measurements taken at the same time as seine and gill net samples (**Table 13** and **Table 14**). The four most abundant species in both seine and gill net samples are all euryhaline, occurring at various times at almost all sites in the Murray Mouth and Northern Lagoon subregions, in salinities ranging from brackish to hypersaline (i.e. 12.9 to 55‰ and greater). *Atherinosoma microstoma*, the only species found in the Southern Lagoon, demonstrated a very high salt tolerance, occurring at extreme hypersalinities up to 133.5‰.

4. Discussion

4.1. Salinity gradient

For the duration of this study (October 2006 to September 2008), the Murray Mouth and Coorong region received no freshwater inflows from the River Murray. Ongoing dredging work kept the mouth open during this period (DWLBC, 2008). Thus, only seawater entered the Murray Mouth and Coorong during the period and continued evaporation resulted in increasing salinities along the Coorong. In our study, mean salinities were 30-43% in the Murray Mouth subregion, 61-86‰ in the Northern Lagoon, and 105-164‰ in the Southern Lagoon. There was no obvious temporal pattern in salinities during our study for either the Murray Mouth or Northern Lagoon, but there were sharp peaks in salinity each March in the Southern Lagoon, presumably due to relatively high evaporative water loss during the preceding summer and a lack of water exchange between the lagoons (Geddes, 2005).

Our salinity measurements, particularly from the Southern Lagoon, are quite high in comparison to a previous study of the Coorong that was undertaken during the 1982 drought, one which included a 16-month period of no freshwater inflows (Geddes & Butler, 1984). In that study, salinities in the Northern Lagoon reached 80‰, while salinities in the Southern Lagoon ranged between 90 and 100‰. The contrast is even greater when we compare our results to the 1983/84 flow year, when, following a period of substantial flows from the River Murray, the Northern Lagoon became brackish (<30‰) and the Southern Lagoon moderately hypersaline (55-70‰) (Geddes, 1987).

4.2. Composition of fish assemblages

4.2.1. Seine net samples

Using the seine net method we collected 66,515 fish representing 26 species collected from a total area of 150,000 m^2 (10 sampling occasions × 10 sites × 3 replicates × 500 m^2). Although few quantitative fish surveys have been conducted in the Murray Mouth and Coorong region, the abundance and diversity of fish species in the current study is comparable to that reported for the Wellstead Estuary in south-western Australia (Young & Potter, 2002), in which 10,951 fish representing 13 species were collected over a total area (according to our calculations) of 27,000 m^2. Unlike the Murray Mouth, which is kept open through ongoing dredging, the Wellstead Estuary is normally landlocked (it occasionally opens at times of high freshwater discharge); however, both regions are similar in that they exhibit a variable salinity gradient with extremely high salinities in some areas. The fish fauna in the similar Wellstead Estuary is described as 'depauperate' in comparison to other temperate estuaries of south-western Australia (Young & Potter, 2002).

The mesh size of 8 mm in the seine nets used in this study was very effective in sampling small-bodied fish species (e.g. atherinids and gobiids) and juvenile fish of large-bodied species. The small-bodied *At. microstoma*, in particular, was very abundant in our samples, making up most of the total number of fish collected throughout the study (>60%), and being the only species found in the Southern Lagoon. This and other small atherinids are particularly important species in the fish fauna of many temperate Australian estuaries, where they are often the dominant species (at least 50% of total number of fish), particularly where salinities are near or above that of seawater (e.g. Potter *et al.*, 1993; Potter & Hyndes, 1994; Valesini *et al.*, 1997; Griffiths & West, 1999; Young & Potter, 2002; Hoeksema & Potter, 2006). The second most abundant species in seine net samples, *Al. forsteri*, is also consistently abundant in south-western Australian estuaries, particularly as juveniles (see Potter & Hyndes, 1999, and references therein).

The next two abundant species, *Hype. vittatus* and *Arr. truttaceus*, are also estuarine-opportunists. The small-bodied *Hype. vittatus* spawns in inshore waters of southern Australia, and appreciable numbers comprising fish as young as the larval phase can be found in the Murray Mouth and Coorong region (Rogers & Ward, 2006). Migratory schools of juvenile *Arr. truttaceus* are found in the Murray Mouth and Coorong region after being distributed into South Australian waters by the Leeuwin current and westerly winds as postlarvae that have been spawned in Western Australia (Cappo *et al.*, 2000). The abundances of early-life stages of *Hype. vittatus* and *Arr. truttaceus* in the Murray Mouth and Coorong suggests this region has (at least) an important nursery function in these species' life cycles.

The fifth most abundant species, the small-bodied *Ga. maculatus*, has an interesting and adaptable life-history strategy. Although this species' life cycle normally includes a partially-catadromous spawning migration, estuarine spawning, supra-tidal egg development, an estuarine-marine larval stage and a postlarval upstream migration, landlocked populations have demonstrated contrasting life-history characteristics, including upstream spawning migration and completion of its life cycle in freshwater (Pollard, 1971; Chapman *et al.*, 2006).

Recent monitoring studies of fish movement and recruitment between the Lower Lakes (above the barrages) and the Murray Mouth and Coorong region (below barrages) further demonstrates the adaptability of this species. Between September 2006 and March 2007, when there were low freshwater discharges via fishways located at Goolwa and Tauwitchere Barrages, large numbers of post-larval *Ga. maculatus* were sampled below the barrage attempting to undertake upstream migration, thus demonstrating typical catadromous behaviour (Bice *et al.*, 2007). However, in the following year, when a negative headloss between the water levels either side of the barrages resulted in seawater intrusion into Lake Alexandrina from the leakage of saltwater through the barrages, the absence of young-of-year *Ga. maculatus* below the barrages was recorded, along with the early presence of reproductively mature adults (September 2008) and the subsequent increase in abundance of young-of-year recruits above the barrages (Jennings *et al.*, 2008). This suggests that *Ga. maculatus* is able to successfully complete its life cycle in a small estuarine gradient in the predominantly freshwater Lower Lakes and thereby take advantage of the dynamic physico-chemical environment at the barrage-fishways interface (Jennings *et al.*, 2008). Such an adaptable life-history strategy may have important implications for the continued spawning and recruitment success of *Ga. maculatus* in this region during drought conditions.

From seine net samples, almost the same number of marine species (10 species, comprising 1 marine straggler and 9 estuarine opportunists) utilised the Murray Mouth and Coorong region as the estuarine group (12 species, comprising 6 solely-estuarine and 6 'estuarine and marine' species). In terms of numbers of fish, however, the solely-estuarine category was dominant (~62%) because of the very high numbers of *At. microstoma*, with marine estuarine-opportunists making up most of the remainder (~35%).

Two catadromous species, *Ga. maculatus* and *Pseuda. urvillii*, collectively made a notable contribution to the total number of fish (1.3%), mainly due to the relative abundance of *Ga. maculatus*. Two species of freshwater fish, *N. erebi* and *Retropinna semoni*, were only found in very low numbers as might be expected as the Murray Mouth received no freshwater input from the Lower Lakes during the period.

4.2.2. Gill net samples

The catches in gill net samples were much less than those with a seine net as the small-bodied fish were not captured in these larger mesh static nets. Of the 16 species caught using a gill net, 11 were larger representatives of species that were also collected using the seine net. The five other species caught using a gill net were marine species (marine stragglers or estuarine-opportunists) and were generally caught in very low numbers, with the exception of the estuarine-opportunist, *Mu. cephalus*, which was the fourth most abundant species caught using this method. The seine net, on the other hand, collected 15 species (out of 26) that were not caught using a gill net, 13 of which are small-bodied and/or slender fish.

The most common species caught in gill net samples was the estuarine opportunist, *Arr. truttaceus*, with catches comprising relatively large juveniles. *Aldrichetta forsteri* and *Mu. cephalus* were the second and fourth most abundant species. These two opportunistic mugilid species were also common in several south-western Australian estuaries (Potter & Hyndes, 1999). Whereas only few *Mu. cephalus* were caught in the Northern Lagoon compared to the Murray Mouth, the opposite was found for *Al. forsteri*. It appears that, on the basis of numbers caught and length-frequency distributions, adult *Al. forsteri* move into the Northern Lagoon after spending their juvenile stage in the Murray Mouth subregion. The third most abundant species was the relatively large opportunist, *Arg. hololepidotus*, which was predominantly represented by juveniles (<750 mm L_T) since the Murray Mouth subregion provides an important habitat for juveniles of this species (Ferguson *et al.*, 2008). The freshwater *N. erebi* was the fifth most abundant. Although *N. erebi* mainly completes its life cycle in freshwater, it is known to be a resilient species that can tolerate high salinities (as well as high temperatures, high turbidities and low dissolved oxygen) (Briggs & McDowall, 1996; Lintermans, 2007). Nevertheless, its occurrence in this study in the Northern Lagoon at salinities as high as 48‰ possibly represents the upper salinity tolerance for this species.

Gill net catches were dominated by species that complete their life cycle at sea, with the top four species all being categorised as marine estuarine-opportusnists. These numbers reflect the ability of these large-bodied adult and juvenile fish to take advantage of the permanently-open mouth and favourable marine conditions that the Murray Mouth and Coorong region provided during the study.

4.2.3. Total species

A grand total of 31 fish species was recorded from both seine and gill net samples; this comprised 30 teleost species (bony fishes) and 1 ray species (cartilaginous fish) (**Table 4**). Of these, 6 species had not been recorded in previous inventories of some 77 species of the region (including freshwater species) (Eckert & Robinson, 1990; Higham et al., 2002). These additional species are all marine species (i.e. either estuarine opportunists or marine stragglers), and include the clinid *Heteroclinus heptaeolus*, the clupeid *Sardinops neopilchardus*, the pleuronectid *Ammotretis rostratus*, the pomatomid *Pomatomus saltatrix*, the syngnathid *Stigmatopora argus*, and the myliobatid *Myliobatis australis* (**Table 4** and **Table 5**). Importantly, all 11 'estuarine' species identified by Higham *et al.* (2002) as characteristic of the Murray Mouth and Coorong region were collected in this study, albeit some were in quite low densities.

4.3. Length-frequency distributions of key species

In addition to describing the composition of fish assemblages, length frequency distributions for seven key species were measured in order to gain more detailed information with respect to the utilisation of the Murray Mouth and Coorong by particular life stages of these species.

4.3.1. *Atherinosoma microstoma*

The broad temporal scale of sampling (three-monthly) made the modal progression of *At. microstoma* cohorts between samples somewhat unclear. Nevertheless, it appears that early-spawned fish from a September-December spawning season (Molsher *et al.*, 1994) only just begin to appear in seine net samples during November/December. Rapid growth occurs over summer until early autumn, by which time it has attained most of its growth and formed a single cohort with a wide size range, probably as a result of multiple spawnings per fish over a protracted spawning period. Its growth slows considerably over winter before spawning in spring and dying shortly after at approximately one year of age (Molsher *et al.*, 1994), with a small proportion perhaps surviving to the second year of growth.

4.3.2. *Aldrichetta forsteri*

Based on gonad development of adults, Harris (1968) concluded that *Al. forsteri* spawn within the Murray Mouth and Coorong region between February and early April. Hall (1984), on the other hand, adopted an alternative hypothesis by Chubb *et al.* (1981) that *Al. forsteri* generally spawn outside estuaries and recently hatched juveniles enter by active swimming. More recently, however, another more complex theory has been proposed. Pellizzari (2001) suggested that, based on back-calculations from daily growth increments in otoliths from juveniles, *Al. forsteri* spawns all year round, and that spawning during winter months occurs outside the Murray Mouth, with recruitment of juveniles within the region some months later. He reasoned that the Murray Mouth and Coorong *Al. forsteri* population is derived from both the ‘eastern’ population of Victoria and Tasmania, which spawns in summer, and the ‘western’ population of Western Australia, which spawns in winter (Thomson, 1957). Whilst our results are not detailed enough to confirm any of these theories, the length-frequency distributions nevertheless demonstrate modal progression of clearly distinguishable cohorts, which is characteristic of a species with a relatively distinct spawning season. These cohorts presumably represent year classes, and up to four year classes were present in the region at any one time.

Of the key species, only the length-frequency distributions for *Al. forsteri* showed a noticeable difference in size structure between subregions, with relatively few fish <170 mm L_T and most fish >170 mm L_T occurring in the Northern Lagoon compared to the Murray Mouth. We are uncertain of the reason for this observation, although an increase in salinity tolerance with growth does not appear to be a factor since recent sublethal tank experiments on much smaller juveniles suggests a high salinity tolerance (upper LD_{50} of 89.2‰ at 14°C, unpubl. data). However, one explanation for larger *Al. forsteri* mainly occurring in the Northern Lagoon is that this subregion provides greater refuge from seals or other predators than the Murray Mouth subregion where they are more prevalent (Q. Ye, pers. comm.).

4.3.3. *Rhombosolea tapirina*

Adult *Rh. tapirina* are found in sheltered bays, estuaries, and inshore coastal waters, where they prefer sand, silt and muddy substrates (Last *et al.* 1983; Kailola *et al.* 1993; Gomon *et al.* 2008). They are not generally found in marine waters adjacent to the Coorong lagoons and is believed to complete its life cycle within the Murray Mouth and Coorong region (Hall 1984). Length frequency data obtained in this study supports the theory of an ‘estuarine’ *Rh. tapirina* population in this region, with a wide size range sampled, from young juvenile stage (18 mm L_T)

through to near maximum length for this species (355 mm L_T). Studies of reproductive biology of Tasmanian *Rh. tapirina* populations indicate that this species spawns multiple times during a protracted season, from March to October (Kurth, 1957; Crawford, 1984). Our unpublished gonadosomatic data for adults sampled from the Murray Mouth and Coorong suggests that spawning within this region is restricted to winter months (June-August), although there was a paucity of samples collected between March and May.

After being spawned in winter, the growth of juveniles could be detected from a modal size class of 40-50 mm L_T in December to 70-80 mm L_T in March. However, further growth of this cohort was uncertain, with fish larger than ~110 mm L_T occurring only sporadically on most sampling occasions. Most *Rh. tapirina* of all sizes were collected using the seine net, yet the commercial catch of this species is primarily taken by large mesh gill net. This suggests that gill nets used in this study (which are configured to include mesh sizes used by commercial fishers) may have been set at locations where this species occurs in low numbers, and that further monitoring, possibly through a combined fishery-dependent and independent sampling program, would be useful to ascertain whether the *Rh. tapirina* population has a more 'complete' size and age distribution.

4.3.4. *Afurcagobius tamarensis*

Like *At. microstoma*, *Af. tamarensis* is a small-bodied species that spawns in spring and completes its life cycle in estuaries (Larson & Hoese, 1996). Despite the lack of information on age and growth of *Af. tamarensis*, this species probably has a short lifespan of perhaps just over one year. Our unpublished gonadosomatic data indicates that the spawning period for *Af. tamarensis* possibly extends beyond spring, with ovarian development most advanced during October, December and January. In either case, length-frequency distributions show that, after being spawned in spring or summer, this species first appears in March as small as 20 mm L_T and belonging to a cohort with a modal size class of 35-40 mm L_T. The progression of this cohort can be traced through to at least November at a modal size of ~70 mm L_T and an approximate age of 12 months.

4.3.5. *Argyrosomus hololepidotus*

The Murray Mouth and Coorong *Arg. hololepidotus* population is comprised almost exclusively of juveniles (<750 mm L_T), whilst the nearshore marine fishery comprises reproductively mature and sub-mature adults (800-1500 mm L_T) that aggregate at the interface of the River Murray plume during the spring-summer (November to March) spawning period (Hall, 1984; Ferguson *et al.*, 2008). Larval development is thought to occur at sea with juveniles entering the Murray Mouth several months later at 100-150 mm L_T (Hall, 1986). The length-frequency distributions obtained in this study certainly conform to these life history descriptions, with juveniles as small as 128 mm L_T and belonging to a cohort with a modal size of <200 mm L_T appearing in December (approximately one year of age). Modal progression of this cohort indicates that juveniles reach a modal size class of ~350 mm L_T over the subsequent 12-month period (at two years of age).

4.3.6. *Acanthopagrus butcheri* and *Pseudaphrites urvillii*

Only few *Ac. butcheri* and *Pseuda. urvillii* were collected using seine or gill nets on any sampling occasion. Small sample sizes of these species could be due to a number of possible reasons, including species' behaviour making it difficult to sample effectively, low actual abundances, an ineffective sampling method (e.g. non-selective gear type for these species, poor positioning of nets), or a combination of these. Recent poor recruitment of *Pseuda. urvilli* has also been suggested, which is probably related to the closed barrages and fishways preventing this species undertaking spawning migrations (also discussed later).

This study aimed to sample multiple species of fish assemblages at a time rather than target individual species, and only slight modification to the sampling methodology may be required to sample a particular species much more effectively.

4.4. Link between salinity and fish assemblages

It has been known for some time now that salinity is an overwhelmingly important factor in the ecological health of the Coorong (e.g. Geddes & Butler, 1984; Geddes, 1987, 2003, 2005).

Through a descriptive account of seine net and gill net collections conducted over a two-year period and the subsequent multivariate analyses of the component fish assemblages, the results of this study reiterate the effects of a large salinity gradient on the fish assemblages along the length of the Murray Mouth and Coorong region. Specifically, it describes the assemblages during an extended drought period for the region, where salinities have generally ranged from saline (~30‰) in the Murray Mouth subregion to extreme hypersaline (167.6‰) in the Southern Lagoon. Further, it perhaps provides a comprehensive sampling methodology and, despite being conducted during a drought, the results obtained establish a reference or baseline (during a drought) by which future assessment can be made of the relative health of the fish assemblages in the region.

The general decline in species diversity with increasing distance from the Murray Mouth observed in this and previous studies is believed to be a response to the strong salinity gradient because of the increasing osmoregulatory stress and/or diminishing food resources, which force certain fish taxa out of the area (Whitfield, 1999). When environmental pressures are selective towards a low number of species inhabiting a particular area, both predation and competition for food resources decreases, which provide opportunities for those remaining few species to extend their ecological niche (Colburn, 1988). The absence of potential predators and competitors in hypersaline conditions is assumed to allow species that are able to tolerate these conditions broader access to food, space and habitat, and thereby compensate for the added energetic cost of osmoregulation (Vega-Cendejas & Hernández de Santillana, 2004). The utilisation of such opportunities is best exemplified in this study by the dominance of *At. microstoma* in the Northern Lagoon (~92% of the total number of fish) and its occurrence as the only fish species in the Southern Lagoon, which place it as a keystone species in the structuring of fish assemblages throughout the Murray Mouth and Coorong region.

Prior to this study, *At. microstoma* had demonstrated laboratory salinity tolerances of 3.3-108‰ (lower-upper LD_{50}) (Lui, 1969), and an even greater tolerance range in natural conditions. On one occasion in March 1985, a few individuals were collected near Tea Tree Crossing in the Southern Lagoon, where 149‰ total dissolved solids (≈130‰ salinity) was recorded (Geddes, 1987). These observations rank *At. microstoma* alongside the cyprinotontid *Cyprinodon variegatus*, which has been recorded at salinities approaching 140‰ (Gunther, 1956), as one of the most salt-tolerant fish species in the world. In the current study, salinities were recorded as high as 167.6‰, and *At. microstoma* was collected up to 133.5‰, suggesting that salinities in the Southern Lagoon often exceeded its salinity tolerance.

The abundant species *Al. forsteri*, *Hype. vittatus* and *Arr. truttaceus* were also important as a secondary influence on the composition of fish assemblages in the Murray Mouth and Coorong region. These are marine-estuarine opportunists and so the composition of fish assemblages in this study can probably be regarded as typical only of assemblages of the region during an extended drought period.

The limited distribution of species is also related to salinity and the drought. Geddes (1987) observed that following above average barrage flows during 1983-84, salinities fell as low as 55‰ in the Southern Lagoon and *Ac. butcheri*, *Al. forsteri* and *Pseuda. urvillii* occurred in the northern parts of the Southern Lagoon. The hypersaline to extremely hypersaline waters of the lagoons in the current study has resulted in an extreme environmental gradient along which species diversity and abundance are drastically limited (Simier *et al.*, 2004).

4.5. Implications of drought (no freshwater inflows)

The effects of reduced or no freshwater inflows on fish in estuarine and coastal ecosystems include: impediment to migration of diadromous species without attractant flows, particularly when there are physical barriers (e.g. barrages); lack of stimulus for spawning; indirect impact on spawning and recruitment success as a result of modified water temperature and salinity; alteration of nursery habitat with changes in food, temperature, turbidity and salinity; reduction in primary production and trophic structure of ecosystem; and changes in fish assemblages (see Drinkwater & Frank (1994) and Gillanders & Kingsford (2002) for thorough reviews of these effects).

With respect to the key species in this study, the continuation of the drought and an ongoing lack of freshwater inflows to the Murray Mouth and Coorong region is believed to have negative effects on *Rh. tapirina*, *Arg. hololepidotus*, *Ac. butcheri* and *Pseuda. urvillii*, while it is unknown if or how the remaining three species (*Al. forsteri*, *At. microstoma* and *Af. tamarensis*) are affected.

Argyrosomus hololepidotus adults in spawning condition aggregate outside the Murray Mouth during November-January when there are large freshwater discharges across the barrages (Hall, 1984, 1986). In subsequent months the juveniles enter the Murray Mouth and Coorong region. Hall (1984) found, by examining the correlation of freshwater flows with catch rates of *Arg. hololepidotus* between 1976/77 and 1982/83, a significant positive relationship existed between flows and catch rates 15 and 27 months later, which is consistent with the estimated age of recruitment to the fishery in the second or third year. These observations support the hypothesis that, for *Arg. hololepidotus*, freshwater flows may be an important cue for spawning and may promote the recruitment of juveniles. Ferguson (2008) examined the age structures from commercial catches of *Arg. hololepidotus* in 2001 and 2002 and concluded that the population within or near the Murray Mouth and Coorong region was extremely dependent on the presence of a few strong year classes resulting from years of above average flows. This implies that the population's capacity to withstand or recover from years of reduced flows, combined with commercial and recreational fishing pressure is threatened by the current extended drought conditions.

Hall (1984) found a positive correlation between freshwater discharge across the barrages and catch rates of *Rh. tapirina* 38 months later. This implies that spawning and/or recruitment success of *Rh. tapirina* may also be related to freshwater inflows. It has also been suggested that, since *Rh. tapirina* spawns during winter months (June-August) before the normally high flow season, larvae and juveniles could potentially take advantage of any enhanced biological productivity (i.e. food availability) related to freshwater inflows, which may result in faster growth rates and, therefore, higher survival rates and recruitment success (Robins & Ye, 2007).

In contrast to *Arg. hololepidotus* and *Rh. tapirina*, lag-correlation coefficients between flows and subsequent catch rates of *Ac. butcheri* from the Lakes and Coorong Fishery were negative, indicating that annual year-class strength was inversely proportional to flow (Hall, 1984). This finding supports other studies undertaken in the Gippsland Lakes of south-eastern Australia, where it was shown that annual recruitment of this species is highly variable (Hobday & Moran, 1983; Morison *et al.*, 1998), and that weaker year classes tended to coincide with years of high spring river flows and below average temperatures, while dominant year classes resulted from spawning during relatively dry springs (Hobday & Moran, 1983). To further investigate this potential relationship and other possible causal mechanisms for the Murray Mouth and Coorong population, work is currently underway to estimate the year-class strength of *Ac. butcheri* obtained from commercial catches during 2006-2008 (along with *Al. forsteri* and *Rh. tapirina*), and then to correlate year-class strength with flows prior to the drought.

The unique life history requirements of migratory diadromous species make these species extremely vulnerable to current environmental stresses in the Lower Lakes, Murray Mouth and Coorong (SAMDBNRM, 2008). Fish passage has generally been available to these species through the operation of barrage gates and a network of channels connecting the Lower Lakes and the Murray Mouth and Coorong. However, under current drought conditions, no options for fish passage exist and freshwater and salt water environments have effectively become isolated. For *Pseuda. urvillii*, recent studies have shown that in September and October 2006, when there was last some connectivity between the Lower Lakes and the Murray Mouth and Coorong via barrage fishways and island channels, male and female *Pseuda. urvillii* co-occurred below Tauwitchere Barrage and substantial recruitment of young-of-year fish was apparent in subsequent months (Bice *et al.*, 2007). However, in the following year, when there was no connectivity, it was found that this species was largely segregated by sex, with mature females aggregating above the barrage and males generally below the barrage, and it appeared that recruitment was consequently poor (Jennings *et al.*, 2008). The continuation of the current drought conditions and lack of connectivity between the Lower Lakes and the Murray Mouth and Coorong could potentially lead to recruitment failure for this species (Jennings *et al.*, 2008).

Small juveniles of all seven key species were collected in each year of the current study. These fish were presumably less than one year old, which demonstrate that, despite the drought, spawning and recruitment of the key species were still occurring. In particular, *Atherinosoma microstoma*, *Al. forsteri*, *Rh. tapirina* and *Af. tamarensis* populations appeared healthy, whereas *Arg. hololepidotus*, *Ac. butcheri* and *Pseuda. urvillii* appeared in low numbers. However, the numbers of these species are relative to this study only, and may be biased by the sampling methods used. The relative success of spawning and recruitment for any of these species can only be properly determined through longer-term monitoring of their numbers using the same sampling methodology.

4.6. Conclusions

There is a high likelihood that the extended drought conditions and the subsequent lack of freshwater input and increases in salinity throughout the Murray Mouth and Coorong have influenced the composition of fish assemblages and severely limited distributions.

Several years ago the overall ecological health of the Coorong was considered poor and possibly at an historical low point for the region with respect to its biodiversity and productivity (Geddes, 2003). For fish communities, the present situation is likely to be even worse as a result of the low mean annual flow volume across the barrages of 176 GL yr^{-1} during 2004-2008 and the significantly higher salinities than in any earlier survey.

If a normal flow regime were to return to the Murray Mouth and Coorong, we recommend that the current study is repeated in order to understand whether and how the composition of fish assemblages of this region responds to non-drought conditions. We hypothesise that the freshening of the Murray Mouth and Coorong through either an increase in freshwater inflows or greater rate of exchange with less saline waters of the sea would result in an increase in species diversity and abundance and a greater southward distributional range of some species throughout the region. However, there is considerable risk that, for those species that need periodic freshwater input for some part of their life cycle, spawning and recruitment success may have already progressively weakened from consecutive years of the current drought. If drought conditions continue, diadromous species and other flow-dependent species are particularly at risk.

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Tables

Table 1. Details of coordinates, approximate distance from mouth, and sampling gear used for each of the ten sites of the Murray Mouth and Coorong. Sites are listed by subregion, with site codes in parentheses (see **Fig. 1** for map showing locations).

Site	Latitude (°S)	Longitude (°E)	Dist. from mouth (km)	Sampling gear
Murray Mouth				
Beacon 19 (M1)	35.534	138.832	6.5	Seine and gill nets
Boundary Ck Lower (M2)	35.564	138.923	3.5	Seine net only
Boundary Ck Structure (M3)	35.556	138.934	5.7	Seine and gill nets
Camp Site (M4)	35.568	138.932	4.4	Seine net only
Pelican Point (M5)	35.595	139.014	12.8	Seine net only
Northern Lagoon				
Mark Point (N1)	35.638	139.076	20.3	Seine and gill nets
Noonameena (N2)	35.757	139.232	40.2	Seine and gill nets
Hell's Gate (N3)	35.903	139.398	62.9	Seine net only
Southern Lagoon				
Jack Point (S1)	36.042	139.576	85.8	Seine net only
Salt Creek (S2)	36.132	139.638	98.4	Seine net only

Table 2. The number of replicate seine net samples collected at each of the 10 sites in the Murray Mouth, Northern Lagoon and Southern Lagoon subregions on 10 occasions between October 2006 and September 2008.

Date	Site										Total
	M1	M2	M3	M4	M5	N1	N2	N3	S1	S2	
Oct-06	3	3	3	3	3	3	3	3	3	3	30
Nov-06	3	3	3	3	3	3	3	3	3	3	30
Dec-06	3	3	3	3	3	3	3	3	3	3	30
Mar-07	3	3	3	3	3	3	3	3	3	3	30
Jun-07	3	3	3	3	3	3	3	3	3	3	30
Sep-07	3	3	3	3	3	3	3	3	3	3	30
Dec-07	3	3	3	3	3	3	3	3	3	3	30
Mar-08	3	3	3	3	3	3	3	3	3	3	30
Jun-08	3	3	3	3	3	3	3	3	3	3	30
Sep-08	3	3	3	3	3	3	3	3	3	3	30
Total	30	30	30	30	30	30	30	30	30	30	300

Table 3. The number of replicate gill net samples collected at each of 4 sites in the Murray Mouth and Northern Lagoon subregions on 10 occasions between October 2006 and September 2008. ns, not sampled.

Date	Site				Total
	M1	M3	N1	N2	
Oct-06	ns	3	3	ns	6
Nov-06	3	3	3	3	12
Dec-06	3	3	3	ns	9
Mar-07	3	3	ns	3	9
Jun-07	3	3	3	3	12
Sep-07	3	3	3	3	12
Dec-07	3	3	3	3	12
Mar-08	3	3	3	3	12
Jun-08	3	3	3	3	12
Sep-08	3	3	3	3	12
Total	27	30	27	24	108

Table 4. Family, scientific and common names of all fish species collected from the Murray Mouth and Coorong region between October 2006 and September 2008. Species not previously recorded from the region (in Eckert & Robinson, 1990, or Higham *et al.*, 2002) are denoted with an asterisk (*).

Family	Scientific name	Common name
Class Osteichthyes (bony fishes), subclass Teleostei		
Arripidae	*Arripis georgianus* (Valenciennes, 1831)	Australian herring
Arripidae	*Arripis truttaceus* (Cuvier, 1829)	Western Australian salmon
Atherinidae	*Atherinosoma microstoma* (Günther, 1861)	Smallmouth hardyhead
Carangidae	*Pseudocaranx dentex* (Bloch & Schneider, 1801)	Silver trevally
Clinidae	*Heteroclinus heptaeolus* (Ogilby, 1885)*	Ogilby's weedfish
Clupeidae	*Hyperlophus vittatus* (Castelnau, 1875)	Sandy sprat
Clupeidae	*Nematalosa erebi* (Günther, 1868)	Bony bream
Clupeidae	*Sardinops neopilchardus* (Steindachner, 1879)*	Australian sardine
Engraulidae	*Engraulis australis* (Shaw, 1790)	Australian anchovy
Galaxiidae	*Galaxias maculatus* (Jenyns, 1842)	Common galaxias
Gobiidae	*Afurcagobius tamarensis* (Johnston, 1883)	Tamar goby
Gobiidae	*Arenigobius bifrenatus* (Kner, 1865)	Bridled goby
Gobiidae	*Pseudogobius olorum* (Sauvage, 1880)	Bluespot goby
Gobiidae	*Tasmanogobius lasti* (Hoese, 1991)	Scary's Tasmangoby
Hemiramphidae	*Hyporhamphus melanochir* (Valenciennes, 1847)	Southern garfish
Hemiramphidae	*Hyporhamphus regularis* (Günther, 1866)	River garfish
Mugilidae	*Aldrichetta forsteri* (Valenciennes, 1836)	Yelloweye mullet
Mugilidae	*Liza argentea* (Quoy & Gaimard, 1825)	Goldspot mullet
Mugilidae	*Mugil cephalus* (Linnaeus, 1758)	Sea mullet
Pleuronectidae	*Ammotretis rostratus* (Günther, 1862)*	Longsnout flounder
Pleuronectidae	*Rhombosolea tapirina* (Günther, 1862)	Greenback flounder
Pomatomidae	*Pomatomus saltatrix* (Linnaeus, 1766)*	Tailor
Pseudaphritidae	*Pseudaphritis urvillii* (Valenciennes, 1831)	Congolli
Retropinnidae	*Retropinna semoni* (Weber, 1895)	Australian smelt
Sciaenidae	*Argyrosomus hololepidotus* (Lacépède, 1802)	Mulloway
Sparidae	*Acanthopagrus butcheri* (Munro, 1949)	Black bream
Syngnathidae	*Stigmatopora argus* (Richardson, 1840)*	Spotted pipefish
Terapontidae	*Pelates octolineatus* (Jenyns, 1840)	Western striped grunter
Tetraodontidae	(multiple species, see Materials and Methods)	Toadfish spp.
Tetrarogidae	*Gymnapistes marmoratus* (Cuvier, 1829)	Soldier
Class Elasmobranchii (sharks and rays)		
Myliobatidae	*Myliobatis australis* (Macleay, 1881)*	Southern eagle ray

Table 5. Life-cycle category, ranking by abundance (R), numbers (*n*), and percentage contribution (%) of each fish species in the Murray Mouth, Northern Lagoon and Southern Lagoon subregions, derived from seine net samples collected at all sites between October 2006 and September 2008. Mean lengths and length ranges for key species are also given. Numbers were calculated after seine net samples were adjusted to no. fish 500 m^{-2} and then summed.

Species	Life cycle	Total region			Murray Mouth			Northern Lagoon			Southern Lagoon			Mean length (mm)	Length range (mm)
		R	*n*	%	R	*n*	%	R	*n*	%	R	*n*	%		
Atherinosoma microstoma	E	1	40216	60.5	3	2587	10.1	1	35964	91.8	1	1666	100.0	53	17-91
Aldrichetta forsteri	O	2	10959	16.5	2	8867	34.5	2	2092	5.3				73	26-308
Hyperlophus vittatus	O	3	10370	15.6	1	9748	38.0	3	622	1.6					
Arripis truttaceus	O	4	1780	2.7	4	1694	6.6	6	86	0.2					
Galaxias maculatus	C	5	866	1.3	5	866	3.4								
Hyporhamphus regularis	E	6	494	0.7	6	474	1.8	8	20	<0.1					
Rhombosolea tapirina	E&M	7	470	0.7	7	286	1.1	4	183	0.5				66	18-355
Afurcagobius tamarensis	E	8	316	0.5	10	215	0.8	5	101	0.3				46	20-77
Ammotretis rostratus	O	9	285	0.4	11	205	0.8	7	80	0.2					
Engraulis australis	E&M	10	252	0.4	9	236	0.9	9	15	<0.1					
Family Tetraodontidae	E&M	11	242	0.4	8	240	0.9	12	2	<0.1					
Arripis georgianus	O	12	69	0.1	12	68	0.3	13	1	<0.1					
Argyrosomus hololepidotus	O	13	49	<0.1	13	49	0.2							193	128-380
Tasmanogobius lasti	E	14	45	<0.1	14	39	0.2	10	6	<0.1					
Arenigobius bifrenatus	E&M	15	34	<0.1	15	34	0.1								
Acanthopagrus butcheri	E	16	25	<0.1	16	25	<0.1							269	105-484
Hyporhamphus melanochir	E&M	17	15	<0.1	17	15	<0.1								
Pseudaphritis urvillii	C	18	9	<0.1	18	7	<0.1	11	3	<0.1				131	40-230
Pseudogobius olorum	E	=19	5	<0.1	=19	5	<0.1								
Gymnapistes marmoratus	O	=19	5	<0.1	=19	5	<0.1								
Nematolosa erebi	F	21	3	<0.1	21	3	<0.1								
Sardinops neopilchardus	S	=22	2	<0.1	=22	2	<0.1								
Liza argentea	E&M	=22	2	<0.1	=22	2	<0.1								
Retropinna semoni	F	=24	1	<0.1	=24	1	<0.1								
Heteroclinus heptaeolus	O	=24	1	<0.1	=24	1	<0.1								
Myliobatis australis	O	=24	1	<0.1	=24	1	<0.1								
Total number of species			26			26			13			1			
Total number of fish			66515			25676			39174			1666			

Table 6. Numbers of species and individuals (*n*), and their percentage contributions (%), to each life-cycle category in the Murray Mouth, Northern Lagoon and Southern Lagoon subregions, derived from seine net samples collected at all sites between October 2006 and September 2008.

Life-cycle category	Total region		Murray Mouth		N. Lagoon		S. Lagoon	
	n	%	*n*	%	*n*	%	*n*	%
Species								
Marine straggler	1	3.8	1	3.8				
Estuarine-opportunist	9	34.6	9	34.6	5	38.5		
Solely estuarine	6	23.1	6	23.1	4	30.8	1	100.0
Estuarine & marine	6	23.1	6	23.1	3	23.1		
Catadromous	2	7.7	2	7.7	1	7.7		
Freshwater	2	7.7	2	7.7				
Total	26		26		13		1	
Individuals								
Marine straggler	2	<0.1	2	<0.1				
Estuarine-opportunist	23520	35.4	20639	80.4	2881	7.4		
Solely estuarine	41101	61.8	3345	13.0	36090	92.1	1666	100.0
Estuarine & marine	1014	1.5	813	3.2	200	0.5		
Catadromous	875	1.3	872	3.4	3	<0.1		
Freshwater	3	<0.1	3	<0.1				
Total	66515		25676		39174		1666	

Table 7. Life-cycle category, ranking by abundance (R), numbers (*n*), and percentage contribution (%) of each fish species in the Murray Mouth and Northern Lagoon subregions, derived from gill net samples collected at Beacon 19 (Site M1), Boundary Creek Structure (M3), Mark Point (N1) and Noonameena (N2) between October 2006 and September 2008. Mean lengths and length ranges for key species are also given.

Species	Life cycle	Total region			Murray Mouth			Northern Lagoon			Mean length (mm)	Length range (mm)
		R	*n*	%	R	*n*	%	R	*n*	%		
Arripis truttaceus	O	1	1114	41.6	1	892	61.2	2	222	18.2		
Aldrichetta forsteri	O	2	999	37.3	3	166	11.4	1	833	68.2	236	145-375
Argyrosomus hololepidotus	O	3	396	14.8	2	266	18.3	3	130	10.6	313	155-710
Mugil cephalus	O	4	77	2.9	4	70	4.8	=5	7	0.6		
Nematolosa erebi	F	5	22	0.8	5	21	1.4	=10	1	<0.1		
Pseudaphritis urvillii	C	6	17	0.6	=8	5	0.3	4	12	1.0	216	180-265
Rhombosolea tapirina	E&M	7	16	0.6	7	9	0.6	=5	7	0.6	235	105-340
Arripis georgianus	O	8	13	0.5	6	13	0.9					
Hyporhamphus regularis	E	9	6	0.2	=8	5	0.3	=10	1	<0.1		
Acanthopagrus butcheri	E	10	5	0.2	=10	4	0.3	=10	1	<0.1	336	310-394
Pelates octolineatus	O	11	4	0.1	=10	4	0.3					
Ammotretis rostratus	O	=12	3	0.1				7	3	0.2		
Family Tetraodontidae	O	=12	3	0.1	=12	1	<0.1	=8	2	0.2		
Pomatomus saltatrix	O	14	2	0.1				=8	2	0.2		
Stigmatopora argus	S	=15	1	<0.1				=10	1	<0.1		
Pseudocaranx dentex	S	=15	1	<0.1	=12	1	<0.1					
No. species/groups			16			16			16			
Grand Total			2679			1457			1222			

Table 8. Numbers of species and individuals (*n*), and their percentage contributions (%), to each life-cycle category in the Murray Mouth and Northern Lagoon subregions, derived from gill net samples collected at Beacon 19 (Site M1), Boundary Creek Structure (M3), Mark Point (N1) and Noonameena (N2) between October 2006 and September 2008.

Life-cycle category	Total region		Murray Mouth		N. Lagoon	
	n	%	*n*	%	*n*	%
Species						
Marine straggler	2	12.5	1	7.7	1	7.7
Estuarine-opportunist	9	56.3	7	53.8	7	53.8
Solely estuarine	2	12.5	2	15.4	2	15.4
Estuarine & marine	1	6.3	1	7.7	1	7.7
Catadromous	1	6.3	1	7.7	1	7.7
Freshwater	1	6.3	1	7.7	1	7.7
Total	16		13		13	
Individuals						
Marine straggler	2	0.1	1	0.1	1	0.1
Estuarine-opportunist	2611	97.5	1412	96.9	1199	98.1
Solely estuarine	11	0.4	9	0.6	2	0.2
Estuarine & marine	16	0.6	9	0.6	7	0.6
Catadromous	17	0.6	5	0.3	12	1.0
Freshwater	22	0.8	21	1.4	1	0.1
Total	2679		1457		1222	

Table 9. One-way ANOSIM results for tests on differences between subregions, years and seasons for seine net samples collected between October 2006 and September 2008.

Factor (*n*)	Global *R*	*P*	Sig. pairwise comparisons	Details
Subregion (3)	0.626	0.001	3/3	MM *vs* NL, MM *vs* SL, NL *vs* SL
Year (2)	0.022	0.121	-	
Season (4)	0.026	0.121	-	

Table 10. SIMPER results indicating which species contributed most to the overall dissimilarity between significantly different subregions (from ANOSIM) derived from seine net samples collected at all sites between October 2006 and September 2008. Consistency ratio (CR) is the ratio of the mean to standard deviation of the dissimilarities between groups, with larger values indicating greater consistency. A cumulative cut-off of 75% was applied. Note that non-transformed mean abundances are presented to aid interpretation.

Species	Mean abundance (no. fish 500 m^{-2})		CR	Contrib. %	Cumul. %
M. Mouth *vs* N. Lagoon: mean dissimilarity = 71.2%					
	M. Mouth	N. Lagoon			
Atherinosoma microstoma	17.2	399.6	1.3	21.1	21.1
Aldrichetta forsteri	59.1	23.2	1.3	16.7	37.8
Arripis truttaceus	11.3	1.0	1.2	10.8	48.6
Hyperlophus vittatus	65.0	6.9	1.0	10.1	58.7
Rhombosolea tapirina	1.9	2.0	1.2	7.1	65.8
Hyporhamphus regularis	3.2	0.2	1.0	6.4	72.2
Tetraodontidae	1.6	<0.1	1.1	6.4	78.7
M. Mouth *vs* S. Lagoon: mean dissimilarity = 91.1%					
	M. Mouth	S. Lagoon			
Aldrichetta forsteri	59.1	0.0	2.0	22.6	22.6
Arripis truttaceus	11.3	0.0	1.3	12.8	35.5
Atherinosoma microstoma	17.2	27.8	1.2	11.5	46.9
Hyperlophus vittatus	65.0	0.0	0.9	9.8	56.7
Rhombosolea tapirina	3.2	0.0	1.6	9.4	66.2
Tetraodontidae	1.6	0.0	1.1	7.2	73.3
Hyporhamphus regularis	3.2	0.0	1.0	7.1	80.4
N. Lagoon *vs* S. Lagoon: mean dissimilarity = 75.8%					
	N. Lagoon	S. Lagoon			
Atherinosoma microstoma	399.6	27.8	1.3	57.0	57.0
Aldrichetta forsteri	23.2	0.0	0.8	11.4	68.4
Rhombosolea tapirina	0.2	0.0	0.6	10.1	78.5

Table 11. One-way ANOSIM results for tests on differences between subregions for gill net samples collected between October 2006 and September 2008.

Factor (*n*)	Global *R*	*P*	Sig. pairwise comparisons	Details
Subregion (2)	0.148*	0.021	1/1	MM *vs* NL

Table 12. SIMPER results indicating which species contributed most to the overall dissimilarity between significantly different subregions (from ANOSIM) derived from gill net samples collected at all sites between October 2006 and September 2008. Consistency ratio (CR) is the ratio of the mean to standard deviation of the dissimilarities between groups, with larger values indicating greater consistency. A cumulative cut-off of 75% was applied. Note that non-transformed mean abundances are presented to aid interpretation.

Species	Mean abundance (no. fish net set^{-1})		CR	Contrib. %	Cumul. %
M. Mouth *vs* N. Lagoon: mean dissimilarity = 71.0%					
	M. Mouth	N. Lagoon			
Arripis truttaceus	16.4	5.0	1.1	36.0	36.0
Aldrichetta forsteri	1.7	15.7	1.3	25.6	61.6
Argyrosomus hololepidotus	3.6	1.8	1.1	16.2	77.8

Table 13. Salinity ranges of the five most abundant species (R, overall abundance rank) and key species (*) collected using a seine net between October 2006 and September 2008. The occurrence and mean density *x* of these species at each site (no. fish 500 m^{-2}) is also indicated by shading: (blank) *x* = 0; ░ 0 < *x* ≤ 1; ▒ 1 < *x* ≤ 10; ▓ 10 < *x* ≤ 100; █ 100 < *x* ≤ 1000; ■ *x* > 1000.

Species	R	Salinity (‰)		Density									
		Min.	Max.	M1	M2	M3	M4	M5	N1	N2	N3	S1	S2
*Atherinosoma microstoma**	1	12.9	133.5	▒	▒	▓	▒	▓	▓	■	▓	▒	▓
*Aldrichetta forsteri**	2	12.9	74.1	▓	▓	▓	▓	▓	▓	▓			
Hyperlophus vittatus	3	12.9	69.2	█	▓	▓	▒	▓	▓	▒			
Arripis truttaceus	4	12.9	55.1	▓	▓	▒	▓	▒	▒	░			
Galaxias maculatus	5	30.2	44.8	░	▓	░							
*Rhombosolea tapirina**	7	12.9	74.1	▒	▒	▒	▒	░	▒	░			
*Afurcagobius tamarensis**	8	12.9	60.1	▒	░	░	░	▒	▒				
*Argyrosomus hololepidotus**	13	28.0	43.0	░		░		▒					
*Acanthopagrus butcheri**	16	30.3	42.2	░	░			░					
*Pseudaphritis urvillii**	18	38.6	62.4	░	░			░	░	░			

Table 14. Salinity ranges of the five most abundant species (R, overall abundance rank) and key species (*) collected using a gill net between October 2006 and September 2008. The occurrence and mean catch *x* of these species at each site (no. fish net set^{-1}) is also indicated by shading: (blank) *x* = 0; ░ 0 < *x* ≤ 1; ▒ 1 < *x* ≤ 10; ▓ 10 < *x* ≤ 100.

Species	R	Salinity (‰)		Catch			
		Min.	Max.	M1	M3	N1	N2
Arripis truttaceus	1	12.9	60.1	▓	▓	▒	░
*Aldrichetta forsteri**	2	12.9	62.4	▒	▒	▓	▓
*Argyrosomus hololepidotus**	3	12.9	62.4	▒	▒	▒	░
Mugil cephalus	4	12.9	62.4		▒	░	░
Nematolosa erebi	5	12.9	48.0	░	░	░	
*Pseudaphritis urvillii**	6	30.3	74.1	░	░	░	░
*Rhombosolea tapirina**	7	28.0	60.1	░	░	░	
*Acanthopagrus butcheri**	8	30.3	60.1	░		░	

Figures

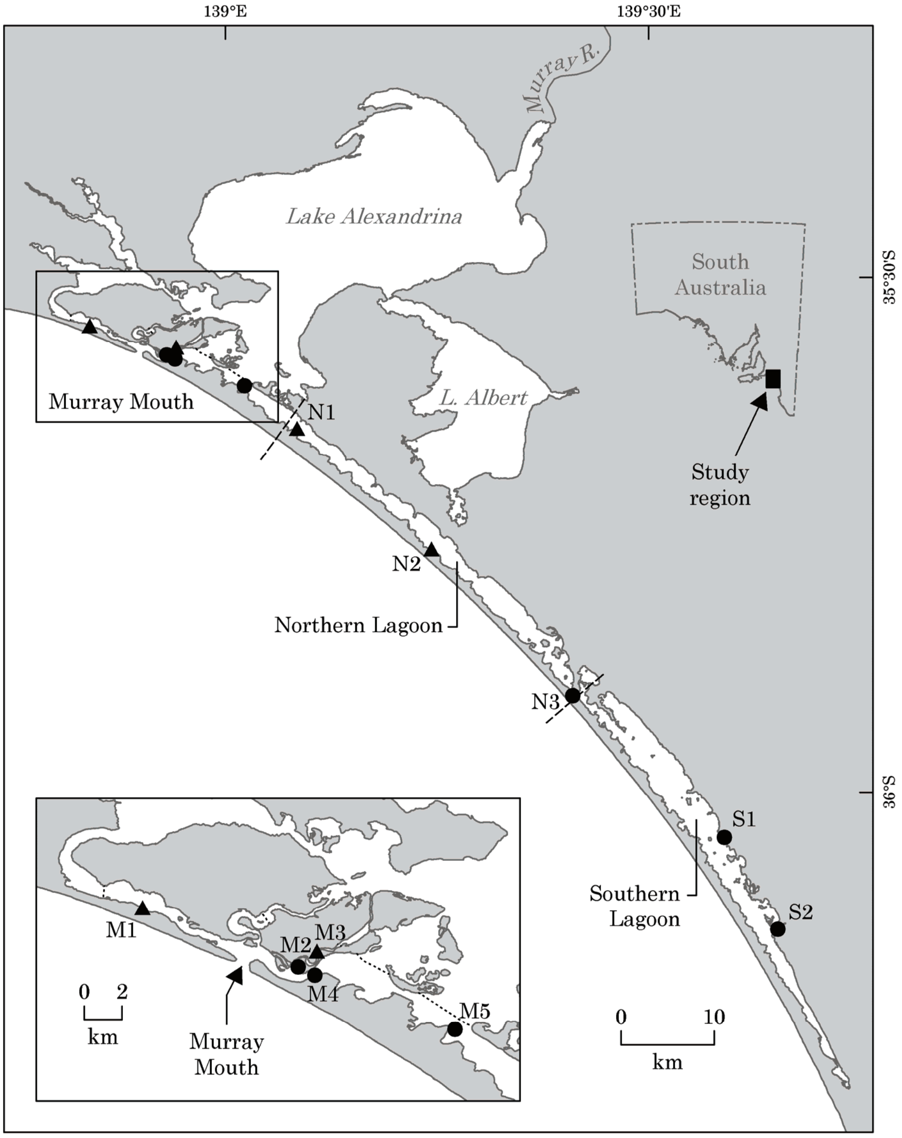

Fig. 1. Map showing the locations of the ten sampling sites in the Murray Mouth and Coorong region. Dashed lines indicate the Murray Mouth, Northern Lagoon and Southern Lagoon subregions. Inset map shows the locations of the sites, the barrages (dotted lines) and the Murray Mouth in the Murray Mouth subregion. Refer to **Table 1** for site details. ● Seine net only sites; ▲ seine and gill net sites.

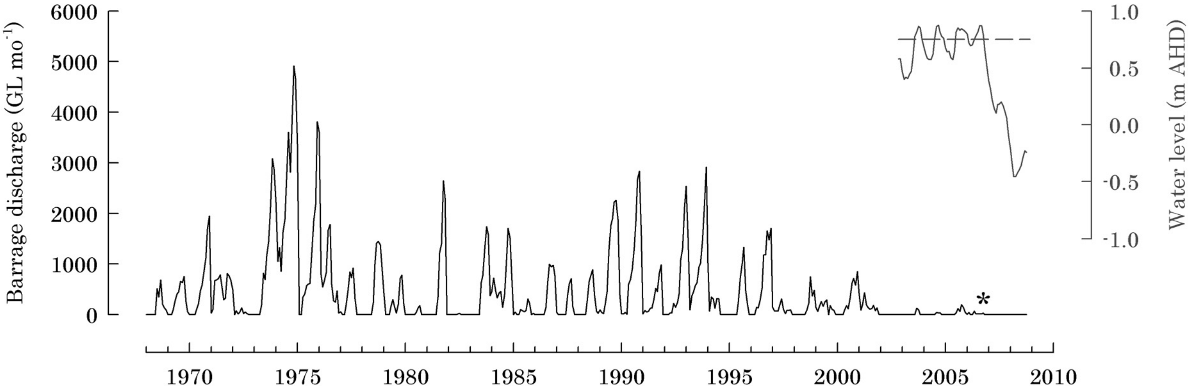

Fig. 2. Average monthly flow volume across the barrages from January 1968 to October 2008 (source: MDBC, 2008). Asterisk (*) indicates commencement of current study. 2nd *Y*-axis indicates the mean monthly water level (in metres Australian Height Datum, AHD) for Lake Alexandrina above Goolwa Barrage (source: DWLBC, 2008).

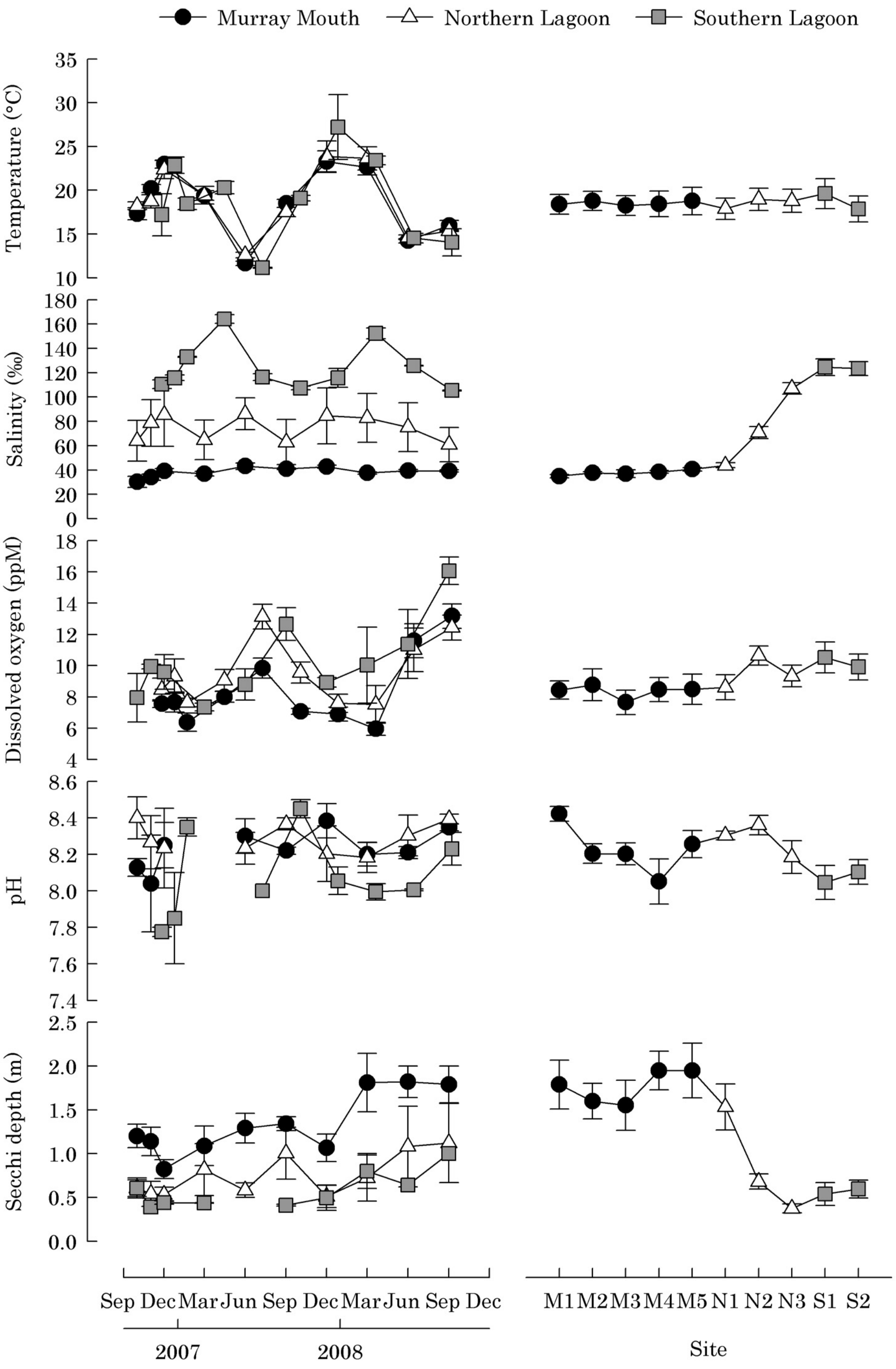

Fig. 3. Mean values ± 1 S.E. for water temperature, salinity, dissolved oxygen, pH and secchi depth for subregions on each sampling occasion (sites pooled, left graphs) and for each site (sampling occasions pooled, right graphs) within the Murray Mouth and Coorong region between October 2006 and September 2008.

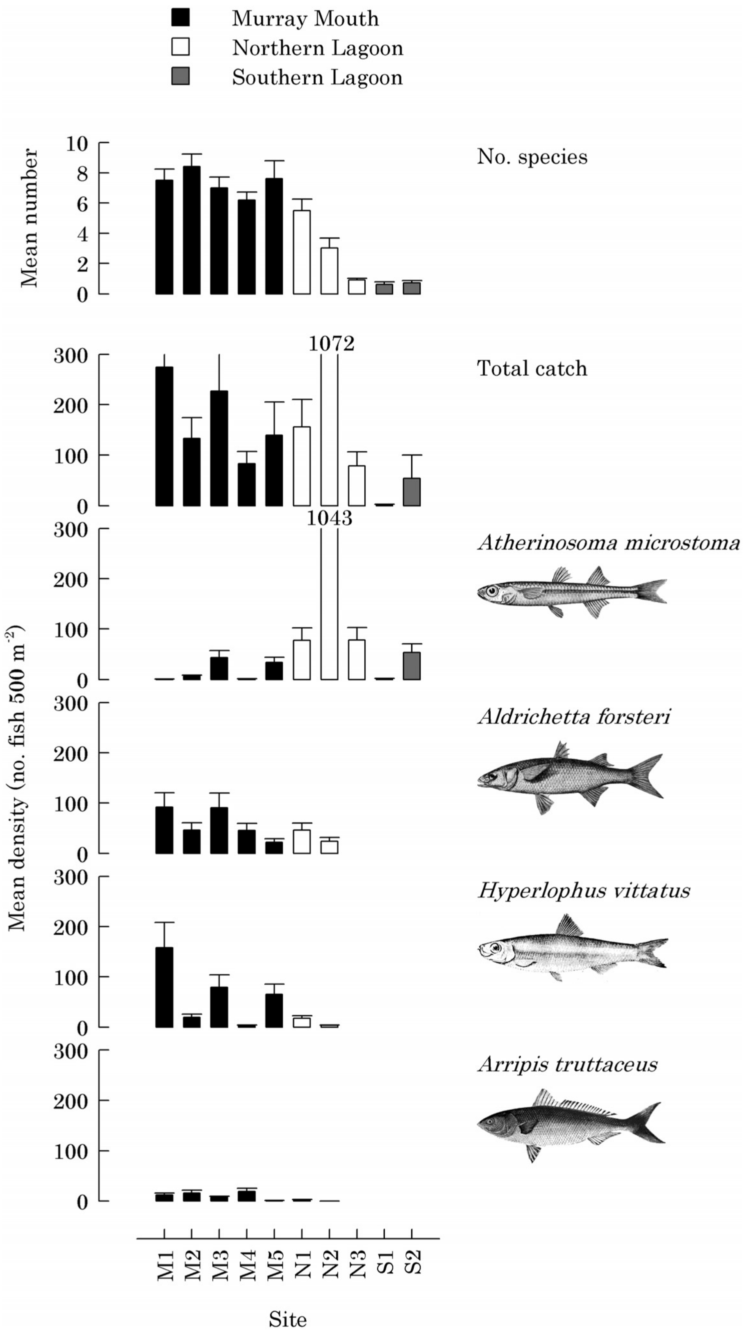

Fig. 4. Mean number of species and density of fish ± 1 S.E. derived from seine net samples collected at all sites between October 2006 and September 2008, including the densities of the four most abundant species collected using this method.

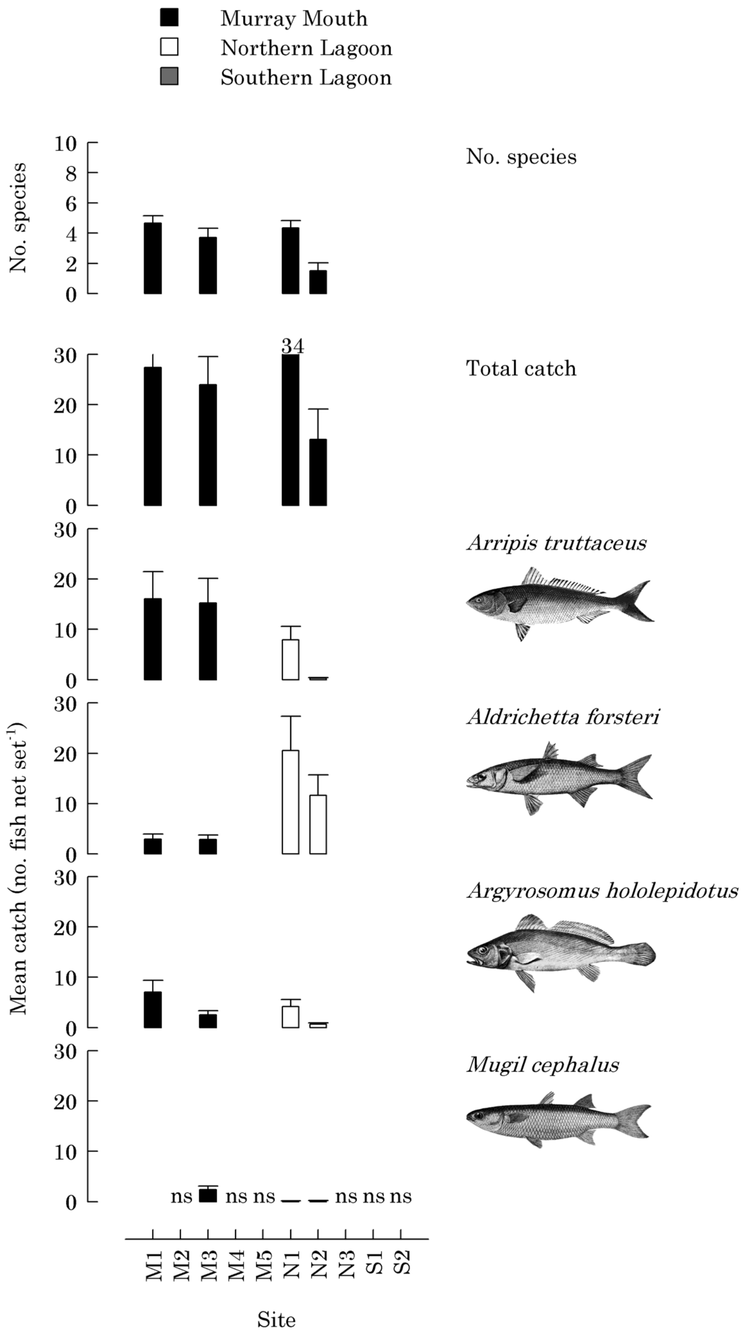

Fig. 5. Mean number of species and density of fish ± 1 S.E. derived from gill net samples collected at Sites M1, M3, N1 and N2 between October 2006 and September 2008, including the densities of the four most abundant species collected using this method.

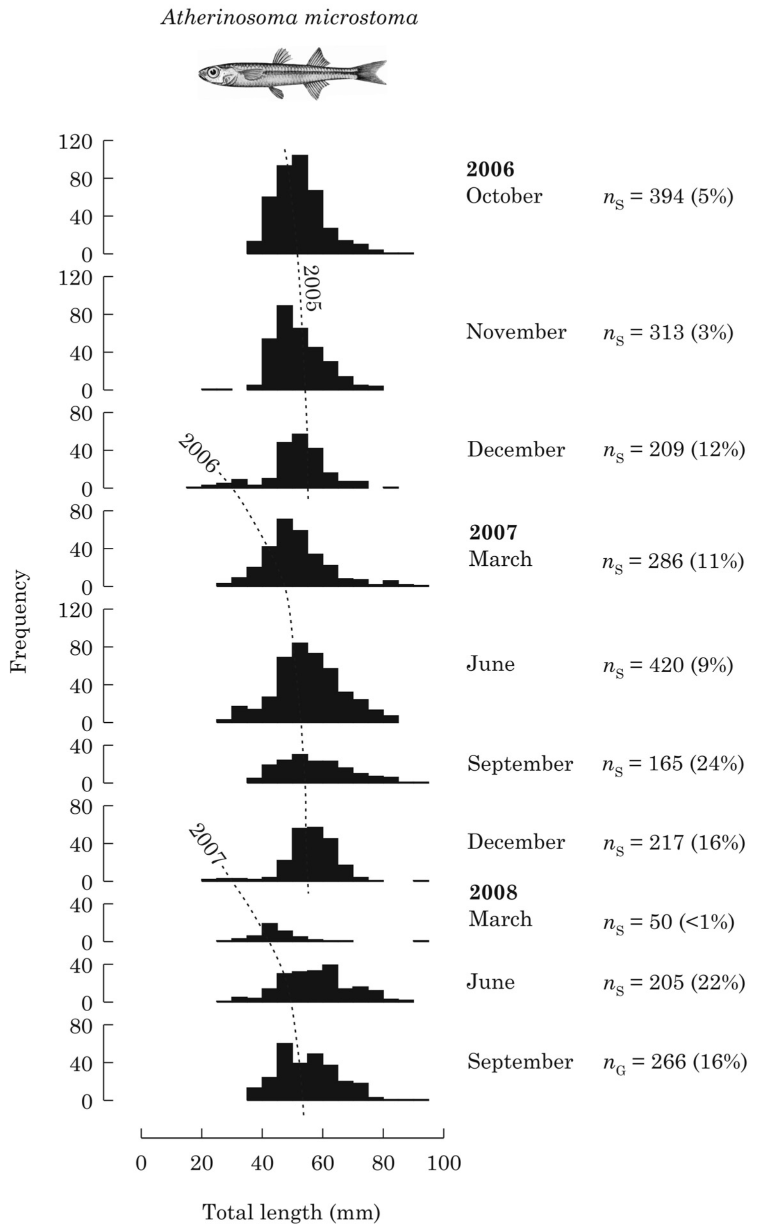

Fig. 6. Length-frequency histograms for smallmouth hardyhead (*Atherinosoma microstoma*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine net. Dashed lines indicate modal progression of probable year classes. n_S = number of fish collected using seine net. Percentages in parentheses indicate that a subsample was measured.

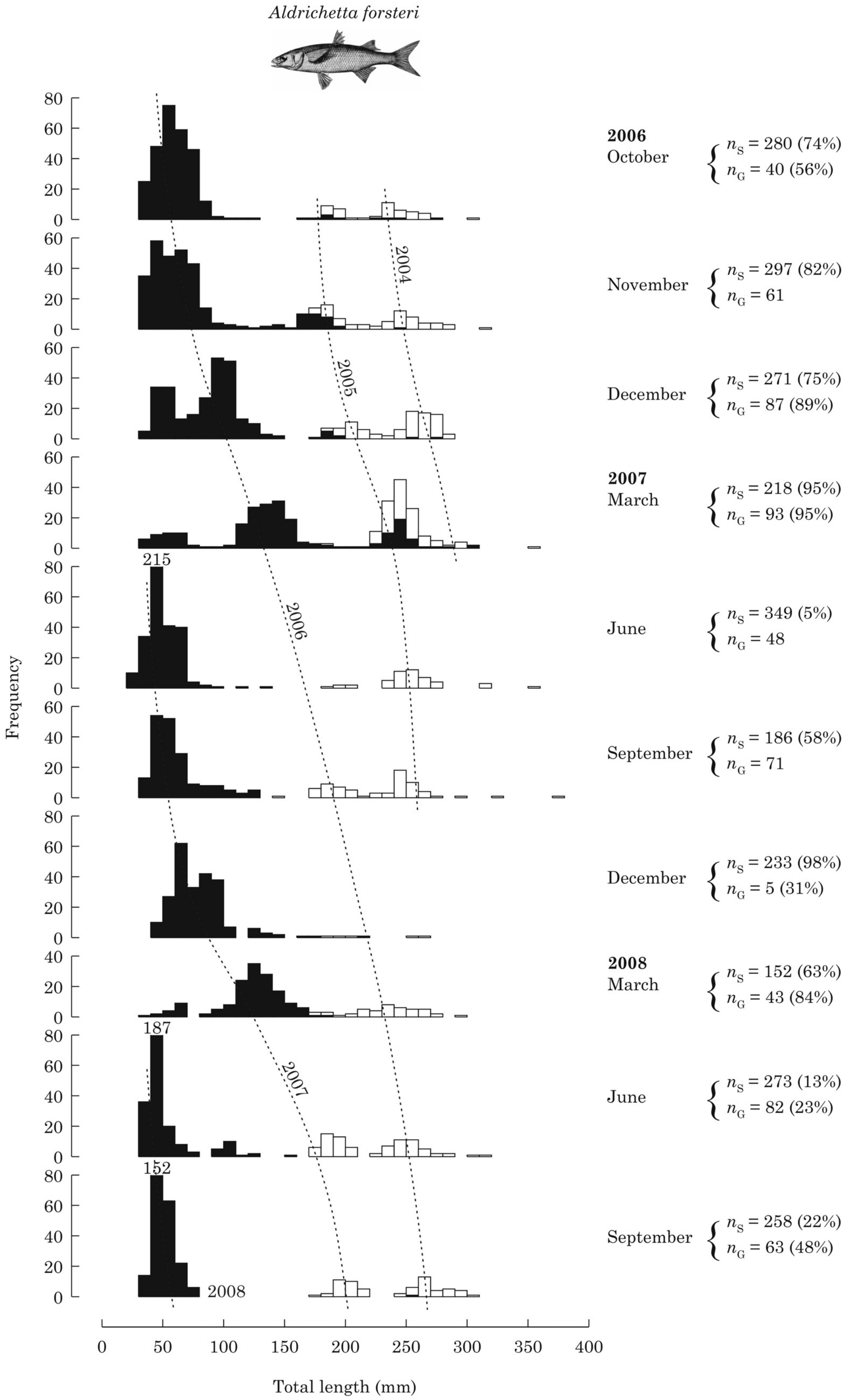

Fig. 7. Length-frequency histograms for yelloweye mullet (*Aldrichetta forsteri*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). Dashed lines indicate modal progression of probable year classes. n_S = number of fish collected using seine net, n_G = number of fish collected using gill nets. Percentages in parentheses indicate that a subsample was measured.

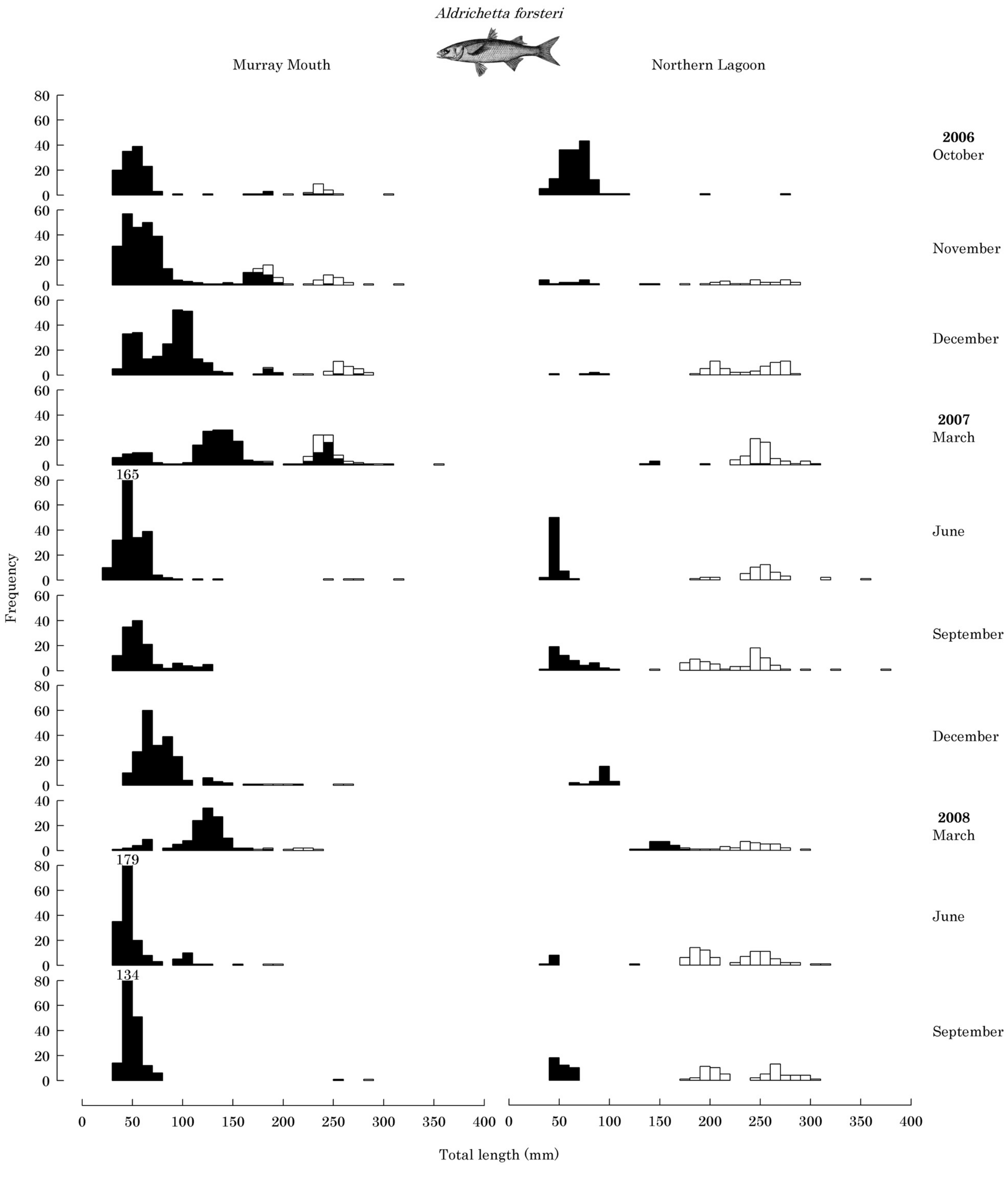

Fig. 8. Length-frequency histograms for yelloweye mullet (*Aldrichetta forsteri*) collected from the Murray Mouth (left graphs) and Northern Lagoon (right graphs) subregions between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively).

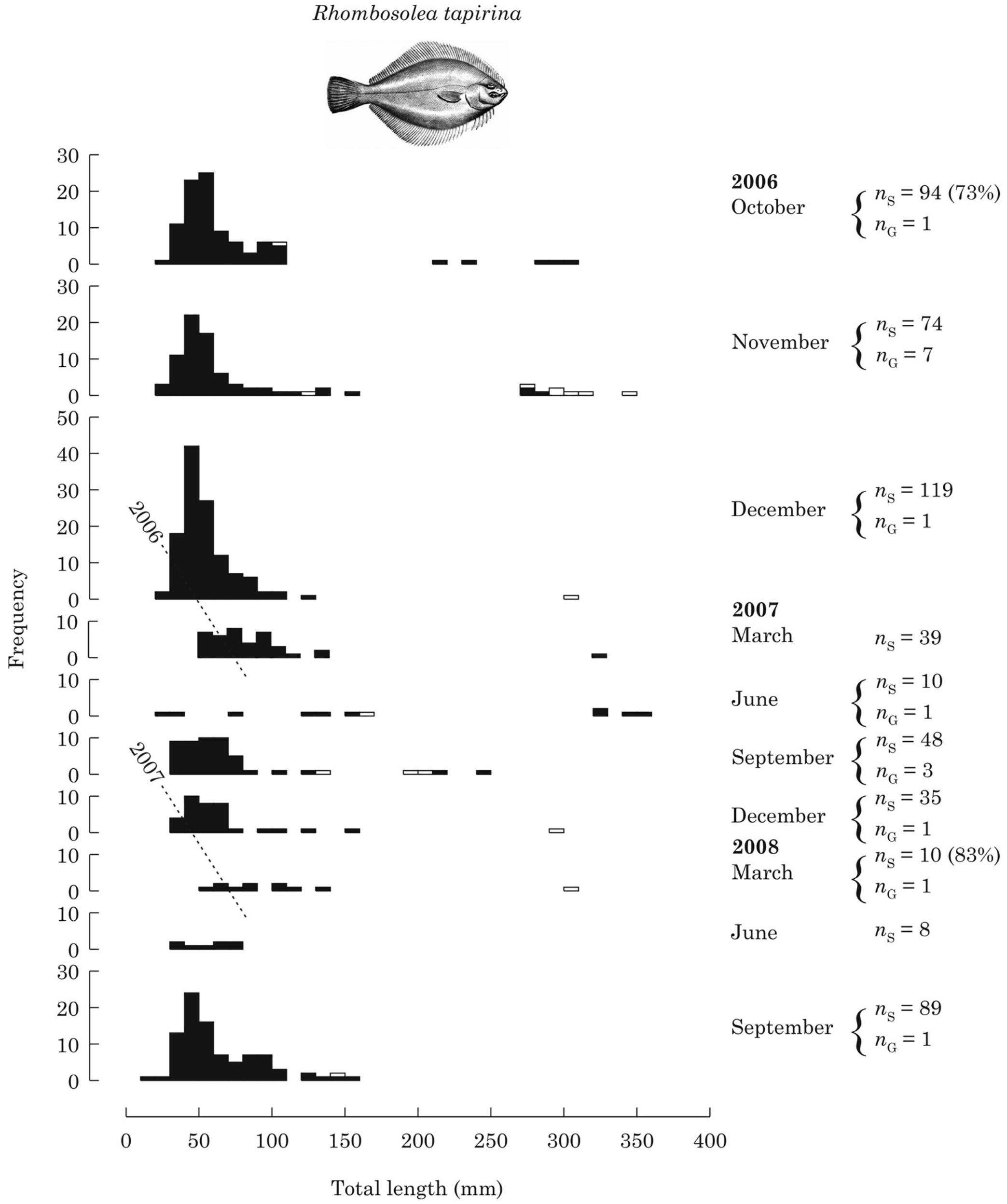

Fig. 9. Length-frequency histograms for greenback flounder (*Rhombosolea tapirina*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). Dashed lines indicate modal progression of probable year classes. n_S = number of fish collected using seine net, n_G = number of fish collected using gill nets. Percentages in parentheses indicate that a subsample was measured.

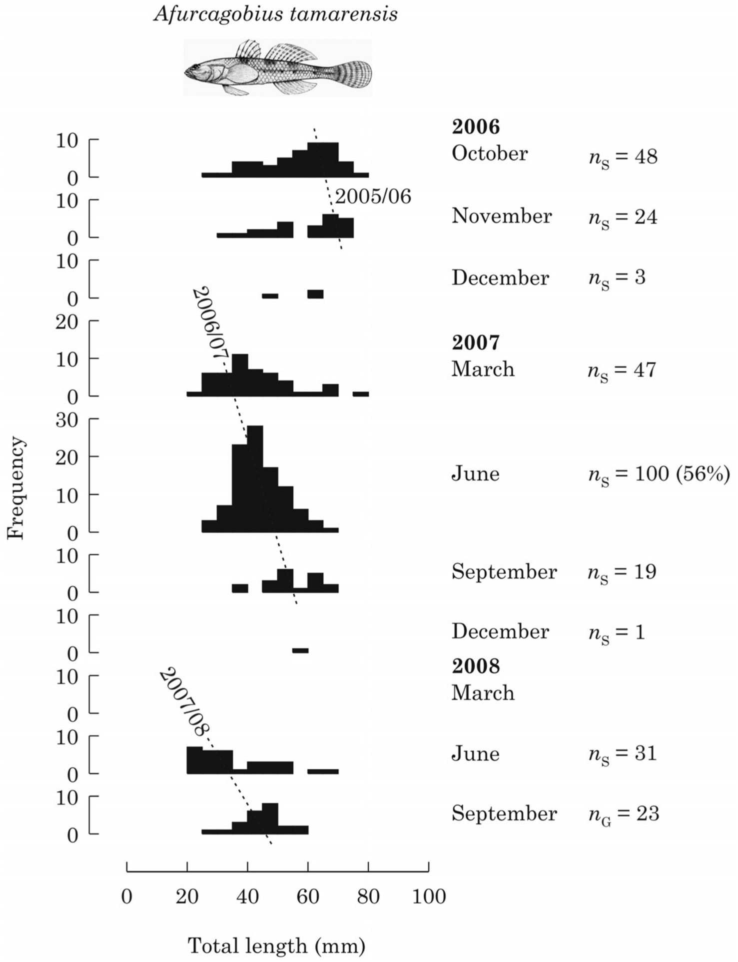

Fig. 10. Length-frequency histograms for Tamar goby (*Afurcagobius tamarensis*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine net. Dashed lines indicate modal progression of probable year classes. n_S = number of fish collected using seine net. Percentage in parentheses indicates that a subsample was measured. The drawing of *Af. tamarensis* was reproduced with permission from Last *et al.* (1983).

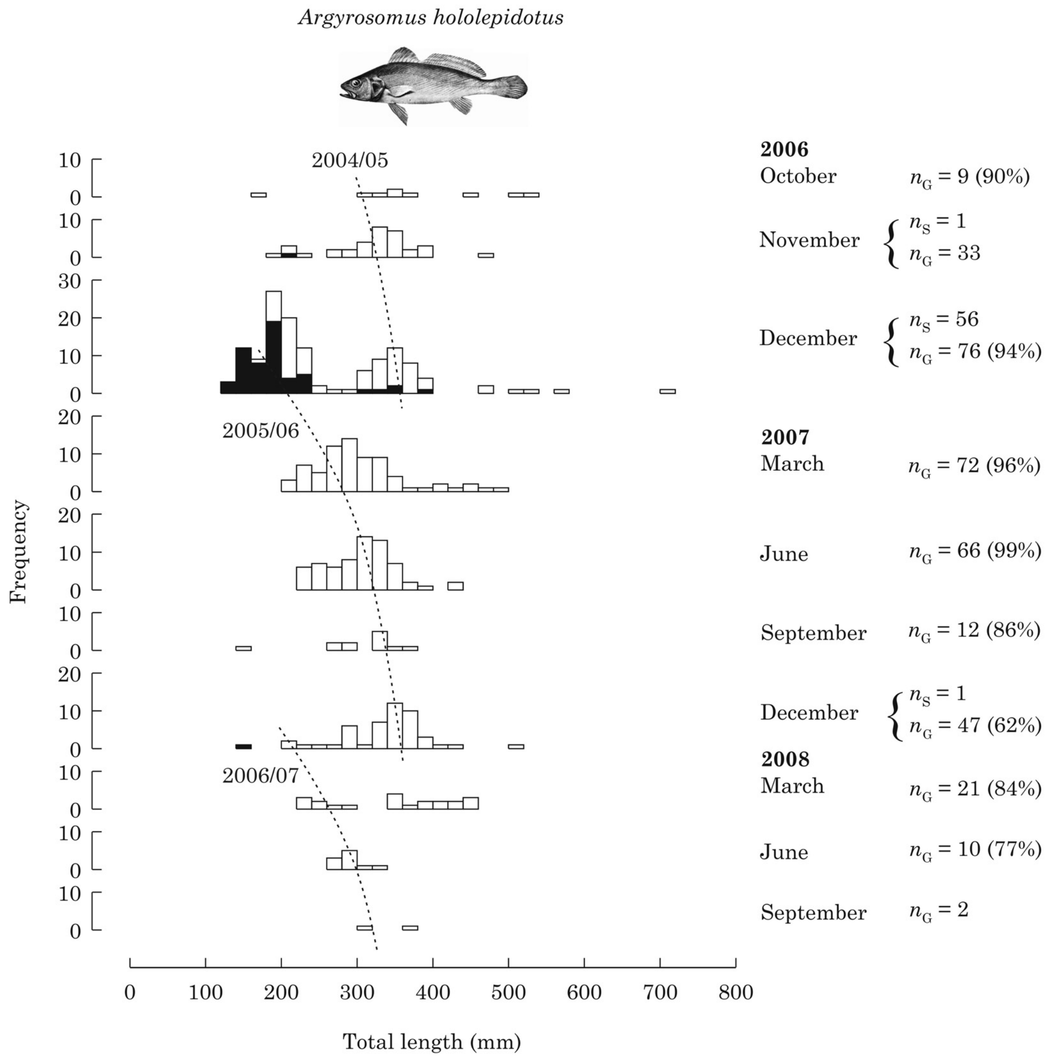

Fig. 11. Length-frequency histograms for mulloway (*Argyrosomus hololepitodes*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). Dashed lines indicate modal progression of probable year classes. n_S = number of fish collected using seine net, n_G = number of fish collected using gill nets. Percentages in parentheses indicate that a subsample was measured.

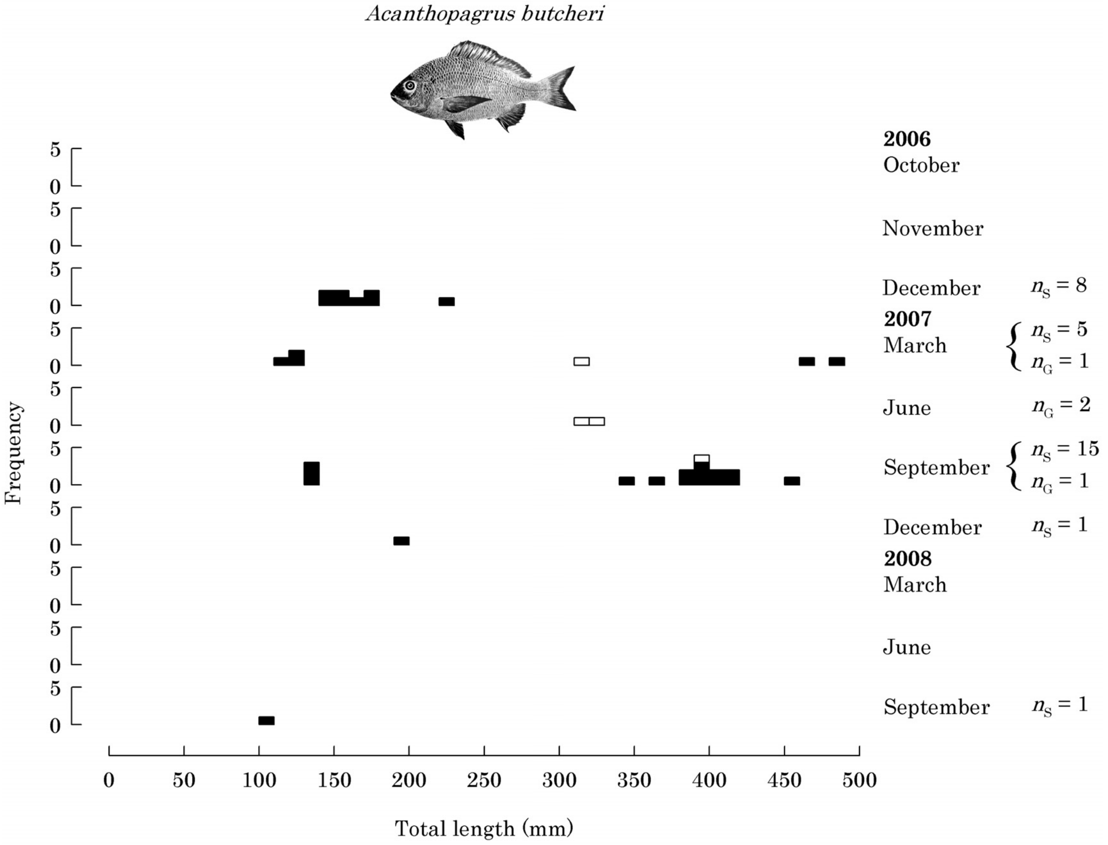

Fig. 12. Length-frequency histograms for black bream (*Acanthopagrus butcheri*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). n_S = number of fish collected using seine net, n_G = number of fish collected using gill nets.

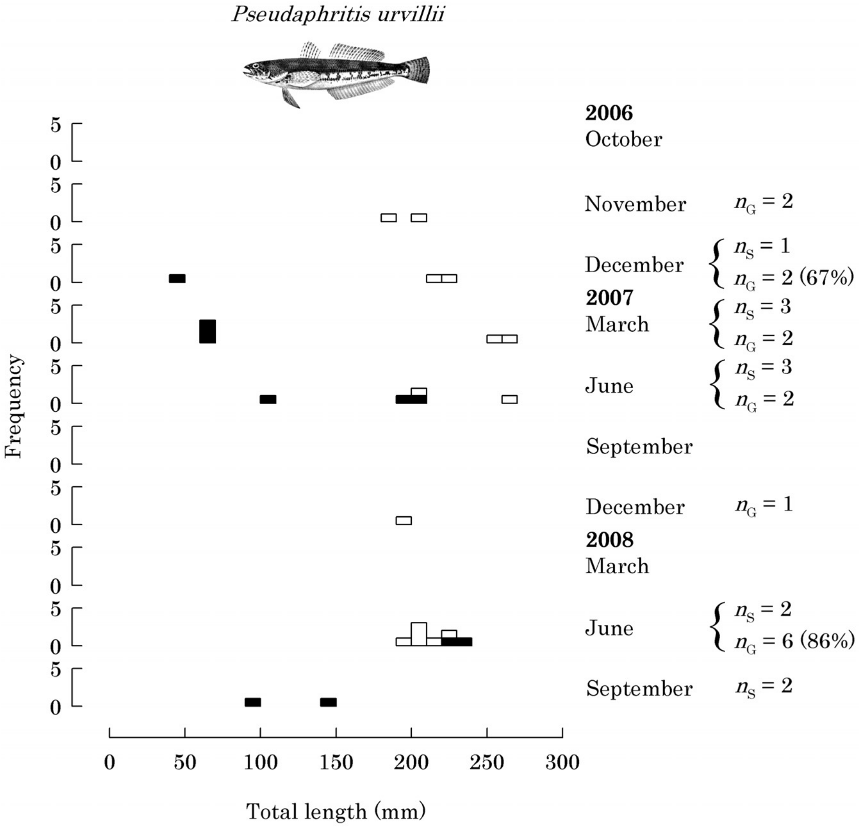

Fig. 13. Length-frequency histograms for congolli (*Pseudaphrites urvillii*) collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). n_S = number of fish collected using seine net, n_G = number of fish collected using gill nets. Percentages in parentheses indicate that a subsample was measured.

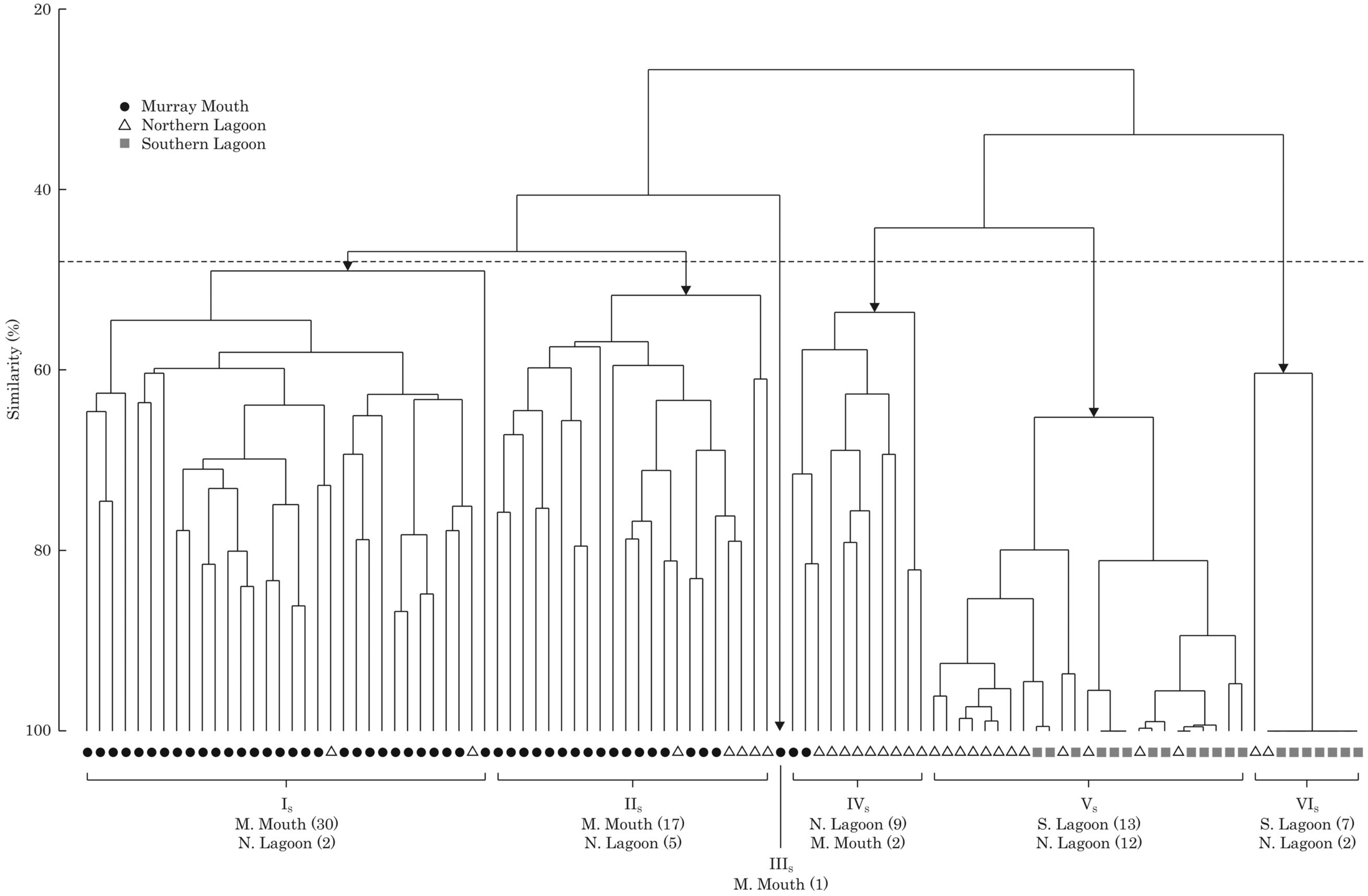

Fig. 14. Dendrogram of the species abundance data for all 100 seine net samples (10 sites × 10 sampling occasions) collected from the Murray Mouth, Northern Lagoon and Southern Lagoon subregions between October 2006 and September 2008. Classification of samples was carried out using group average clustering from Bray-Curtis similarities (including a dummy variable) on fourth-root transformed data. The six similarity profile groups (Groups I_S-VI_S) are indicated by the vertical branches with arrowheads that bisect the 48% similarity threshold.

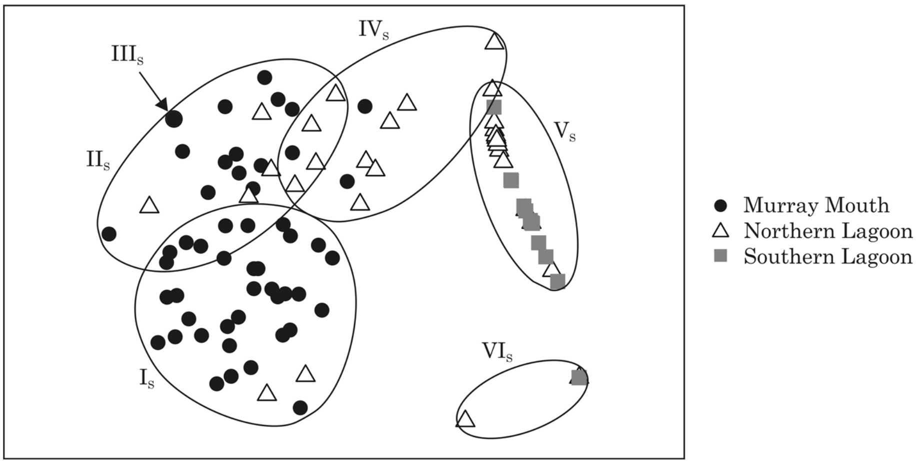

Fig. 15. MDS ordination of the species abundance data for all 100 seine net samples (10 sites × 10 sampling occasions) collected from the Murray Mouth, Northern Lagoon and Southern Lagoon subregions between October 2006 and September 2008. Boundaries indicate the six similarity profile groups (Groups I_S-VI_S) at similarity levels of 48%. Stress = 0.14.

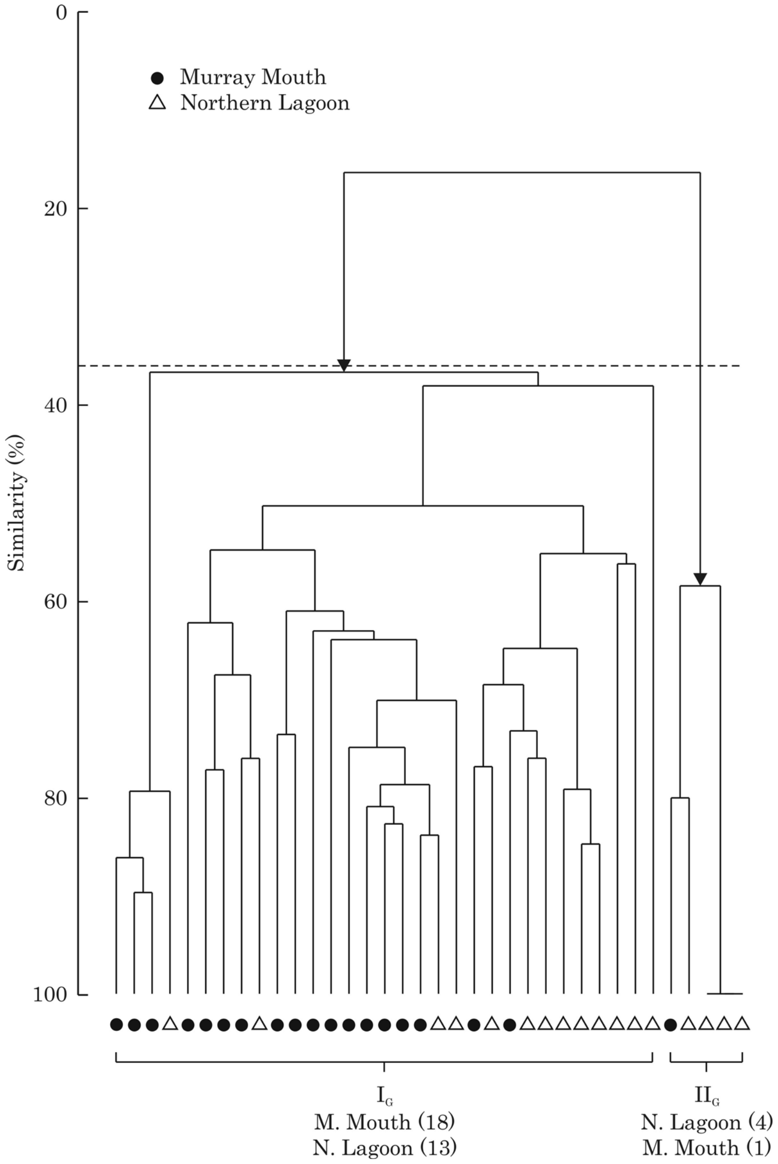

Fig. 16. Dendrogram of the species abundance data for all 36 gill net samples (4 sites × 8-10 sampling occasions) collected from the Murray Mouth and Northern Lagoon subregions between October 2006 and September 2008. Classification of samples was carried out using group average clustering from Bray-Curtis similarities (including a dummy variable) on square-root transformed data. The two similarity profile groups (Groups I_G and II_G) are indicated by the vertical branches with arrowheads that bisect the 36% similarity threshold.

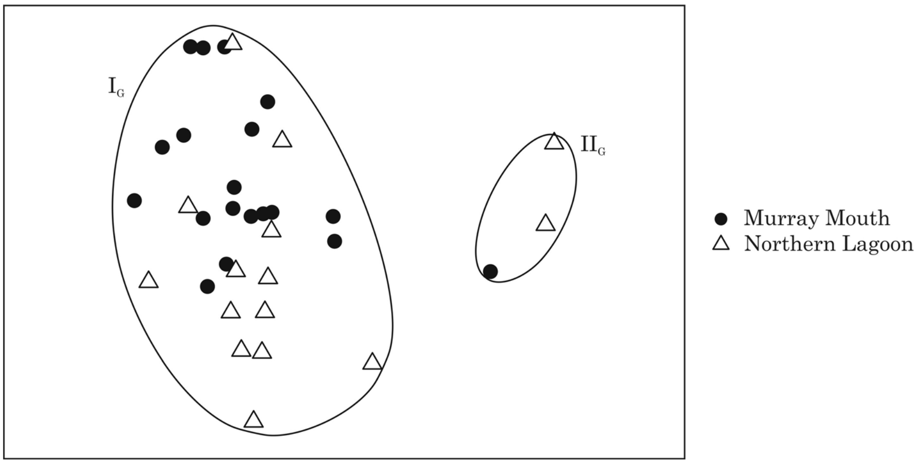

Fig. 17. MDS ordination of the species abundance data for all 36 gill net samples (4 sites × 8-10 sampling occasions) collected from the Murray Mouth and Northern Lagoon subregions between October 2006 and September 2008. Boundaries indicate the two similarity profile groups (Groups I_G and II_G) at similarity levels of 36%. Stress = 0.13.

Appendices

Appendix A. Raw species abundance data for seine net samples collected from all ten sites of the Murray Mouth, Northern Lagoon and Southern Lagoon subregions between October 2006 and September 2008 (each cell represents the number of fish collected from three 592 m^2 replicates).

Site	Date	*A.bif*	*A.but*	*A.for*	*A.geo*	*A.hol*	*A.mic*	*A.ros*	*A.tam*	*A.tru*	*E.aus*	*G.mac*	*G.mar*	*H.hep*	*H.mel*	*H.reg*	*H.vit*	*L.arg*	*M.aus*	*N.ere*	*P.olo*	*P.urv*	*R.sem*	*R.tap*	*S.neo*	*T.las*	Tetrao
M1	Oct-06	30		20			1	5	32	2														27		26	5
M1	Nov-06			21				8	3	1		6			2		2							13			1
M1	Dec-06			113		5	1			91						14					3			2			1
M1	Mar-07		3	90						7						14	140							2			13
M1	Jun-07			2150			30				1																
M1	Sep-07	1	15	33					17	289														2		1	27
M1	Dec-07	3		77		1			1	30		1												8		1	22
M1	Mar-08			9			2			10														1			3
M1	Jun-08			720			5		2								27							1			2
M1	Sep-08	2	1	20				2	23	10						6	5450					2		34			5
M2	Oct-06			23			3			14						2								3			27
M2	Nov-06			82			40	1	4	244		2	6			4		2						10		1	4
M2	Dec-06			46	3		2		1	33		2			2	6	83							4			10
M2	Mar-07		2	24	1		21		1	1	1				1	43	550							3			3
M2	Jun-07			1260			95		6							30	2							2			4
M2	Sep-07			50			10			55		1000			1	30					2			9			2
M2	Dec-07		1	33			8			23					1	5								2			
M2	Mar-08			39	1		2			11		1			7	32								1			
M2	Jun-08			20			58		12		250					3	62					2			1		
M2	Sep-08			58			1			200														12			
M3	Oct-06			13			52		1	11						3	1							4			2
M3	Nov-06			156		1	85		1	69					1		4			2			1	7			2
M3	Dec-06			54		4	12			83	4					3	284							31			
M3	Mar-07			102			749		1	7	7					10	2500							23			2
M3	Jun-07	3		1730			200		5							11	14									6	
M3	Sep-07			67			4			52						11								9			1
M3	Dec-07			41	8		165			4		13			2									1			1
M3	Mar-08			11	1					3						4											
M3	Jun-08			690			272			1						4											
M3	Sep-08			357			3			35						25								1			
M4	Oct-06			42			17	20		219							1							10			4
M4	Nov-06			47	2			32		152														14		1	
M4	Dec-06			28			4	8		1							3							13			39

Site	Date	*A.bif*	*A.but*	*A.for*	*A.geo*	*A.hol*	*A.mic*	*A.ros*	*A.tam*	*A.tru*	*E.aus*	*G.mac*	*G.mar*	*H.hep*	*H.mel*	*H.reg*	*H.vit*	*L.arg*	*M.aus*	*N.ere*	*P.olo*	*P.urv*	*R.sem*	*R.tap*	*S.neo*	*T.las*	Tetrao
M4	Mar-07			5						158						5	3							4			38
M4	Jun-07			720			31	5	1		9					5	80							1	1		4
M4	Sep-07			54			4	97		73							3							13			
M4	Dec-07			17	1					6														14			1
M4	Mar-08			43				4		2														6			2
M4	Jun-08			605				11		1							29							4			27
M4	Sep-08			46				38		72														30			
M5	Oct-06			32			298	3	2								104							4		3	
M5	Nov-06			40			65	2	9	1						1	139									4	7
M5	Dec-06	1	8	117	64	47	150	1	2	5						186	111		1	1		1		1			2
M5	Mar-07			1			80		13							4	130									2	1
M5	Jun-07			231			502		118		8			1		2	1650					3		5		1	14
M5	Sep-07			16												12	28							2			1
M5	Dec-07			44			60			12						3	31							1			1
M5	Mar-08			117				6		2					1	83								2			6
M5	Jun-08			127													111				1						
M5	Sep-08			58			31			16														3			
N1	Oct-06			127			657	40	13	7							14							81		1	
N1	Nov-06			14			139	43	7	8						3	279							24			
N1	Dec-06			5			905	11		1														68			
N1	Mar-07						183		32								8					2		3		1	1
N1	Jun-07			1430			300		50		2					1	120							2		5	
N1	Sep-07			1						75						2								12			
N1	Dec-07			26			576									3	173							8			
N1	Mar-08			21						1														2			
N1	Jun-08			1				1	17								22							2			1
N1	Sep-08																							3			
N2	Oct-06			121			5050			2						2	70										
N2	Nov-06			2			8150																	6			
N2	Dec-06						685																				
N2	Mar-07			8			1140									13						1		4			
N2	Jun-07						2980																				
N2	Sep-07			101	1		242			8	16						49							1			
N2	Dec-07						466																				
N2	Mar-08						16400																				
N2	Jun-08			10			582										1							1			
N2	Sep-08			610			1350																				
N3	Oct-06						275																				
N3	Nov-06						990																				

Site	Date	*A.bif*	*A.but*	*A.for*	*A.geo*	*A.hol*	*A.mic*	*A.ros*	*A.tam*	*A.tru*	*E.aus*	*G.mac*	*G.mar*	*H.hep*	*H.mel*	*H.reg*	*H.vit*	*L.arg*	*M.aus*	*N.ere*	*P.olo*	*P.urv*	*R.sem*	*R.tap*	*S.neo*	*T.las*	Tetrao
N3	Dec-06						2																				
N3	Mar-07						363																				
N3	Jun-07						534																				
N3	Sep-07						405																				
N3	Dec-07																										
N3	Mar-08						17																				
N3	Jun-08						28																				
N3	Sep-08						162																				
S1	Oct-06						31																				
S1	Nov-06						1																				
S1	Dec-06						1																				
S1	Mar-07																										
S1	Jun-07						27																				
S1	Sep-07						4																				
S1	Dec-07																										
S1	Mar-08																										
S1	Jun-08																										
S1	Sep-08						1																				
S2	Oct-06						1665																				
S2	Nov-06						16																				
S2	Dec-06						17																				
S2	Mar-07																										
S2	Jun-07						8																				
S2	Sep-07						18																				
S2	Dec-07						94																				
S2	Mar-08																										
S2	Jun-08																										
S2	Sep-08						89																				

Appendix B. Raw species abundance data for gill net samples taken from four sites of the Murray Mouth and Northern Lagoon subregions between October 2006 and September 2008 (each cell represents the number of fish caught from three net set replicates).

Site	Date	*A.but*	*A.for*	*A.geo*	*A.hol*	*A.ros*	*A.tru*	*H.reg*	*M.cep*	*N.ere*	*P.oct*	*P.sal*	*P.urv*	*R.tap*	*S.arg*	Tetrao
M1	Nov-06		8		11		12	1						1		
M1	Dec-06		27		45		40									
M1	Mar-07	1	22	11	51		123			3	4		2			
M1	Jun-07	1	3		47		149									
M1	Sep-07	1			4		28	1								1
M1	Dec-07		5		21		29							1		
M1	Mar-08	1	9	1	6		11									
M1	Jun-08		5		3		3	3								
M1	Sep-08		1		2		39									
M3	Oct-06		27		1		12		1	1						
M3	Nov-06		30		12		6		1	16				4		
M3	Dec-06		2		8		2			1			1	1		
M3	Mar-07		15		8		26									
M3	Jun-07		1										1			
M3	Sep-07						116							1		
M3	Dec-07		5		36		14						1			
M3	Mar-08		6	1	11		101		63					1		
M3	Jun-08						93		5							
M3	Sep-08						88									
N1	Oct-06		45		9		10							1	1	
N1	Nov-06		23		10		5			1			1	2		2
N1	Dec-06		69		28								2			
N1	Jun-07	1	44		20		1						1	1		
N1	Sep-07				9		16							2		
N1	Dec-07		6		19		7									
N1	Mar-08		36		8		67		3			2				
N1	Jun-08		331		10		43						2			
N1	Sep-08					3	66							1		
N2	Nov-06												1			
N2	Mar-07		61		16				2							
N2	Jun-07															
N2	Sep-07		70		1		7	1								
N2	Dec-07															
N2	Mar-08															
N2	Jun-08		18										5			
N2	Sep-08		130						2							

Appendix C. Water quality measurements recorded from all ten sites of the Murray Mouth, Northern Lagoon and Southern Lagoon subregions between October 2006 and September 2008 (correspond to seine net samples).

Site	Date	Temp (°C)	Sal (‰)	DO (ppM)	pH	Secchi (mm)
M1	Oct-06	18.5	29.5	7.0	8.3	1200
M1	Nov-06	21.1	30.2	9.5	8.7	1720
M1	Dec-06	22.6	33.1	7.3	8.5	1100
M1	Mar-07	20.6	30.3	8.1		700
M1	Jun-07	12.2	35.7	10.2	8.5	800
M1	Sep-07	16.8	38.8	6.9	8.3	1085
M1	Dec-07	22.7	40.9	8.2	8.5	1180
M1	Mar-08	19.6	38.2	6.3	8.4	2500
M1	Jun-08	13.3	38.2	9.1	8.3	2000
M1	Sep-08	17.3	40.4	12.4	8.4	1160
M2	Oct-06	18.9	34.3	8.1	8.1	1350
M2	Nov-06	19.8	33.4	8.0	7.9	1265
M2	Dec-06	22.7	40.6	7.1	8.3	550
M2	Mar-07	20.2	37.5	7.5		990
M2	Jun-07	12.3	42.8	11.7	8.5	1350
M2	Sep-07	19.2	40.9	7.0	8.2	1350
M2	Dec-07	21.0	39.7	6.8	8.2	
M2	Mar-08	23.5	37.4	4.7	8.1	1050
M2	Jun-08	14.6	38.6	15.6	8.1	1100
M2	Sep-08	16.4	38.6	11.7	8.3	2000
M3	Oct-06	17.7	12.9	8.2	8.1	890
M3	Nov-06	20.5	28.0	7.3	8.4	830
M3	Dec-06	21.6	43.0	4.2	7.8	660
M3	Mar-07	19.4	42.2	7.0		700
M3	Jun-07	10.9	39.4	8.9	8.3	1580
M3	Sep-07	19.0	43.3	7.0	8.2	1340
M3	Dec-07	20.4	44.8	5.8	8.2	740
M3	Mar-08	22.7	40.7	5.4	8.3	2000
M3	Jun-08	14.3	39.6	11.2	8.2	2000
M3	Sep-08	16.9	42.3	12.0	8.4	
M4	Oct-06	15.3	38.0	7.4	8.0	1620
M4	Nov-06	18.6	37.7	8.0	7.1	955
M4	Dec-06	24.1	37.5	7.2	8.2	1050
M4	Mar-07	19.3	37.2	9.0		1930
M4	Jun-07	11.5	48.0	8.0	8.2	1430
M4	Sep-07	19.2	40.5	7.8	8.2	1590
M4	Dec-07	25.8	41.7	6.1	8.3	890
M4	Mar-08	22.5	35.1	6.3	8.0	1000
M4	Jun-08	14.7	38.1	11.5	8.2	2000
M4	Sep-08	14.3	37.4	14.0	8.3	2000
M5	Oct-06	16.1	36.6	7.1	8.1	940
M5	Nov-06	21.0	41.0	5.5	8.1	915
M5	Dec-06	23.9	42.2	6.1	8.5	750
M5	Mar-07	17.4	37.6	8.4		1120
M5	Jun-07	11.4	50.1	10.4	8.0	
M5	Sep-07	18.3	41.4	6.7	8.2	1340
M5	Dec-07	26.4	46.4	7.7	8.7	1450
M5	Mar-08	24.8	36.3	7.1	8.1	2500
M5	Jun-08	14.2	42.6	10.6	8.3	2000
M5	Sep-08	15.0	37.8	15.8	8.4	2000
N1	Oct-06	18.0	40.4	7.3	8.2	740
N1	Nov-06	17.2	48.0	7.9	8.3	800
N1	Dec-06	21.0	45.1	7.1	8.4	630
N1	Mar-07	17.4	37.8	7.7		1400

Site	Date	Temp (°C)	Sal (‰)	DO (ppM)	pH	Secchi (mm)
N1	Jun-07	12.0	60.1	12.3	8.2	730
N1	Sep-07	17.3	39.0	8.5	8.3	1520
N1	Dec-07	22.9	46.9	6.4	8.4	740
N1	Mar-08	24.6	44.6	5.9	8.4	1240
N1	Jun-08	14.1	44.0	9.8	8.3	2000
N1	Sep-08	15.2	38.7	13.7	8.4	2000
N2	Oct-06	17.6	55.1	9.8	8.4	700
N2	Nov-06	19.5	74.1	11.5	8.5	510
N2	Dec-06	24.4	77.6	7.8	8.5	600
N2	Mar-07	20.4	62.4	9.9		600
N2	Jun-07	13.1	96.7	12.4	8.1	575
N2	Sep-07	18.5	50.3	10.8	8.4	1000
N2	Dec-07	21.4	80.3	8.3	8.3	490
N2	Mar-08	25.3	91.6	9.9	8.1	420
N2	Jun-08	14.9	69.2	13.8	8.5	600
N2	Sep-08	15.4	57.3	12.6	8.4	860
N3	Oct-06	19.1	96.6	8.3	8.6	380
N3	Nov-06	19.5	114.1	8.6	8.0	310
N3	Dec-06	21.7	133.2	8.0	7.8	370
N3	Mar-07	20.5	94.0	9.6		450
N3	Jun-07	12.7	101.9	14.7	8.4	440
N3	Sep-07	16.7	99.5	9.4	8.4	495
N3	Dec-07	27.3	126.2	8.0	7.9	300
N3	Mar-08	21.0	112.5	6.8	8.1	500
N3	Jun-08	14.9	112.6	9.5	8.1	640
N3	Sep-08	15.5	86.9	11.0	8.4	500
S1	Oct-06	19.6	107.0	9.5	7.8	510
S1	Nov-06	21.9	113.4	9.8	7.6	
S1	Dec-06	19.1	133.5	8.5	8.3	460
S1	Mar-07	21.0	167.6	7.1		430
S1	Jun-07	11.1	113.5	9.8	8.0	
S1	Sep-07	18.8	105.8	13.7	8.5	420
S1	Dec-07	30.9	123.4	9.2	8.0	350
S1	Mar-08	23.9	156.7	7.6	8.0	1000
S1	Jun-08	15.1	125.5	13.6	8.0	640
S1	Sep-08	15.6	105.0	17.0	8.3	
S2	Oct-06	14.8	114.1	6.4	7.8	700
S2	Nov-06	23.8	118.0	10.1	8.1	390
S2	Dec-06	17.8	132.6	10.7	8.4	420
S2	Mar-07	19.6	160.6	7.6		440
S2	Jun-07	11.2	119.1	7.8	8.0	
S2	Sep-07	19.4	109.1	11.6	8.4	400
S2	Dec-07	23.5	108.0	8.6	8.1	640
S2	Mar-08	22.9	147.9	12.5	8.0	600
S2	Jun-08	14.0	126.0	9.2	8.0	640
S2	Sep-08	12.5	105.7	15.2	8.1	1000

Appendix D. Water quality measurements recorded from four sites of the Murray Mouth and Northern Lagoon subregions between October 2006 and September 2008 (correspond to gill net samples).

Site	Date	Temp (°C)	Sal (‰)	DO (ppM)	pH	Secchi (mm)
M1	Nov-06	21.1	30.2	9.5	8.7	1720
M1	Dec-06	22.6	33.1	7.3	8.5	1100
M1	Mar-07	20.6	30.3	8.1		700
M1	Jun-07	12.2	35.7	10.2	8.5	800
M1	Sep-07	16.8	38.8	6.9	8.3	1085
M1	Dec-07	22.7	40.9	8.2	8.5	1180
M1	Mar-08	19.6	38.2	6.3	8.4	2500
M1	Jun-08	13.3	38.2	9.1	8.3	2000
M1	Sep-08	17.3	40.4	12.4	8.4	1160
M3	Oct-06	15.8	14.0	8.1	8.3	890
M3	Nov-06	20.5	28.0	7.3	8.4	830
M3	Dec-06	21.6	43.0	4.2	7.8	660
M3	Mar-07	19.4	42.2	7.0		700
M3	Jun-07	10.9	39.4	8.9	8.3	1580
M3	Sep-07	19.0	43.3	7.0	8.2	1340
M3	Dec-07	20.4	44.8	5.8	8.2	740
M3	Mar-08	22.7	40.7	5.4	8.3	2000
M3	Jun-08	14.3	39.6	11.2	8.2	2000
M3	Sep-08	16.9	42.3	12.0	8.4	
N1	Oct-06	15.0	37.6	7.4	8.2	1300
N1	Nov-06	17.2	48.0	7.9	8.3	800
N1	Dec-06	21.0	45.1	7.1	8.4	630
N1	Jun-07	12.0	60.1	12.3	8.2	730
N1	Sep-07	17.3	39.0	8.5	8.3	1520
N1	Dec-07	22.9	46.9	6.4	8.4	740
N1	Mar-08	24.6	44.6	5.9	8.4	1240
N1	Jun-08	14.1	44.0	9.8	8.3	2000
N1	Sep-08	15.2	38.7	13.7	8.4	2000
N2	Nov-06	19.5	74.1	11.5	8.5	510
N2	Mar-07	20.4	62.4	9.9		600
N2	Jun-07	13.1	96.7	12.4	8.1	575
N2	Sep-07	18.5	50.3	10.8	8.4	1000
N2	Dec-07	21.4	80.3	8.3	8.3	490
N2	Mar-08	25.3	91.6	9.9	8.1	420
N2	Jun-08	14.9	69.2	13.8	8.5	600
N2	Sep-08	15.4	57.3	12.6	8.4	860