

Flow related fish and fisheries ecology in the Coorong, South Australia



**Qifeng Ye, Jason Earl, Luciana Bucater, Katherine Cheshire,
Dale McNeil, Craig Noell and David Short**

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**SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022**

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Final Report

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1. Non-Technical Summary

2006/045. Flow Related Fish and Fisheries Ecology in the Coorong, South Australia

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OBJECTIVES

1. To determine the distribution, relative abundance and size structure of key fish species and how these relate to habitat and environmental conditions (e.g. salinity, temperature) in the Murray Estuary and Coorong.
2. To examine aspects of reproductive biology and influence of environmental conditions on spawning success of key species in the region.
3. To investigate the influence of environmental conditions (e.g. salinity, temperature) on the critical early life stages of key species.
4. To investigate the relationship between freshwater flows (timing, quantity and duration) and recruitment success and fisheries production of key commercial species.

Five species were selected as key species:

- black bream (*Acanthopagrus butcheri*) – commercially important estuarine species.
- yelloweye mullet (*Aldrichetta forsteri*) – commercially important marine/estuarine opportunist.
- greenback flounder (*Rhombosolea tapirina*) – commercially important estuarine and marine species.
- Tamar goby (*Afurcagobius tamarensis*) - important trophic level small-bodied estuarine species.
- congolli (*Pseudaphritis urvillii*) – conservation significant catadromous species.

Additional species of interest included:

- mulloway (*Argyrosomus hololepidotus*) – commercially important marine/estuarine opportunist.
- small mouthed hardyhead (*Atherinosoma microstoma*) - estuarine species.

Outcomes achieved

The project outputs have contributed to or will lead to the following outcomes:

1. The ability to compare the effect of various flow regimes and management scenarios or actions on the abundance and distribution of fish populations and fisheries for the region.
2. The opportunity to incorporate fishery and ecological considerations through the CSIRO Flagship CLLAMMecology Program into a decision-support system framework for the region. The findings of the study will be used to quantify the environmental, social, and economic tradeoffs of water use in the Murray-Darling Basin. Cost benefit analyses will be used to determine the volume of water required to maximise fisheries production, preserve fish biodiversity and maintain a viable commercial and recreational fishing communities in the CLLAMM region.
3. Improved ecological health in the Coorong and Murray Mouth, and other estuaries in southeastern Australia, through better knowledge of the role of freshwater in estuarine processes and functions and improved management of water resources. This will be of both private and public benefit.
4. Sustainable production of both the Lower Lakes irrigation agriculture and estuarine fisheries from the water resources available as a consequence of a better understanding of the relative importance of freshwater flows to these industries.
5. Provides an understanding of flow related fish ecology that will inform ongoing fisheries management by PIRSA and the natural resource management by the partner agencies in the CLLAMM region (SA DENR, SA MDBNRMB and DFW; now DEWNR).
6. Water Management Plans and other related Natural Resource Management Plans that allocate water in an ecological sustainable manner to environmental needs, as well as sustainable production.
7. Increased stakeholder and community awareness about the environmental and economic benefits and costs of providing freshwater flows to estuaries.

The findings of this study are discussed in context of the importance of freshwater flow to fish habitats and recruitment dynamics in the estuarine system, emphasising that maintaining a salinity gradient and connectivity between the freshwater, Coorong and marine system is paramount to the ecological health of the Coorong fish community and the fishery.

The importance of quantitative assessment and linkage between freshwater flows and ecological outcomes has been increasingly recognised in recent years. Information is particularly lacking for estuarine fisheries in Australia. The Coorong, Lower Lakes and Murray Mouth (CLLAMM) region supports a significant local economy based on irrigation/agriculture/tourism and commercial/recreational fisheries. The region also has a high biodiversity value, recognised by Ramsar Wetland and Living Murray Icon Site status. However, the economic and biodiversity values of the region are currently under threat due to the reduction in flows from upstream abstraction. A number of environmental flow and engineering options have been considered to help improve the social, economic and environmental value of the system, including ecologically sustainable fisheries. However, there is a lack of biophysical system knowledge required to assess and predict the potential environmental benefits of the different management options. Knowledge gaps include flow-related fish ecology, which is critical for water management to enhance spawning and recruitment of native fish, thus supporting ecologically sustainable fisheries in the region.

The South Australian Lakes and Coorong Fishery Management Plan identified flows as an important factor impacting key commercial and recreational species. However, there has been little research on specific flow and habitat requirements of these fish. This led to the present study, aiming to address flow-related ecology of key fish species of commercial, recreational, conservation and/or ecological significance (*A. butcheri*, *R. tapirina*, *A. forsteri*, *P. urvillii* and *A. tamarensis*) in the Murray Estuary and Coorong. This project was conducted as a part of the CLLAMMecology Research Program (2006-2009), and was supported by the CSIRO Flagship Collaborative Fund and the South Australian Murray-Darling Basin Natural Resources Management Board.

During the study period (October 2006 to September 2008), the lower Murray system was in drought, and there was no freshwater released through the Murray barrages to the Coorong. This precluded any *in-situ* investigation of ecological response to flow events in the Coorong. Nevertheless, a strong north-south salinity gradient that increased with distance from the Murray Mouth persisted throughout the study; mean salinities of 30–40 ppt were recorded in the Murray Mouth subregion, 61–86 ppt in the North Lagoon, and 105–164 ppt in the South Lagoon. This allowed us to study the impact of ‘lack of flows’ on fish assemblages and various aspects of biology and ecology in the region.

Quantitative assessment of the fish assemblages of the Murray Mouth and Coorong region was conducted over a two-year period under prolonged drought conditions. A total of 31 species, consisting of estuarine, marine estuarine-opportunist, marine straggler, freshwater and catadromous species, were collected by seine and gill netting. Notably, six of the marine species had not been recorded in previous inventories for the region. Length-frequency distributions were obtained to identify cohorts for key species to gain an understanding of the recruitment pattern (timing and duration of these cohorts) and fish growth (modal progression) in the region. A general decline in species diversity occurred with increasing distance from the mouth, with only a single species was present in the South Lagoon. Fish assemblages tended to be more similar between sites, either within the same subregion or proximate to

one another, with no temporal differences (by year or season) detected. Among several water quality variables considered, salinity was found to most significant driver of variation in the structure of fish assemblages and was also strongly correlated to species abundances.

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 influenced the composition of fish assemblages observed in this study. These conditions may have negative implications for *R. tapirina*, *A. hololepidotus*, *A. butcheri* and *P. urvillii* based on knowledge of these species' life histories and low densities recorded in the current study. The decline in species diversity with distance from the mouth is likely a response to the greater osmoregulatory stress and diminishing food resources, thus limiting the amount of available habitat for most species. We recommend that the results of this study be treated as a baseline by which future quantitative assessments can be made, particularly under non-drought conditions.

A targeted study (July 2007 to July 2008) provides a baseline of key aspects of reproductive biology (including sex ratios, spawning time and duration, size at first maturity and macroscopic and microscopic characteristics of ovaries) for five key species during drought conditions. Sex ratios for all species, were heavily weighted towards females. Most species, with the exception of *A. forsteri*, exhibited plasticity in size at maturity either between different subregions or as a result of environmental stressors. Seasonal spawning guilds were identified for all species, consisting of spring (*A. butcheri*), spring/summer (*A. tamarensis*), summer/autumn/winter (*A. forsteri*) and winter (*R. tapirina* and *P. urvillii*) spawners. All species were identified as multiple batch spawners, i.e. they developed and released batches of oocytes on multiple occasions throughout the reproductive season (see Cheshire et al. (2013)). Microscopic analysis suggested spawning for *P. urvillii* may not have occurred in the Coorong during this study. It was suggested that the low flow conditions in the Coorong may have directly impacted the reproductive biology of the key species. Ensuring appropriate salinity ranges and connectivity between fresh, estuarine and marine waters is integral for the spawning and recruitment success of many Coorong species.

An experimental approach was used to investigate the influence of salinity on critical life stages (i.e. juveniles) and thus, recruitment success of key species. Gradual acclimation trials were conducted in aquaria to establish tolerance thresholds at 14 °C (representative 'winter' temperature) and 23 °C (representative 'summer' temperature) for each species. Daily measurements were taken for mortalities and behavioural changes. Probit analysis was applied to estimate a species Lethal Concentration (LC) values for 10%, 50% and 90% mortalities. Daily Feeding Response Scores and Stress Scores were also calculated from behavioural observations. Juveniles of all species trialled tolerated high salinity levels approximately twice the concentration of sea-water. There was, however, a gradient of relative tolerance across species. Behavioural response measures during gradual salinity increase trials provided additional insight into the sub-lethal impacts. The maximum field salinities at which species were caught in the fish assemblage study more clearly divided species into two groups, with species captured in salinities of

over 74 ppt and species captured below 60 ppt. These field patterns suggest that the winter temperature tolerance thresholds for these species were closely related to their distribution throughout the Coorong during 2006 to 2008. A key outcome of the current study is the application of experimentally derived tolerance thresholds to the distribution of fish across a natural salinity gradient in the field. The results suggest that threshold values, in particular LC for 10% and 50% mortalities, can approximate the maximum salinity extent of field distribution of species with moderate accuracy.

Finally, we used time series analysis to explore the relationships between freshwater flow and monthly commercial catches of key species in the South Australian Lakes and Coorong Fishery between July 1984 and June 2008. The autoregressive integrated moving average (ARIMA) modelling technique was adopted. For *A. butcheri* and large *A. hololepidotus* taken from outside the Murray Mouth, catches were best predicted by univariate models (i.e. catches in the previous year alone). For *A. forsteri* and small *A. hololepidotus* taken inside the Murray estuary and Coorong, multivariate models slightly improved predictive power when accounting for the effects of flow and other species catch. For example, it was indicated that increased flow leads to additional catch of *A. forsteri* during the same month, whereas catch of this species had a negative relationship with the catch of *A. hololepidotus*, suggesting a fisher behaviour influence. No model could be specified for *R. tapirina*. Although this study identified limitations of time series modelling when applied to commercial catch data of the Lakes and Coorong Fishery, some of these limitations may be overcome with careful planning of future research. It therefore remains a potentially useful tool to describe the influence of flows on fishery production, as has been demonstrated in other fisheries.

KEY WORDS: fish, flow, salinity, drought, reproductive biology, tolerance, estuaries, fishery, time series modelling.

2. Acknowledgements

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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 and Water Australia and SA Water. The objectives of this program were endorsed by the SA Department of Environment and Natural Resources (DENR, now DEWNR), SA Department for Water (DFW, now DEWNR).

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3. Background

River regulation and freshwater flow extraction for agricultural, industrial and residential use are common practices across Australia and have had severe impacts on water-dependent ecosystems including estuarine environments and coastal fisheries. In recent years, the need for environmental flow allocation is being increasingly recognised within Australia, and worldwide, as part of the sustainable use of water resources in integrated catchment management strategies (Davis and Hirji 2003a: 2003b: 2003c; Dyson *et al.* 2003). However, there is little knowledge of the influence of freshwater flows on estuarine health and fishery production (Gillanders and Kingsford 2002). A limited number of previous studies have indicated that estuary-specific information might be required due to hydrological and biological differences between catchments (Vance *et al.* 1998). Recognising the importance of estuarine health and productivity, the Fisheries Research and Development Corporation (FRDC) and Land and Water Australia requested an assessment of the priority research topics on the effects of freshwater flows into Australian estuaries. Knowledge of the influence of freshwater flow regimes on habitat-biota relationships; flow regime conditions needed to maintain estuarine health; flow and water quality requirements of species (flora and fauna); and more specifically the role of flows on commercial and recreational fisheries species and their supporting ecosystems (e.g. spawning success, migration and distribution, predation rates, trophic pathways) were all among the highest priorities in terms of benefits to management and scientific merits.

The Murray-Darling system, Australia's largest river catchment (an area of 1,063,000 km²), is heavily affected by river regulation (Kingsford 2000). With a total length of 2,530 km, the River Murray has 15 major storages on the main channel between Hume Dam and the sea and a series of 5 barrages near the Murray mouth. The terminal system covers an area of about 140,000 hectares, including the Coorong (a narrow 140 km lagoon system, with two major basins), lower lakes (Lake Albert and Lake Alexandrina) and a dynamic mouth opening to the South Ocean (Jensen *et al.* 2000). The overall economy of the Coorong Lower Lakes and Murray Mouth (CLLAMM) region is worth approximately \$236m/year and is based principally on irrigation agriculture (\$162m/year) and tourism (\$59m/year) with smaller contributions from recreational (\$9.6m/year) and commercial fisheries (\$5m/year). The region also plays a significant role in providing ecosystem services and is recognized internationally as an important wetlands for migratory waders under the Ramsar Convention with 33 bird species listed under international treaties. There are some 78 species of marine and freshwater fish inhabiting the area and it is an important nursery and feeding ground for key commercial species and habitat for ecologically significant fish. The area represents significant intrinsic value for the broader community and has strong spiritual and cultural meaning for Indigenous people. The CLLAMM region has always been the focus of considerable environmental and political interest. It is also one of the six significant ecological assets under the Living Murray initiative.

As in many other coastal catchments, flow reduction and barrage structures have exerted profound impacts to the Coorong estuary and Murray Mouth. These include an 89% reduction of original

estuarine habitat, disrupted transition between fresh and salt conditions, and major barriers for fish movement and migration. The ecological condition of this estuarine system worsened significantly during the recent drought, and from 2002 to 2010 two dredges were installed to maintain the Murray Mouth open, costing \$9m/year. Despite this, the ecological trajectories for the CLLAMM systems are far from certain. Recent studies in the Coorong, in particular, have shown declines in fish stocks and the abundances of aquatic angiosperms, invertebrates and bird populations (Geddes 2003). The capacity to return long term ecological function to the CLLAMM systems through infrastructure upgrade and flow management is largely unknown, although previous releases of small volumes of freshwater over the barrages provided limited ecological benefits (Geddes 2005a). Foundation knowledge and decision tools are required to target and assess the effectiveness of management actions and investment over longer time frames.

In 2008, the CLLAMMecology research cluster was developed in close consultation between South Australian research and management agencies and the CSIRO Flagships Program through the Water for a Healthy Country Flagship. The program aimed to produce a decision-support framework to assess the ecological, social and economic costs and benefits of different management options, particularly through water/flow management. This research framework aimed to link the key levers for management with key biophysical (hydrodynamics, biogeochemistry, ecology) processes. The levers for the Coorong and Murray Mouth region included barrage operation, releases from upstream storages, dredging of the Murray Mouth and releases from the Upper South East Drainage scheme. The CSIRO Water for a Healthy Country Flagship program facilitated the development of an overall system framework for the region, including its hydrodynamic function and social and economic assessment components. CLLAMMecology further complemented these activities by addressing the critical knowledge needs to quantify the potential ecological costs and benefits of possible management action (e.g. flow releases and barrage operations) for the region. By implementing a whole-of-system approach, the study served as one of the few case studies for the integrated catchment management for sustainable water use in the temperate Australia.

A key knowledge gap identified in the CLLAMMecology program was flow-related fish and fisheries ecology. A number of estuarine-lagoonal fish species of commercial value, complete their life cycles in the Coorong estuary and Murray Mouth region. Other fish use the system as refuge, nursery and feeding ground, and a migration pathway at a certain life history stage. The Lakes and Coorong Fisheries Management Plan identified the critical need of environmental flows for the sustainable management of the fisheries in the region. “Ensuring more frequent estuarine fish spawning” is also a main ecological objective for this significant asset in the Living Murray initiative. Previous attempts were made to develop models based on expert opinions such as preference curves for some species/functional groups in the CLLAMM region for incorporation into the Murray Flow Assessment Tool (MFAT). However, these were not based on measured responses to environmental variables, and none of them were spatially explicit, or considered performances over a series of events. The exercise also highlighted the critical

need for quantitative data for this region to develop robust models for signature fish. This FRDC project provides quantitative research to determine environmental conditions that are essential to the maintenance and/or enhancement of fish populations in the region. The information will be used to develop fish response models to evaluate the impact of environmental events on the critical life history stages (e.g. minimum flows/environmental cues to induce spawning) of key species (e.g. *A. butcheri*, *R. tapirina*, *A. forsteri*, *P. urvillii* and gobies) or functional groups.

The lack of freshwater flows to the system during the study period, precluded the proposed in-situ investigation of ecological response of key fish species to freshwater flow events in the Coorong. However, the prolonged period of no-flow facilitated an investigation into the impact of 'no flows' on fish assemblages and various aspects of biology and ecology in the region including fishery productivity. This FRDC project investigates recruitment processes, including spawning and survivorship during the early life stages and how these processes relate to salinity, habitat availability and water quality. The findings of this project will further complement the outcomes of the CLLAMMecology research cluster which included habitat mapping/modelling, study of productivity and tropho-dynamics, research into key species responses, and ecosystem modelling, as well as an independent fish movement/migration project conducted by SARDI Aquatic Sciences. The overall research program will provide a template for the development of other large-scale multidisciplinary models for natural resource management, contributing with a range of outcomes directly related to CLLAMM policies and implementation initiatives, such as: Significant Ecological Asset Management Plan (Living Murray); Ramsar Plan - ecological character and wise use; and Murray-Darling Basin Native Fish Strategy.

4. Need

The importance of quantitative assessment and linkage between freshwater flows and ecological outcomes has been increasingly recognised in recent years. Information is particularly lacking for estuarine fisheries in Australia. The CLLAMM region supports a significant local economy based on irrigation/agriculture/tourism and commercial/recreational fisheries. The region also has a high biodiversity value and is internationally recognised as a Ramsar wetland and Living Murray Icon Site. However, the economy and biodiversity values of the region are under threat due to the reduction in freshwater flows due to the over-exploitation and abstraction of freshwater resources in the Murray-Darling Basin. While several environmental flow and engineering options are currently being considered to help improve the social, economic and environmental values of the system including ecologically sustainable fisheries, there is an inherent lack of biophysical and ecological knowledge required to assess and predict the potential environmental benefits of the different management options.

From 2008 – 2010, the CLLAMMecology research cluster redressed some of the major knowledge gaps on the hydrodynamics, biogeochemistry and ecology of the region. However, the influence of freshwater flow on fish populations and subsequent productivity of commercial and recreational fisheries remains poorly understood. Such information is critical for water management to enhance spawning/recruitment of native fish (key objective of the Environmental Management Plan). In recent years, State/Commonwealth policies to facilitate ecosystem-based, ecologically sustainable fisheries management have been developed and implemented. While, the Lakes and Coorong Fishery Management Plan identified freshwater flows to the estuary as an important issue impacting key commercial/recreational species (*A. hololepidotus*, *A. butcheri*, *R. tapirina*, and *M. ambigua*), research on specific flow/habitat requirements of these species is limited. Therefore, quantitative data on ecological processes that influence the population dynamics (spawning, recruitment and biomass) is needed to facilitate the sustainable management of fisheries and water resources.

This project aims to examine and describe the flow-related ecology of key fish species of commercial/recreational/conservation or ecological significance (i.e. *A. butcheri*, *R. tapirina*, *A. forsteri*, *P. urvillii* and *A. tamarensis*) in the Murray Estuary and Coorong. The lack of freshwater flows to the system, precluded any *in-situ* investigation of ecological response to flow events in the Coorong. However, this facilitated an investigation into the impact of ‘no flows’ on fish assemblages and various aspects of biology and ecology in the region including reproduction, recruitment and fishery productivity.

5. Objectives

1. To determine the distribution, relative abundance and size structure of key fish species and how these relate to habitat and environmental conditions (i.e. salinity, temperature) in the Murray Estuary and Coorong.
2. To examine aspects of reproductive biology and influence of environmental conditions on spawning success of key species in the region.
3. To investigate the influence of environmental conditions (i.e. salinity, temperature) on the critical early life stages of key species.
4. To investigate the relationship between freshwater flows (timing, quantity and duration) and recruitment success and fisheries production of key commercial species.

Five species were selected as key species:

- black bream (*Acanthopagrus butcheri*): a commercially important estuarine species.
- yelloweye mullet (*Aldrichetta forsteri*): a commercially important marine/estuarine-opportunist.
- greenback flounder (*Rhombosolea tapirina*): a commercially important estuarine and marine species.
- Tamar goby (*Afurcagobius tamarensis*): an important trophic level small-bodied estuarine species.
- congolli (*Pseudaphritis urvillii*): a conservation significant catadromous species.

Additional species of interest included:

- mulloway (*Argyrosomus hololepidotus*): a commercially important marine/estuarine opportunist.
- small mouthed hardyhead (*Atherinosoma microstoma*): an estuarine species.

6. Methods

6.1 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 (

Figure 6.1). The long (> 100 km), narrow and shallow (mean depth $\approx$ 2 m) Coorong lagoons extend south-eastward from the Murray Mouth, running parallel to the South Australian coastline, and are isolated from the South Ocean by the Younghusband Peninsula. The Coorong is divided into the North and South Lagoons, which are connected by a very narrow channel at Parnka Point with adjacent shallow sand bars.

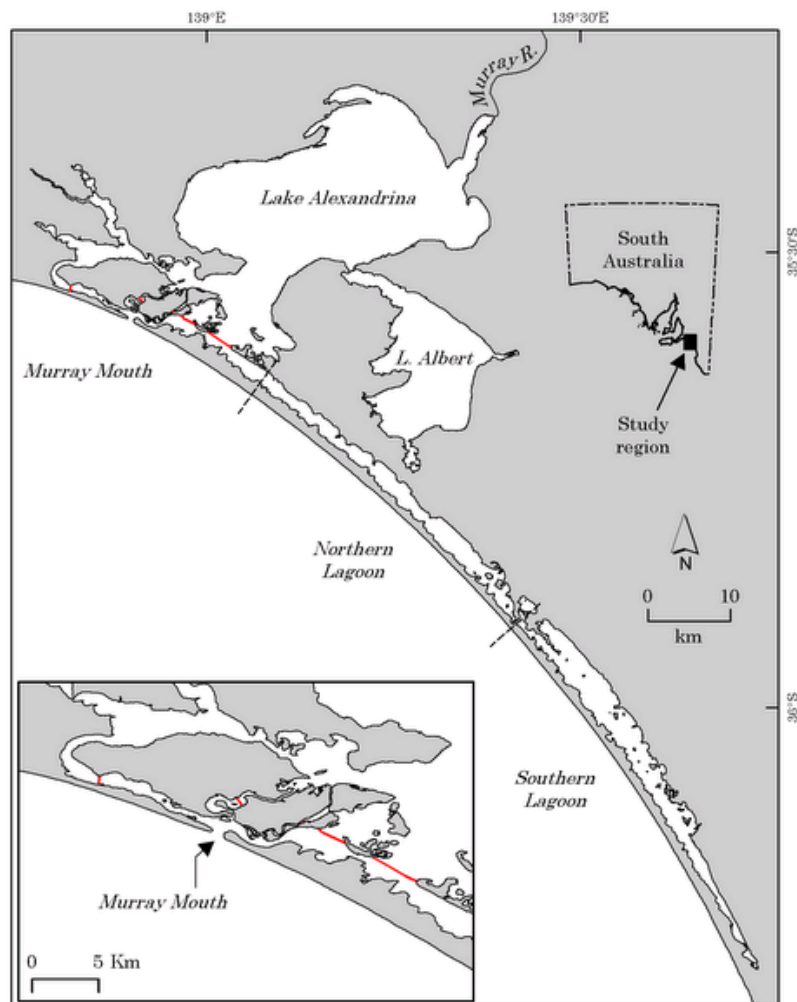


Figure 6.1. Map showing the location of the Murray Mouth and Coorong region in relation to the Murray River and lower lakes (Lakes Alexandrina and Albert). Dashed lines indicate the Murray Mouth, North Lagoon and South Lagoon sub-regions. Inset map shows the locations of the five barrages (red lines) and the Murray Mouth within the Murray Mouth sub-region.

A series of five 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 1940s 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 (Figure 6.2), 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.

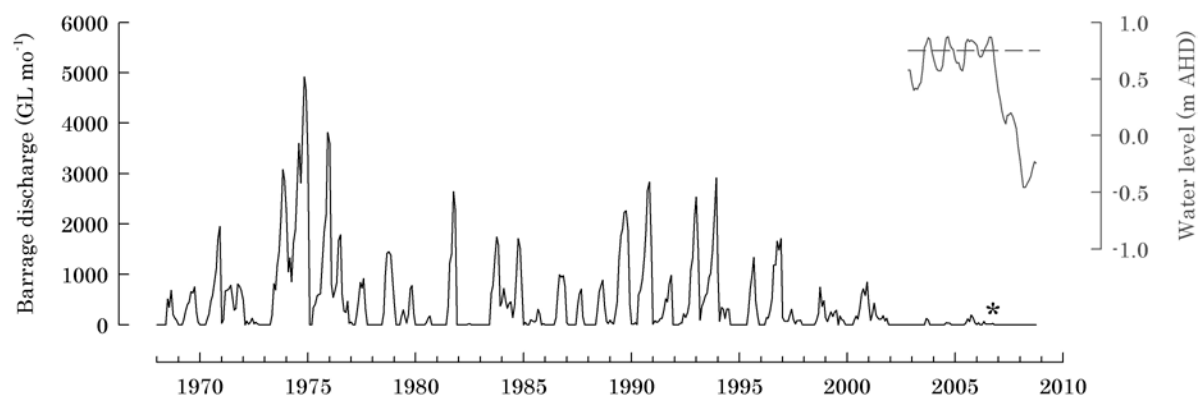


Figure 6.2: Average monthly flow volume across the barrages from January 1968 to October 2008 (source: MDBC 2008). Asterisk (*) indicates commencement of current study. 2nd Y-axis indicates the mean monthly water level (in metres Australian Height Datum, AHD) for Lake Alexandrina above Goolwa Barrage (source: DWLBC 2008).

The Murray Mouth and Coorong region has an estuarine influence, but it is not a typical estuary (Geddes 2003). 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 North and South Lagoons. With construction of the barrages, the ‘estuary’ was reduced to 11% of its original size (Ferguson *et al.* 2008).

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.

For the duration of this study (October 2006 to September 2008), the Murray-Darling Basin, including the lower lakes, Murray Mouth and Coorong, 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 steadily declined and remained well below sea level (Figure 6.2). At such low lake levels it is not possible to release freshwater and, consequently, the Murray Mouth and Coorong region received no freshwater inflows between August 2006 and September 2010. 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.

6.2 Environmental characteristics

Information on the environmental characteristics of each study site was collected periodically throughout the study period to examine the influence of environmental conditions on fish assemblage structure and recruitment processes. 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 (raw data are shown in Noell *et al.* (2009)). The TPS meter was calibrated prior to each sampling occasion. According to the manufacturer, salinity measurements are accurate between 0 ppt and 100 ppt using the recommended standard solution of 36 ppt, however, we obtained an accuracy of -1.2% with a known solution of 150 ppt.

6.3 Fish assemblages

Sampling regime

To examine and describe the fish assemblage composition in the Murray Mouth and Coorong region, fish were collected from ten sites, 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 North Lagoon, and two in the South Lagoon (see Noell *et al.* (2009) for detailed map and site details). Each site was sampled during the day with a 61 m long seine net (22 mm mesh). Three replicate samples were conducted on each sampling occasion. Each replicate swept an area of ~592 m². In addition, several sites were also sampled using sinking composite gill nets. The results of the gill net sampling are shown in Noell *et al.* (2009).

All fish collected were identified to species level and the total number of each species recorded. 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 and Hyndes (1999). For the key species, the total length (TL) of each fish was measured to the nearest 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.

Data analyses

Multivariate analyses were performed to compare the composition of fish assemblages at each site in the CLLAMM region. All multivariate analyses were performed using the PRIMER v6 package (Clarke and Warwick, 2001). Detailed descriptions of the statistical procedures used are shown in Noell *et al.* (2009).

6.4 Reproductive biology

Sampling regime

To examine the reproductive biology for each of the key species, fish were collected from the Murray Mouth and Coorong region on 13 sampling occasions at approximately one-monthly intervals between July 2007 and July 2008. *A. butcheri*, *A. forsteri* and *R. tapirina* were collected by commercial fishers, using monofilament gill nets, with mesh sizes ranging from 2 to 6 inches. *P. urvillii* and *A. tamarensis* were sampled using single winged (6 mm mesh) fyke nets by SARDI researchers. Fyke nets were set overnight (~16 hours), and positioned with the wing facing the bank. The aim was to collect at least 30 fish per species per month, however low catch rates for some species limited sample sizes for some months.

Sample processing and macroscopic analysis

Samples of adult fish for each species were processed in the laboratory. All fish were measured for total length (TL) (to the nearest mm), weighed (to the nearest g), and dissected for the study of reproductive biology within 24 hours of capture. For each fish the gonads were removed, sexed and weighed to 0.1 g. Gonado-somatic indices (GSI) were calculated as:

$$\text{GSI} = [W_g/W_f] * 100\%$$

Where W_g = gonad weight, W_f = gonad-free fish weight.

Ovaries were classified macroscopically to one of five stages of development, based on size, colour and visibility of oocytes (Fowler *et al.* 1999) (Table 6.1). Males were also staged macroscopically and classified to one of three stages of development (Table 6.1).

In addition, from the fish collected for the macroscopic staging, a random sub-sample of ovaries was collected monthly for each species for more detailed analysis by histological preparation and microscopic examination. Histological sections of formalin preserved ovarian tissue were prepared and examined following methods outlined in Fowler *et al.* (1999). The microscopic staging allowed the spent/regressing stage to be separated based on presence/absence of post-ovulatory follicles and level of

atresia. See Cheshire *et al.* (2013) for a detailed description of the microscopic characteristics of ovarian tissue at each stage of development for each of the key species.

Table 6.1. Classification of development of ovaries and testes for macroscopic staging (after Fowler *et al.* 1999).

Gonad Stage	Macroscopic characteristics
F1- Immature	Ovaries small and undeveloped, clear or translucent showing little or no colouration
F2- Developing	Ovaries small but larger F1 and become more orange/yellow/white (varies between species) no individual oocytes discernible.
F3- Developed	Ovaries larger and turgid, yellow/orange in colour, individual oocytes discernible
F4- Hydrated	Large ovaries, taking up a large space in gut cavity, with hydrated oocytes easily discernible.
F5- Regressing /Spent	Ovaries are large, similar in size and colour to F2 stage, however more flaccid with a granular appearance.
M1- Immature	Undeveloped testes usually dark in colour.
M2- Developing	Developing testes whereby they are larger and become grey - white in colour but no milt present.
M3- Developed	Developed testes that are large and white in colour and milt is present

Size at first maturity

The size at maturity was measured for females of all key species. Those individuals with ovaries $\geq$ stage 3 during spawning season were defined as mature. Logistic curves were fitted to describe the percentage of mature male and females at TL using the non-linear least squares (NLIN) procedure in SAS (Anon 1989) according to the equation:

$$P_m = \frac{100}{1 + e^{-k(X-m)}}$$

Where, P_m is % maturity, X is the TL (mm), k is a constant describing how rapidly fish mature, and m is the size at 50% maturity.

6.5 Salinity tolerance trials for key species

The influence of salinity on the behaviour and survival of key fish species in the Coorong and Murray Mouth was investigated using controlled salinity trials. Key fish species trialled were *Acanthopagrus butcheri*, *Aldrichetta forsteri*, *Rhombosolea tapirina*, *Afurcagobius tamarensis*, *Pseudaphritis urvillii*, *Argyrosomus hololepidotus* and *Atherinosoma microstoma*.

Experimental setup: slow acclimation tolerance trials

Juvenile fish of each species were collected from the Lower River Murray and Coorong, except for *A. hololepidotus* juveniles, which were hatchery-reared (see McNeil *et al.* (2013) for size and weight characteristics of fish considered). Once captured and transported back to the SARDI research facility at West Beach, fish were transferred into 2000 L aquaria under controlled environment conditions. All fish were quarantined and treated for potential disease as per Australian Pest and Veterinary Medicine Authority permit no. 8853. Test fish were acclimated in sea water within experimental aquaria for at least one week under experimental conditions prior to testing.

For each species, five fish were acclimated within three 20 L experimental aquaria and at the onset of experimentation salinity was increased. Gradual acclimation style tolerance trials were conducted within aquaria maintained at two test temperatures; 14 °C (representative ‘winter’ temperature) and 23 °C (representative ‘summer’ temperature). At the onset of experiments, test aquaria were subjected to a gradual increase in salinity at a rate of 2 ppt per day from an initial concentration of 35 ppt with the use of Ocean Nature® or Sea-Chem® salt mixed with filtered seawater. Daily measurements of key water quality parameters were recorded including dissolved oxygen, total dissolved solids (as a measure of salinity), pH and temperature.

Experimental measurements were then recorded including: number of mortalities, number of fish actively swimming, presence of any disease or health conditions and maintenance of equilibrium (i.e. maintaining balanced position in the water). An index of feed acceptance and an index of visual stress were also recorded daily. Finally, salinity was reset at the next incremental level within treatment tanks (i.e. 2 ppt higher than the previous day).

Throughout acclimation and trials, a light:dark ratio approximating 12:12 hrs was used. Fish were fed daily with a varied diet of frozen bloodworm, frozen brine shrimp (*Artemia* sp.), live brine shrimp, and 1mm or 5/8 proton aquaculture pellet. Diet was dependant on species specific acceptance of these foods.

Behavioural observations

Daily assessment of fish behaviour via observation was performed prior to resetting of salinity to inform and complement the measurement of lethal threshold and provided insight into some of the potential sub-lethal thresholds that indicate physiological impact prior to lethality. Daily behaviour measurements relating to stress and diminished feeding activity were taken based on Nominal Keys (Table 6.2 and Table 6.3) and used to calculate Daily Feeding Response Scores (DFRS) and Stress Scores (SS). These were made by the same researcher to minimise experimental variation in observational scoring.

Table 6.2. Nominal Key used to score observed feeding response during trials.

Daily Feeding Response Score (DFRS)		
5	High response	Feeding eagerly at surface, feed not reaching floor of tank.
	Medium high response	
4	response	Some feed reaching floor of tank, but consumed within 5mins.
3	Medium response	Most feed reaching floor of tank, but consumed within half an hour.
2	Medium low response	Feed reaching floor of tank, more than half consumed within half an hour.
1	Low response	Feed reaching floor of tank, less than half consumed within half an hour.
0	No response	Feed not consumed, little interest in feeding observed.

Table 6.3. Nominal Key used to score observations of stress during trials.

Stress Score (SS)		
5	High stress	Dark obvious banding increased opercula pumping and constant hiding.
		Dark obvious banding, slightly increased opercula pumping and hiding majority of time.
4	Medium high stress	
3	Medium stress	Some dark banding, often accompanied by hiding.
2	Medium low stress	Faint banding, some hiding from movement.
1	Low stress	No banding, some hiding from movement.
0	No stress	Little flight response, swimming at front of tank in anticipation of feeding.

Data analysis and threshold determination

The survival (%) of test fish under gradually increasing salinity was estimated daily for each trial. Results from the three replicate trials for each species were then analysed using Probit analysis to give a species Lethal Concentration (LC) value. LC values were estimated for levels of salinity that were lethal for 10% (LC₁₀), 50% (LC₅₀) and 90% (LC₉₀) of test fish. For *A. microstoma* the LC₁₀, LC₅₀, and LC₉₀ values were estimated from data reported in Lui (1969) due to the low number of fish available. Probit analyses were carried out using SPSS Version 16.0 and StatsDirect Version 2.6.2. Salinity concentration (ppt) was log¹⁰ transformed for analysis.

Spatial and temporal abundance data for each of the selected species and field salinity data (parts per thousand, ppt) were adopted from the concurrent study described in Section 7.2. Abundances of each species were overlaid as bubbles onto contour salinity graphs and presented through time with increasing distance from the Murray Mouth. LC₅₀ estimates at 14 °C and 23 °C were applied as a threshold of expected field distribution.

6.6 Influence of freshwater flows on fishery production for key species

The Lakes and Coorong Fishery is a multi-species, multi-gear commercial fishery. The four most important species, in terms of landings and value, are *Acanthopagrus butcheri*, *Rhombosolea tapirina*, *Argyrosomus hololepidotus* and *Aldrichetta forsteri*. Since July 1984, licence holders of the Lakes and Coorong Fishery have been required to submit catch and effort returns to the South Australian Government at the end of each month which indicates the target species, the gear types used and the fishing area (FA) where fishing was done (Figure 6.3). The availability of this long uninterrupted time series of data, along with a corresponding time series of flow data (also provided by the Government), provided the opportunity to use time series modelling techniques to investigate the relationships between freshwater inflows and the production of these key species.

The basic working objective of this fishery-dependent study was to identify and characterise relationships between freshwater inflows and production of the key species in the Lakes and Coorong Fishery using time series analysis. Specifically, it is expected that flow has a positive influence on spawning aggregations of *A. hololepidotus* (Ferguson and Ward 2003; Hall 1984), a positive influence on recruitment of *A. forsteri* (Pellizzari 2002), *A. hololepidotus* (Ferguson et al. 2008) and *R. tapirina* (Hall 1984), a negative influence on recruitment of *A. butcheri* (Hobday and Moran 1983; Morison et al. 1998), and these influences are reflected in catches of these species.

For this component of the project, the study region comprised the waters inside the Murray Mouth, the North and South Lagoons of the Coorong, and the waters outside the Murray Mouth, which extend for ~180 km along the coastline (Figure 6.1). It encompasses the saltwater part of the Lakes and Coorong Fishery, which is separated by the barrages from the freshwater part of the fishery, Lakes Alexandrina and Albert. The saltwater part of the fishery was divided into four subregions, each of which comprise two or three FA (i.e. the Murray Mouth comprises FA 6-8, the North Lagoon comprises FA 9-11, the South Lagoon comprises FA 12-14, and the coastal waters outside the Murray Mouth comprise FA 15 and 16) (Figure 6.3).

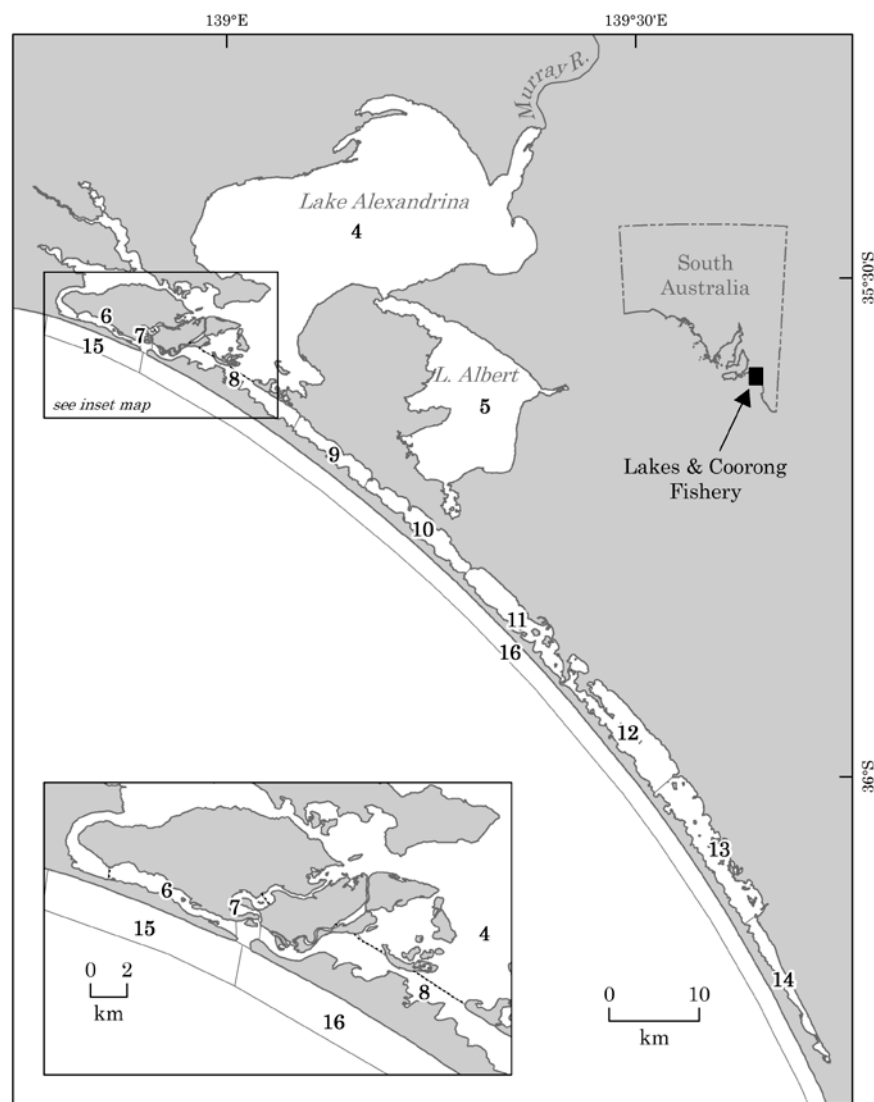


Figure 6.3. Map showing the location of the Murray Mouth (fishing areas 6-8), North Lagoon (9-11), South Lagoon (12-14), and coastal waters (outside the Murray Mouth) (15-16) subregions of the Lakes and Coorong Fishery.

7. Results

7.1 Environmental characteristics

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 (Figure 7.1). 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 South Lagoon in June and December 2007, respectively.

Salinity

Mean salinities for each subregion differed on each sampling occasion; salinities were always lowest in the Murray Mouth and highest in the South Lagoon (Figure 7.1). Mean monthly salinities ranged between ~30 and ~43 ppt in the Murray Mouth, 61 and ~86 ppt in the North Lagoon, and ~105 and ~164 ppt in the South Lagoon. No obvious temporal pattern in mean monthly salinities occurred for either the Murray Mouth or North Lagoon, but sharp peaks in salinity occurred in the South Lagoon around March. Mean salinities at each site generally increased with increasing distance from the mouth, from 35.5 ppt at M1 to 125.1 ppt at Jack Point in the South Lagoon.

Dissolved oxygen

Dissolved oxygen concentrations generally followed similar trends in the Murray Mouth and North Lagoon, with higher concentrations recorded in the North Lagoon on most occasions (Figure 7.1). 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 South Lagoon, mean monthly dissolved oxygen concentrations appeared to peak between September and December, however, measurements were highly variable in this subregion.

pH

Mean monthly pH values were lower in the South Lagoon than in the other two subregions except on two occasions (in December 2006 and September 2008), when the trend was reversed (Figure 7.1). Both the lowest and highest pH of 7.8 and 8.5 were recorded in the South Lagoon, in October 2006 and September 2007, respectively, while pH values in the Murray Mouth and North Lagoon usually fluctuated between ~8.2 and 8.4.

Turbidity

In most months, water transparency generally decreased (= increase in turbidity) with distance from the mouth, as indicated by secchi disk depth measurements (Figure 7.1). Examination of mean secchi disk depth measurements at each site showed that a steep decline in water transparency occurs between Pelican Point in the Murray Mouth subregion (1.45 m) and the South end of the North Lagoon (0.44 m).

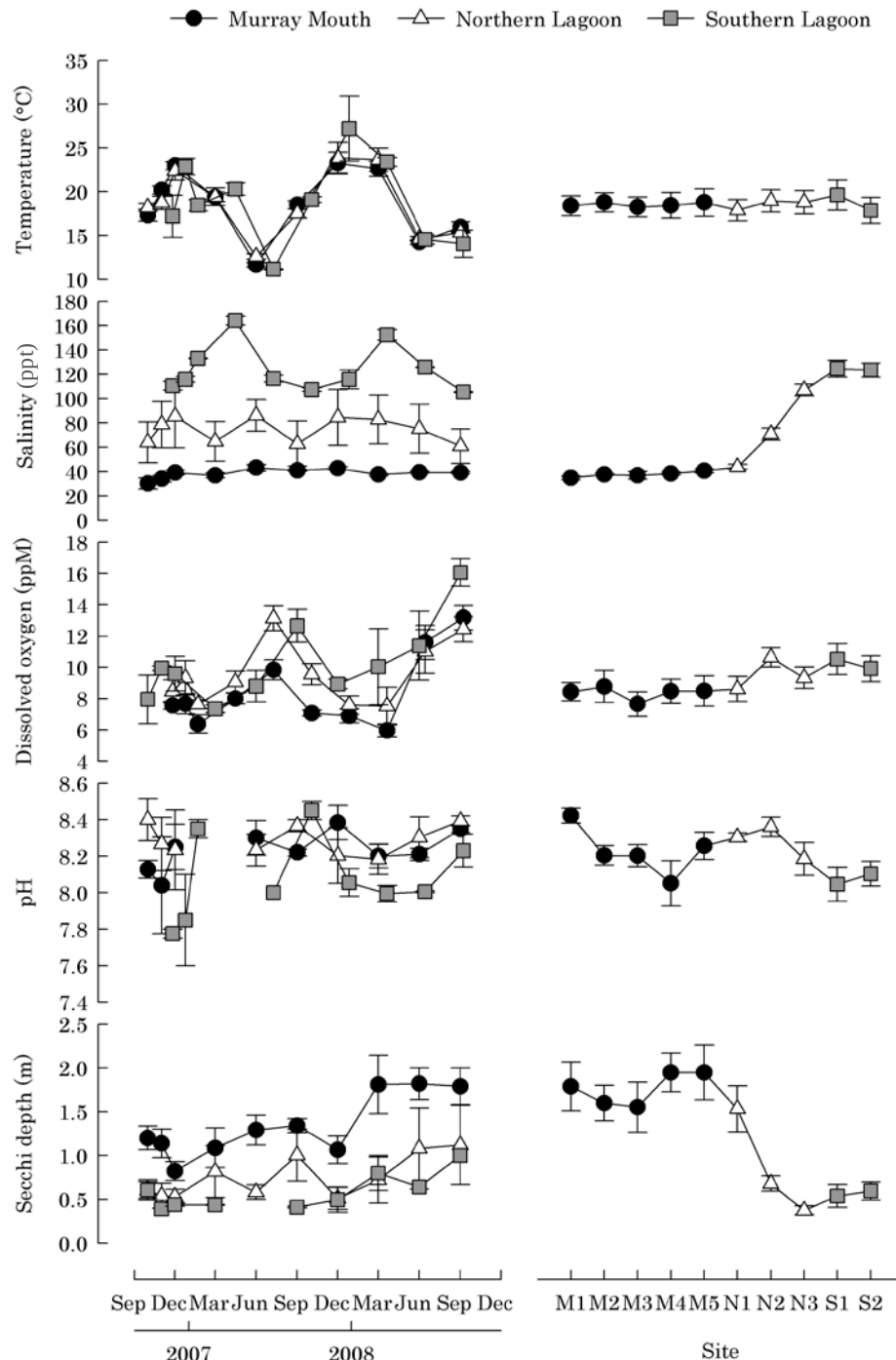


Figure 7.1. Mean values $\pm$ 1 S.E. for water temperature, salinity, dissolved oxygen, pH and secchi depth for subregions on each sampling occasion (sites pooled, left graphs) and for each site (sampling occasions pooled, right graphs: see Noell *et al.* (2009) for map showing location of individual sites) within the Murray Mouth and Coorong region between October 2006 and September 2008.

7.2 Fish assemblage structure and composition

A total of 78,754 fish representing 26 species were caught using the seine net throughout the Murray Mouth and Coorong region between October 2006 and September 2008 (Table 7.1). *A. microstoma* was by far the most abundant species, contributing 60.5% to the total number of fish collected using this method. The second most abundant species, *A. forsteri*, contributed 16.5% to the total number, while the third most abundant, *Hyperlophus vittatus*, contributed 15.6%. These three species collectively accounted for 92.5% of the total catch using the seine net.

All 26 fish species collected were recorded from the Murray Mouth subregion, while 13 were recorded in the North Lagoon, and only 1 species, *A. microstoma*, was found in the South Lagoon (Table 7.1). The five most abundant species in the Murray Mouth subregion were *H. vittatus* (38.0% contribution to total abundance), *A. forsteri* (34.5%), *A. microstoma* (10.1%), *A. truttaceus* (6.6%), and *G. maculatus* (3.4%). In contrast, the North Lagoon was dominated by *A. microstoma* (91.8%), with relatively small contributions by *A. forsteri* (5.3%) and *H. vittatus* (1.6%), and minor contributions by the pleuronectid *R. tapirina* (0.5%) (Table 7.1). Despite the low species diversity in the North Lagoon, a greater total number of fish were collected from that subregion due to the high abundances of *A. microstoma* in that subregion. In addition, a site-specific breakdown of species richness along the longitudinal gradient of the estuarine system showed a general decline in diversity with distance from the Murray Mouth (Figure 7.2). The assemblage structure for each sampling site is described in more detail in Noell *et al.* (2009).

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%). The estuarine-opportunists were more abundant in the Murray Mouth (80.4%), while solely-estuarine species were dominant in the North (92.1%) and South Lagoons (100%).

Table 7.1. Life-cycle category, ranking by abundance (R), relative abundance (n), and percentage contribution (%) of each fish species in the Murray Mouth, North Lagoon and South 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			North Lagoon			South Lagoon			Mean length (mm)	Length range (mm)
		R	n	%	R	n	%	R	n	%	R	n	%		
<i>Atherinosoma microstoma</i>	E	1	40216	60.5	3	2587	10.1	1	35964	91.8	1	1666	100.0	53	17-91
<i>Aldrichetta forsteri</i>	O	2	10959	16.5	2	8867	34.5	2	2092	5.3				73	26-308
<i>Hyperlophus vittatus</i>	O	3	10370	15.6	1	9748	38.0	3	622	1.6					
<i>Arripis truttaceus</i>	O	4	1780	2.7	4	1694	6.6	6	86	0.2					
<i>Galaxias maculatus</i>	C	5	866	1.3	5	866	3.4								
<i>Hyporhamphus regularis</i>	E	6	494	0.7	6	474	1.8	8	20	<0.1					
<i>Rhombosolea tapirina</i>	E&M	7	470	0.7	7	286	1.1	4	183	0.5				66	18-355
<i>Afurcagobius tamarensis</i>	E	8	316	0.5	10	215	0.8	5	101	0.3				46	20-77
<i>Ammotretis rostratus</i>	O	9	285	0.4	11	205	0.8	7	80	0.2					
<i>Engraulis australis</i>	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					
<i>Arripis georgianus</i>	O	12	69	0.1	12	68	0.3	13	1	<0.1					
<i>Argyrosomus hololepidotus</i>	O	13	49	<0.1	13	49	0.2							193	128-380
<i>Tasmanogobius lasti</i>	E	14	45	<0.1	14	39	0.2	10	6	<0.1					
<i>Arenigobius bifrenatus</i>	E&M	15	34	<0.1	15	34	0.1								
<i>Acanthopagrus butcheri</i>	E	16	25	<0.1	16	25	<0.1							269	105-484
<i>Hyporhamphus melanochir</i>	E&M	17	15	<0.1	17	15	<0.1								
<i>Pseudaphritis urvillii</i>	C	18	9	<0.1	18	7	<0.1	11	3	<0.1				131	40-230
<i>Pseudogobius olorum</i>	E	=19	5	<0.1	=19	5	<0.1								
<i>Gymnapistes marmoratus</i>	O	=19	5	<0.1	=19	5	<0.1								
<i>Nematalosa erebi</i>	F	21	3	<0.1	21	3	<0.1								
<i>Sardinops neopilchardus</i>	S	=22	2	<0.1	=22	2	<0.1								
<i>Liza argentea</i>	E&M	=22	2	<0.1	=22	2	<0.1								
<i>Retropinna semoni</i>	F	=24	1	<0.1	=24	1	<0.1								
<i>Heteroclinus heptaeolus</i>	O	=24	1	<0.1	=24	1	<0.1								
<i>Myliobatis australis</i>	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			

Classification of fish assemblages: spatial variation

Classification of the mean densities of each fish species collected using a seine net at each site (10) on each sampling occasion (10) demonstrated 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 significantly similar internal structure, i.e. samples within the same group share a similar fish assemblage pattern (Figure 7.2). 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 (Figure 7.2). Furthermore, ANOSIM demonstrated that highly significant differences were found in the composition of samples between subregions (Global R-statistic = 0.626, $P < 0.001$). All three subregions were highly significantly different from one another (Murray Mouth vs. South Lagoon: R-statistic = 0.958; Murray Mouth vs. North Lagoon: 0.520; North Lagoon vs. South Lagoon: 0.315). No significant differences were found between years or seasons. Detailed results of the ANOSOM are shown in Noell *et al.* (2009).

Ordination using non-metric multidimensional scaling (MDS) is comparable to the results of classification and ANOSIM (Figure 7.3). Thus, all samples collected from the Murray Mouth are distinctly separate from all samples taken from the South Lagoon, while North Lagoon samples are either interspersed with samples from one of the other subregions. Also shown are the groups of samples with similar assemblage structure (at similarity boundaries of 48%).

Specific differences between the groups of samples identified using classification; ANOSIM and ordination were identified using SIMPER. The fish assemblages of the Murray Mouth subregion contained relatively lower numbers of *A. microstoma* and higher numbers of *A. forsteri* and *A. truttaceus* than the North Lagoon, which collectively accounted for almost half (48.6%) of the dissimilarity between the two subregions (Table 7.2). Differences in assemblage structure between the North and South Lagoon were attributed mainly to *A. microstoma* (57.0% dissimilarity) being present at much higher densities in the North Lagoon. The dissimilarity between the Murray Mouth and South Lagoon assemblages can be attributed to all species present having a relatively greater abundance in the Murray Mouth.

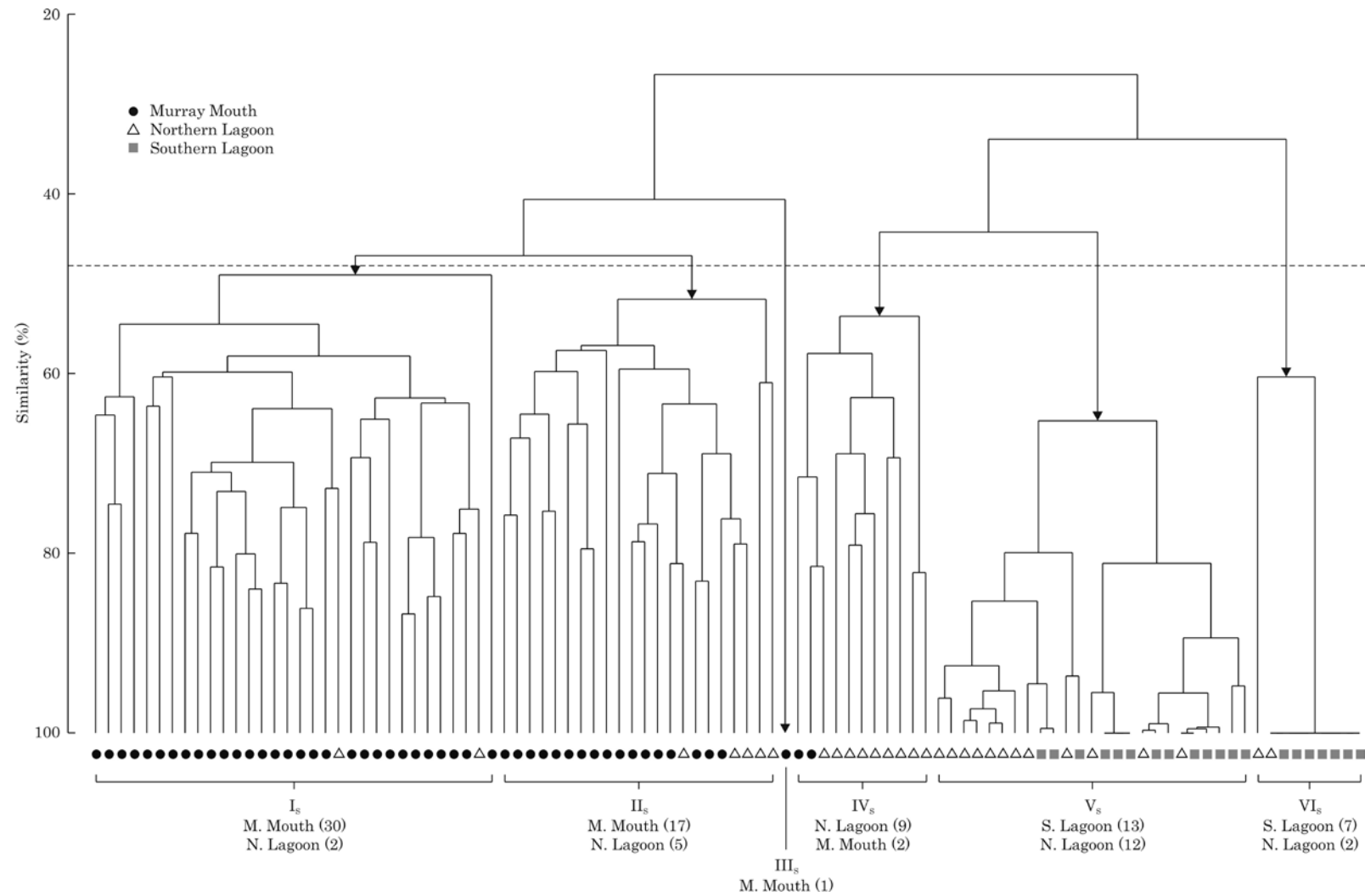


Figure 7.2. Dendrogram of the species abundance data for all 100 seine net samples (10 sites $\times$ 10 sampling occasions) collected from the Murray Mouth, North Lagoon and South Lagoon subregions between October 2006 and September 2008. Classification of samples was carried out using group average 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.

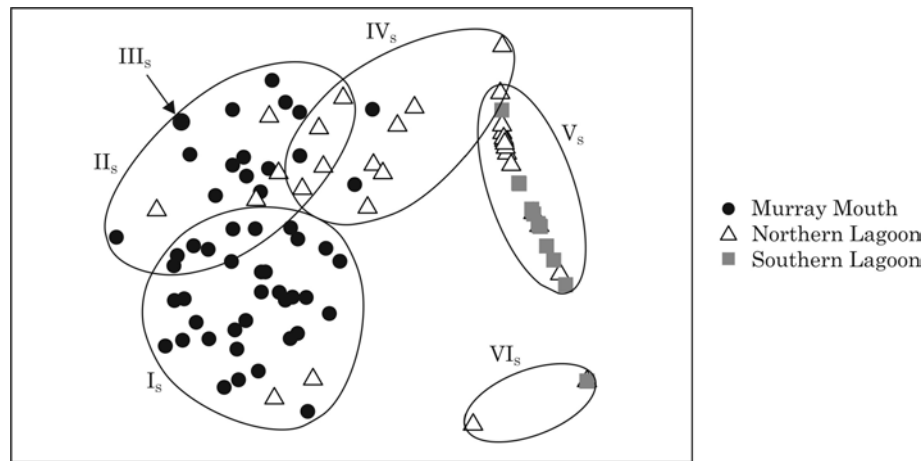


Figure 7.3. MDS ordination of the species abundance data for all 100 seine net samples (10 sites $\times$ 10 sampling occasions) collected from the Murray Mouth, North Lagoon and South Lagoon subregions between October 2006 and September 2008. Boundaries indicate the six similarity profile groups (Groups I_s-VI_s) at similarity levels of 48%. Stress = 0.14.

Table 7.2. 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			
<i>Atherinosoma microstoma</i>	17.2	399.6	1.3	21.1	21.1
<i>Aldrichetta forsteri</i>	59.1	23.2	1.3	16.7	37.8
<i>Arripis truttaceus</i>	11.3	1.0	1.2	10.8	48.6
<i>Hyperlophus vittatus</i>	65.0	6.9	1.0	10.1	58.7
<i>Rhombosolea tapirina</i>	1.9	2.0	1.2	7.1	65.8
<i>Hyporhamphus regularis</i>	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			
<i>Aldrichetta forsteri</i>	59.1	0.0	2.0	22.6	22.6
<i>Arripis truttaceus</i>	11.3	0.0	1.3	12.8	35.5
<i>Atherinosoma microstoma</i>	17.2	27.8	1.2	11.5	46.9
<i>Hyperlophus vittatus</i>	65.0	0.0	0.9	9.8	56.7
<i>Rhombosolea tapirina</i>	3.2	0.0	1.6	9.4	66.2
Tetraodontidae	1.6	0.0	1.1	7.2	73.3
<i>Hyporhamphus regularis</i>	3.2	0.0	1.0	7.1	80.4
N. Lagoon vs. S. Lagoon: mean dissimilarity = 75.8%					
	N. Lagoon	S. Lagoon			
<i>Atherinosoma microstoma</i>	399.6	27.8	1.3	57.0	57.0
<i>Aldrichetta forsteri</i>	23.2	0.0	0.8	11.4	68.4
<i>Rhombosolea tapirina</i>	0.2	0.0	0.6	10.1	78.5

Link between salinity and fish assemblages

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 seine net samples. The correlation (rho-statistic, $\rho = 0.676$) between the salinity data and species abundance data was highly significant ($P < 0.001$).

The salinity ranges of the key study species were examined based on water quality measurements taken at the same time as seine net samples (Table 7.3). The two most abundant species were both euryhaline, occurring at various times at almost all sites in the Murray Mouth and North Lagoon subregions, in salinities ranging from brackish to hypersaline (i.e. 12.9 to 55 ppt and greater). *A. microstoma*, the only species found in the South Lagoon, demonstrated a very high salt tolerance, occurring at extreme hypersalinity up to 133.5 ppt.

Table 7.3. Salinity ranges of the key species (R, overall abundance rank) 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) $x = 0$; $\square$ $0 < x \leq 1$; $\blacksquare$ $1 < x \leq 10$; $\blacksquare$ $10 < x \leq 100$; $\blacksquare$ $100 < x \leq 1000$; $\blacksquare$ $x > 1000$.

Species	R	Salinity (ppt)		Density									
		Min.	Max.	M1	M2	M3	M4	M5	N1	N2	N3	S1	S2
<i>A. microstoma</i>	1	12.9	133.5										
<i>A. forsteri</i>	2	12.9	74.1										
<i>R. tapirina</i>	7	12.9	74.1										
<i>A. tamarensis</i>	8	12.9	60.1										
<i>A. hololepidotus</i>	13	28.0	43.0										
<i>A. butcheri</i>	16	30.3	42.2										
<i>P. urvillii</i>	18	38.6	62.4										

Length-frequency distributions of key species

In addition to describing the composition of fish assemblages, length frequency distributions for key species were developed to gain more detailed information with respect to the utilisation of the region by particular life stages of these species. The length data shown were obtained from both seine and gill net samples. 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 enable the identification of cohorts, 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.

A. microstoma had a TL range of 17-91 mm. In October 2006, the size distribution comprised a single dominant cohort. There is evidence of a second cohort emerging in November/December 2006 which was subsequently evident 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 (see Noell *et al.* (2009) for size structures).

A. forsteri had a TL range of 26-375 mm. Three or four cohorts were clearly identifiable in most months (Figure 7.4). It appears that *A. 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 TL in its first, second and third years of life, respectively.

R. tapirina had a TL range of 18-355 mm TL across all 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 TL. 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. 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 TL during these months. Catches of *R. tapirina* larger than 150 mm TL were small and sporadic, which suggests these larger fish have low catchability using either seine or gill nets (see Noell *et al.* (2009) for size structures).

A. tamarensis had a TL range of 20-77 mm. Following an estimated spawning period of October to January (based on gonadosomatic data), the smallest size class of 20-25 mm TL began to appear in March and June 2007 and again in June 2008. 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 (see Noell *et al.* (2009) for size structures).

A. hololepidotus ranged in TL from 128-710 mm (Figure 7.5). Although a few of these fish reached up to 710 mm TL, most were within the length range of 180-500 mm TL. The progression of a single mode can be traced from December 2006 (modal length class of 180-200 mm TL) to March 2008 (~400 mm TL). 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.

Small juvenile (100-150 mm TL) *A. 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 *A. butcheri* and *P. urvillii* in this study (105-484 and 40-265 mm TL, respectively) and the small numbers collected using either gear type meant that few conclusions can be drawn for either species with respect to relative success in spawning or recruitment (see Noell *et al.* (2009) for size structures).

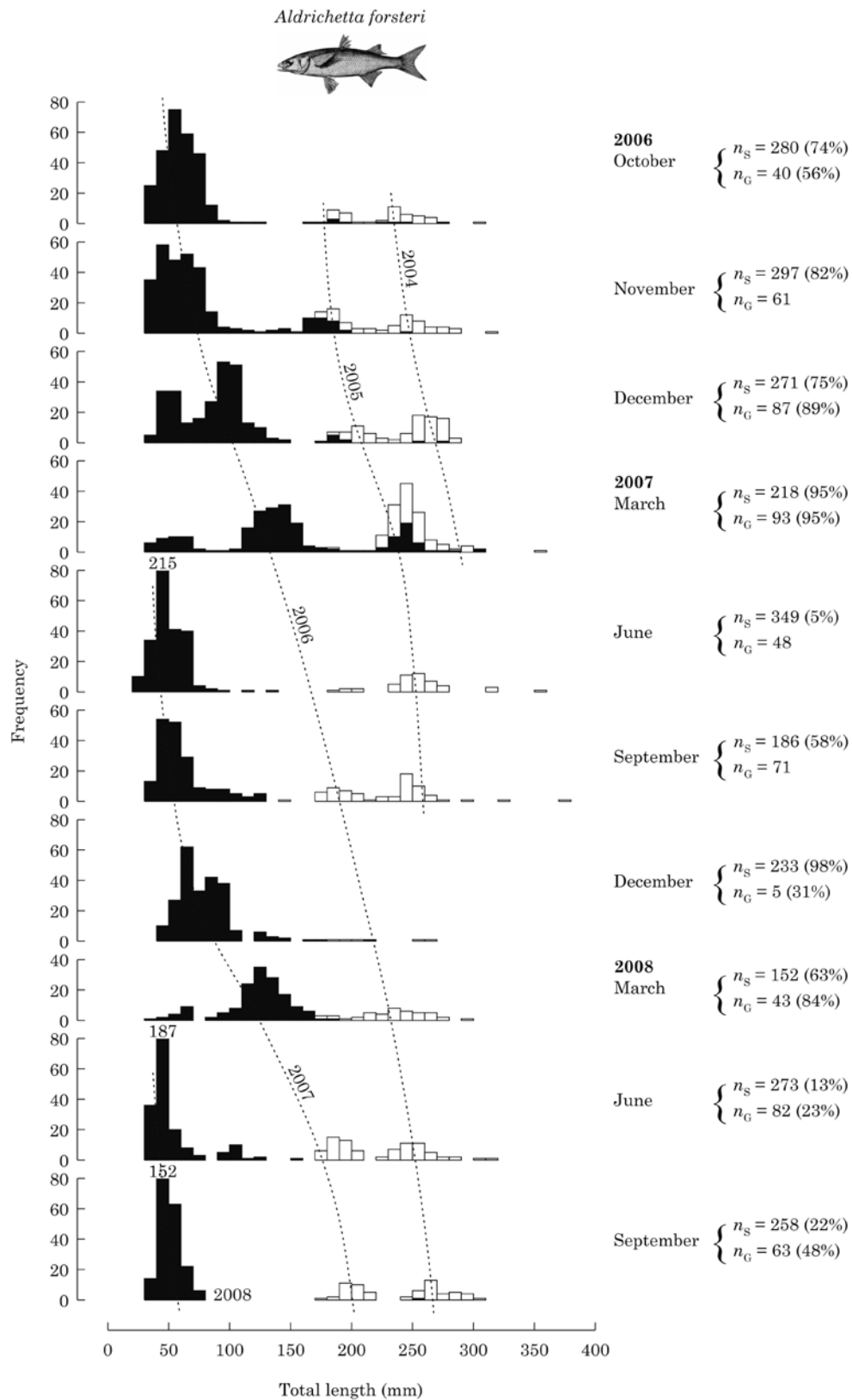


Figure 7.4. Length-frequency histograms for *A. forsteri* collected from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). Dashed lines indicate modal progression of probable year classes. n_s = number of fish collected using seine net, n_g = number of fish collected using gill nets. Percentages in parentheses indicate that a subsample was measured.

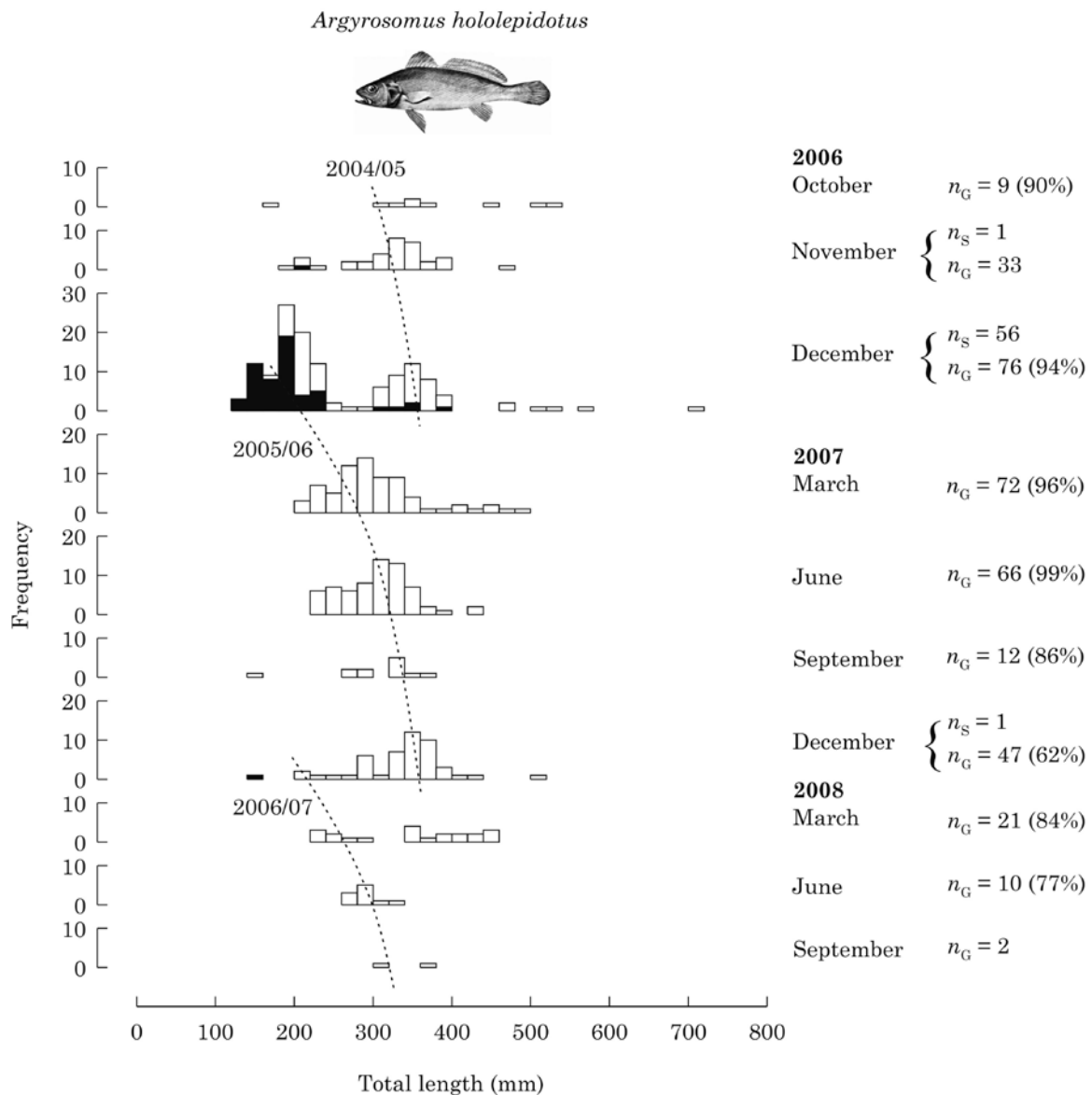


Figure 7.5. Length-frequency histograms for *A. hololepidotus* from the Murray Mouth and Coorong region between October 2006 and September 2008 using seine and gill nets (black and white bars, respectively). Dashed lines indicate modal progression of probable year classes. n_s = number of fish collected using seine net, n_g = number of fish collected using gill nets. Percentages in parentheses indicate that a subsample was measured.

7.3 Reproductive characteristics of key species

Black bream (Acanthopagrus butcheri)

The catch of *A. butcheri* in the Coorong and Murray Mouth region was consistently dominated by female fish throughout the study period. While males were also captured, they were present in very low numbers in most months and absent from catches in December, January and July 2008. See Cheshire *et al.* (2013) for monthly sex ratios.

The monthly GSI for female *A. butcheri* increased from August to November in 2007, suggesting a spring spawning season in the Coorong and Murray Mouth region. Increasing female GSI followed the increase in water temperature early in the season (Figure 7.6a), before dropping substantially in

December 2007 and remaining low for the rest of the sampling period. GSI for males followed a similar pattern to females, increasing from July to November (Figure 7.6b). GSI was highest in males between July and February, although given the relatively small sample size and absence of male fish in December and January; this should be treated with caution.

Mature females ($\geq$ stage 3) were present in samples throughout the sampling period, with the exception of March to May 2006, when no females were collected (Figure 7.7). In July 2007, the majority of females had ripe (stage 4) ovaries, whilst a small percentage ($>20\%$) had developed (stage 3) ovaries. From August to November 2007, the stages varied between developed and ripe. By December only one female was collected, which was at the ripe stage (stage 4). During January and February only resting and developed stage (stage 2 and 3) ovaries were recorded. In June and July 2008, a small number of females were collected, with ovaries being at stages 2 or 3. No spent (stage 5) ovaries were recorded throughout the study period (Figure 7.7).

Half of the population of female *A. butcheri* within the Coorong area were sexually mature at 289 mm TL, whilst the smallest mature female was 270 mm TL (Table 7.4). Half of all males were sexually mature at ≥ 340 mm TL, the smallest mature male was 251 mm TL. Specific parameter estimates for the logistic maturity curves are provided in Cheshire *et al.* (2013).

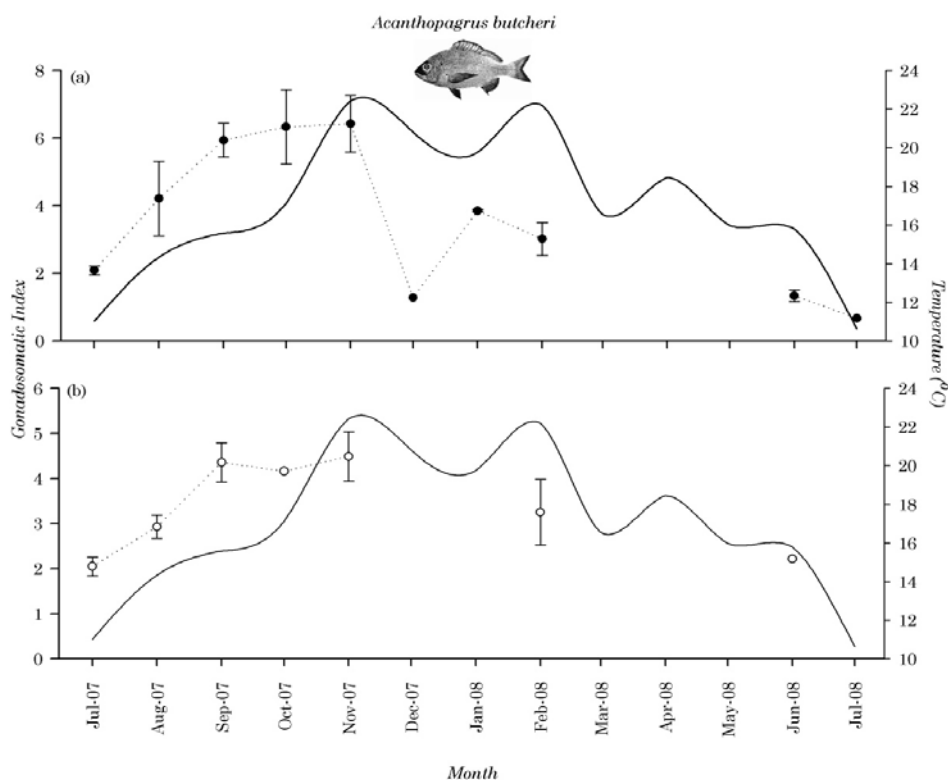


Figure 7.6. Temporal trends in GSI ($\pm$ s.e.) (dotted line) for a) female (n = 91) and b) male (n = 39) *A. butcheri* in the Coorong from July 2007 to July 2008. Solid black line is mean monthly temperature.

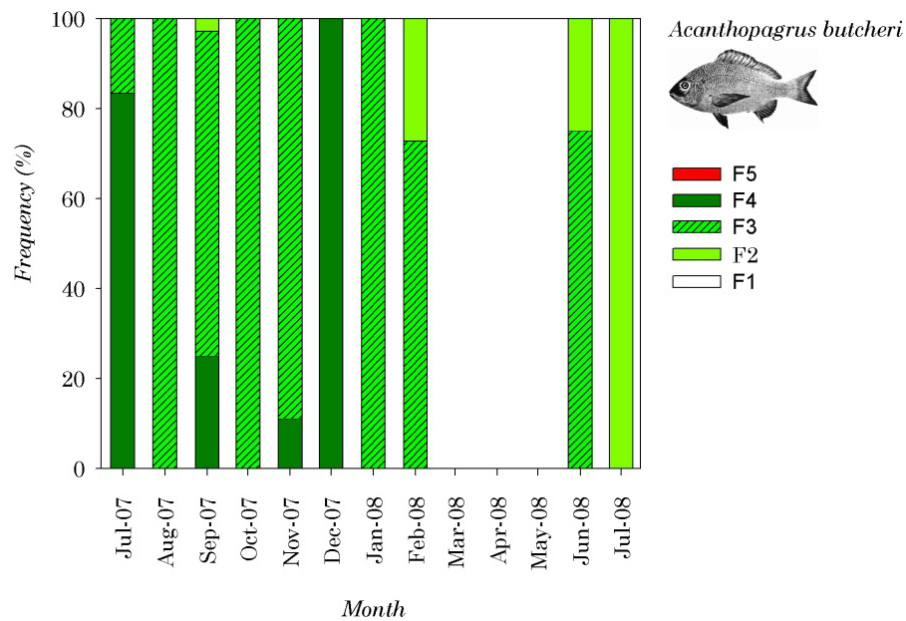


Figure 7.7. Temporal trends in macroscopic stages of gonad development (frequency %) for female *A. butcheri* in the Coorong from July 2007 to July 2008. (n = 91).

Table 7.4. Summary of the parameter estimates for the logistic length at maturity curves for each of the key species.

Species	Sex	n	L ₅₀	SE	95%CL	K	SE	95%CL	R ²
<i>A. butcheri</i>	F	271	289	2.48	284 – 294	0.06	0.008	0.04 – 0.08	0.05
	M	148	340	11.03	316 – 364	0.02	0.004	0.01 – 0.03	0.16
<i>A. forsteri</i>	F	691	256	2.84	250 – 262	0.04	0.005	0.03 – 0.05	0.17
<i>R. tapirina</i>	F	219	203	4.83	192 – 214	0.1	0.048	0.02 – 0.21	0.06
<i>A. tamarensis</i>	F	348	53	1.74	49 – 57	0.15	0.034	0.07 – 0.22	0.18
<i>P. urvillii</i>	F	86	165	1.09	162 – 167	0.13	0.016	0.09 – 0.16	0.02

Yelloweye mullet (Aldrichetta forsteri)

The monthly catches of *A. forsteri* in the Coorong and Murray Mouth region during 2007 and 2008 were typically dominated by female fish. One exception occurred in November 2007, during which time the sample consisted predominantly of male fish. See Cheshire *et al.* (2013) for monthly sex ratios.

GSI for female *A. forsteri* remained high throughout most months except for the period of October–December (Figure 7.8a), and GSI for males followed an almost identical pattern to the females (Figure 7.8b). This suggests that *A. forsteri* has a protracted spawning season across summer/autumn/winter in the Murray Estuary and Coorong.

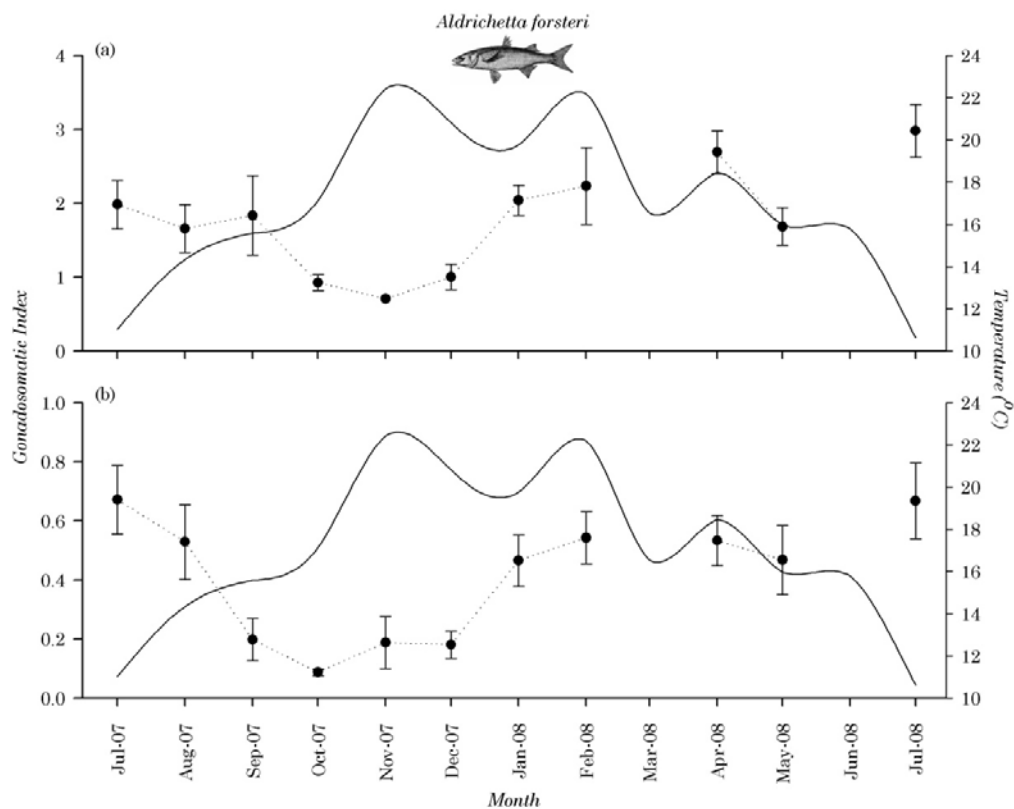


Figure 7.8. Temporal trends in GSI ($\pm$ s.e.) (dotted line) for a) female (n = 479) and b) male (n = 125) *A. forsteri* in the Coorong from July 2007 to July 2008. Solid black line is mean monthly temperature.

Females with developed, hydrated, spent or regressing ovaries ($\geq$ stage 3) were collected throughout the sampling period, although no samples were collected in March and June 2008, and only one female was collected in November 2007 (Figure 7.9). Patterns of ovarian development indicated an extended spawning period of *A. forsteri* with no distinct seasonality.

Half the population of female *A. forsteri* were sexually mature at the size ≥ 256 mm TL, the smallest mature individual was of 226 mm TL (Table 7.4). Insufficient numbers of mature males were collected to estimate size at maturity. The smallest mature male was 220 mm TL.

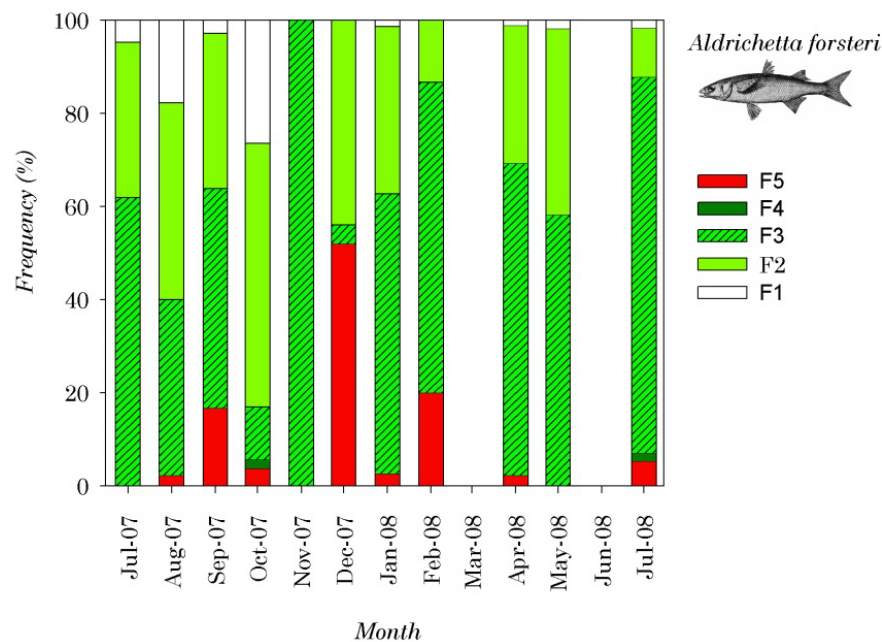


Figure 7.9. Temporal trends in macroscopic stages of gonad development (frequency %) for female *A. forsteri* in the Coorong from July 2007 to July 2008 (n = 479).

Greenback flounder (Rhombosolea tapirina)

The catch of *R. tapirina* from the Coorong and Murray Mouth region during 2007 and 2008 was dominated by female fish. Only three males were collected throughout the entire sampling period. See Cheshire *et al.* (2013) for monthly sex ratios.

GSI for female *R. tapirina* was highest in July 2007 and decreased gradually in the following months (Figure 7.10a). This temporal trend coincided with increasing water temperatures, and suggests that *R. tapirina* in the Coorong and Murray Mouth region is a winter spawner (Figure 7.10a). Female GSI was lowest from November to February, i.e. during the summer months when water temperatures were highest. GSI for males cannot be extrapolated to spawning season as only one individual was collected on three occasions (Figure 7.10b).

Temporal trends in macroscopic staging for female *R. tapirina* suggests that spawning condition was reached (stage 4) and that spawning had occurred (stage 5) during August and September 2007 (Figure 7.11). Following this period, mature ovaries returned to a resting state (stage 3) and immature and developing (stage 1 and 2) ovaries were recorded from November 2007. Regressing (stage 5) ovaries were identified in January; unfortunately no samples were collected between March and May 2008; and fish appeared to be returning to spawning condition in June 2008. These results are generally consistent with the temporal patterns of variation in female GSI.

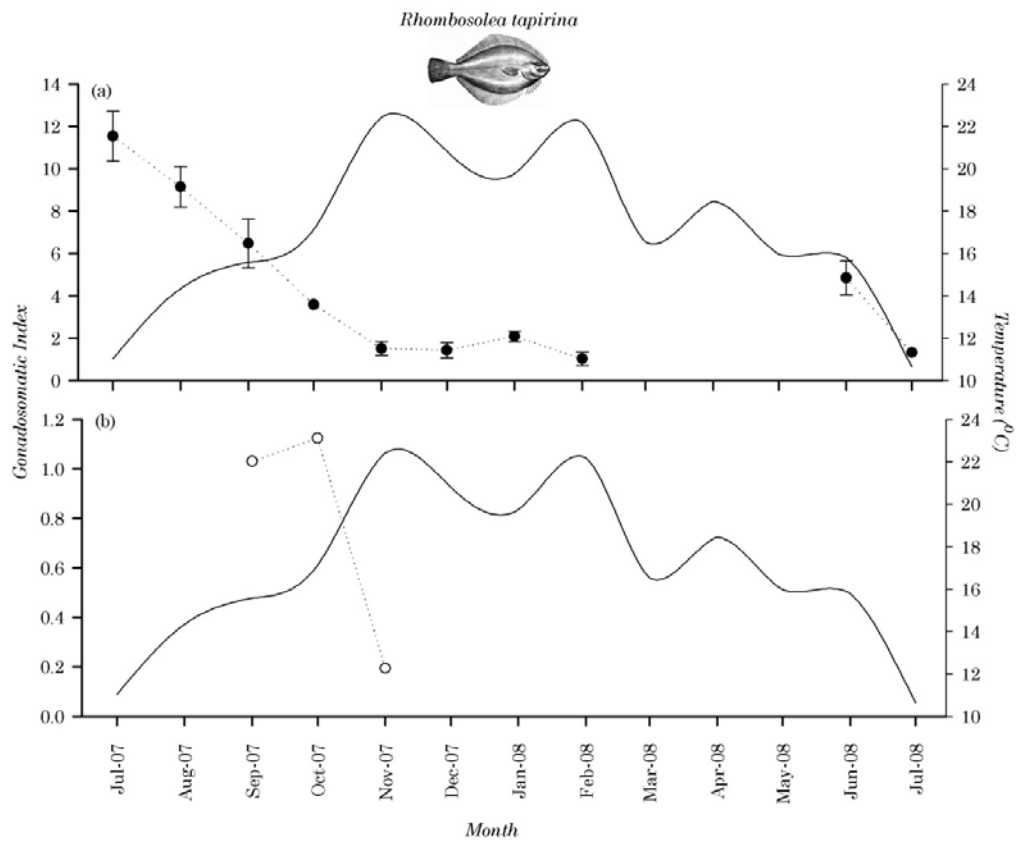


Figure 7.10. Temporal trends in GSI ($\pm$ s.e.) (dotted line) for a) female ($n = 105$) and b) male ($n = 3$) *R. tapirina* in the Coorong from July 2007 to July 2008. Solid black line is mean monthly temperature

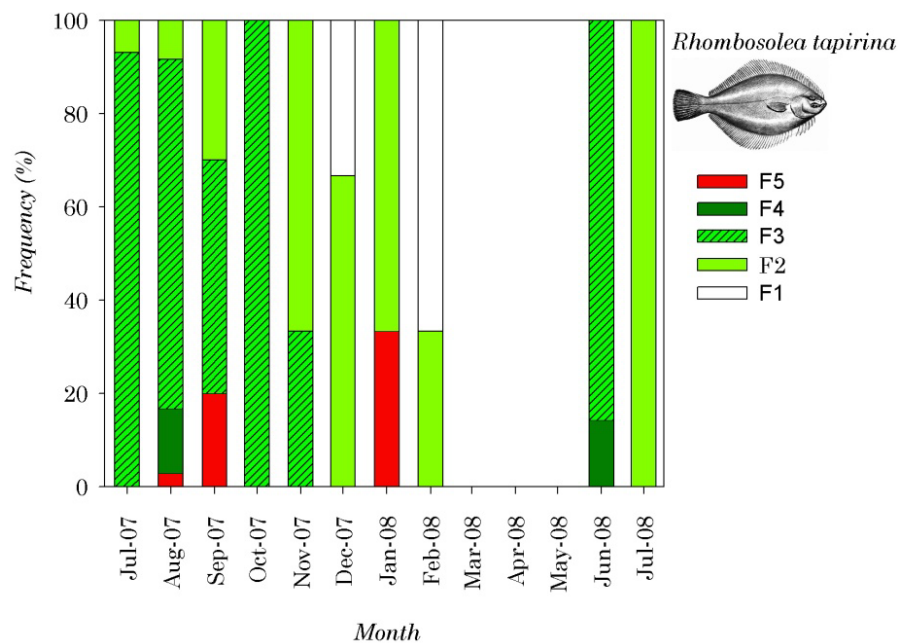


Figure 7.11. Temporal trends in macroscopic stages of gonad development (frequency %) for female *R. tapirina* in the Coorong from July 2007 to July 2008. ($n = 105$)

Half the female population of *R. tapirina* within the Coorong area were sexually mature at ≥ 203 mm, whilst the smallest mature individual recorded was 211 mm TL (Table 7.4). Insufficient numbers of mature males were collected to develop a model to estimate size at 50% maturity.

Tamar goby (Afurcagobius tamarensis)

Catches of *A. tamarensis* from the Coorong and Murray Mouth region were dominated by females in most months, although sex ratios (female: male) approximated 1:1 during December 2007 and April and May 2008. Males were present throughout most of the season, although in low proportions. See Cheshire *et al.* (2013) for monthly sex ratios.

Female GSI for *A. tamarensis* appeared to be high between October and February, generally coinciding with the warmer temperatures (Figure 7.12a), suggesting a spring/summer spawning period. Female GSI declined to the lowest during April and May 2008 (Figure 7.12a). Variation in male GSI followed a slightly different pattern to the females, peaking in November 2007 (Figure 7.12b).

Mature female ($\geq$ stage 3) *A. tamarensis* were present in the estuarine system throughout the study period. Ripe females (stage 4) were recorded in low numbers from August 2007 through to January 2008 suggesting a spring/summer spawning season (Figure 7.13). No regressing (stage 5) ovaries were recorded throughout the sampling period. Immature fish (stage 1) were recorded periodically between October 2007 and July 2008, and formed a large proportion of the females surveyed in April 2008. The spawning period identified by ovarian development is generally consistent with that shown in female GSI patterns

Female *A. tamarensis* within the Coorong area had reached 50% sexual maturity at 53 mm TL, whilst the smallest mature female collected was 45 mm TL (Table 7.4). There were insufficient numbers of mature males collected to develop a model to estimate size at 50% maturity, however, the smallest mature male collected was 65 mm TL.

Congolli (Pseudaphritis urvillii)

The catch of *P. urvillii* was dominated by females in all months throughout the sampling season, with the highest percentage of males recorded in May 2008 (approximately 40%). See Cheshire *et al.* (2013) for monthly sex ratios.

The temporal variation in female GSI for *P. urvillii* indicated that GSI was highest from July to September 2007 (Figure 7.14). Female GSI was low throughout the rest of the season under high temperatures during summer and appeared to rise again in May 2008 as water temperatures decreased (Figure 7.14a). Male GSI followed similar patterns as the females, although due to smaller sample sizes and absence of males in some months, this should be interpreted cautiously (Figure 7.14b).

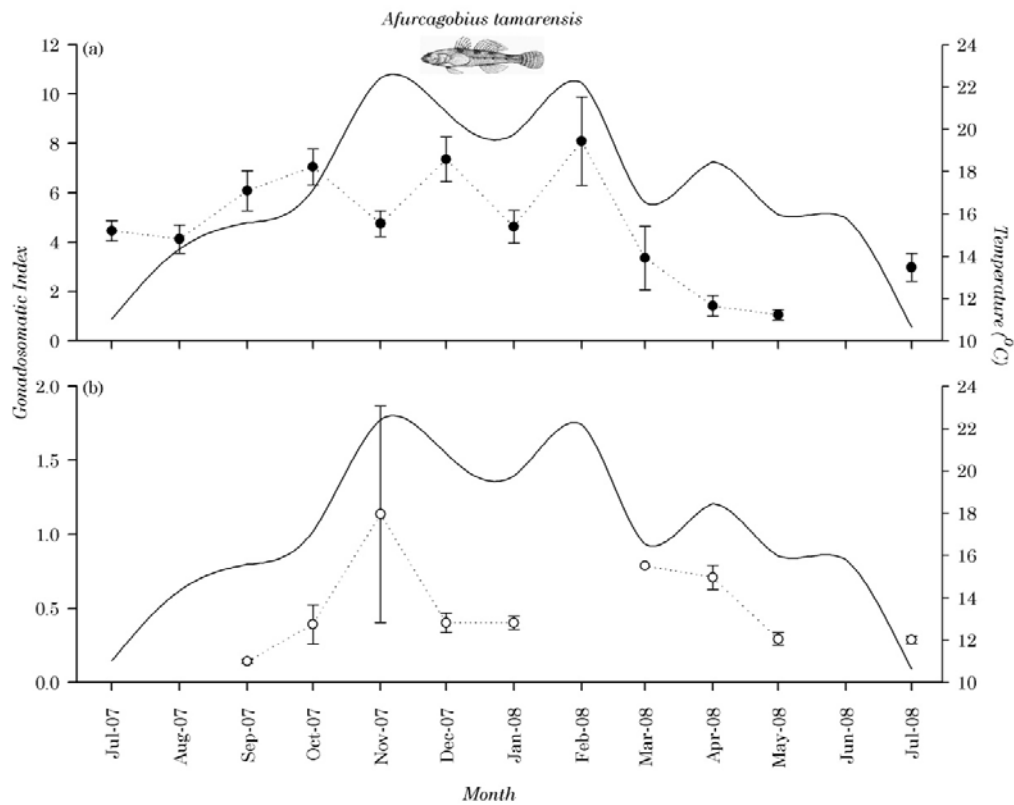


Figure 7.12. Temporal trends in GSI ($\pm$ s.e.) (dotted line) for a) female ($n = 420$) and b) male ($n = 137$) *A. tamarensis* the Coorong from July 2007 to July 2008. Solid black line is mean monthly temperature

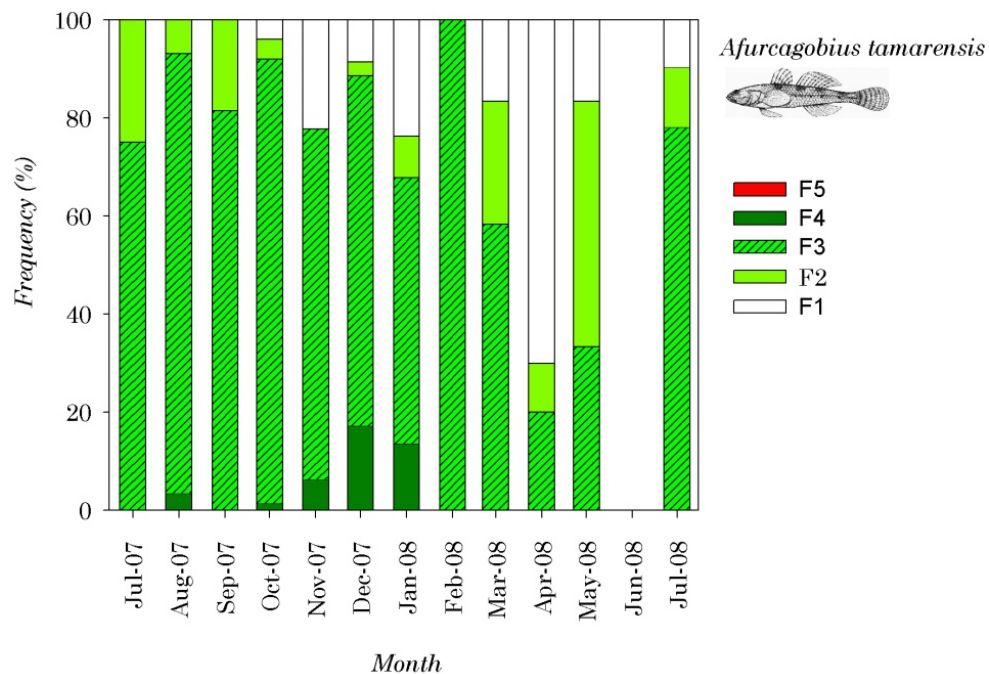


Figure 7.13. Temporal trends in macroscopic stages of gonad development (frequency %) for female *A. tamarensis* in the Coorong from July 2007 to July 2008. ($n = 420$).

Mature female ($\geq$ stage 3) *P. urvillii* were only recorded from July to September 2007, and in April, June and July 2008. From October 2007 to March 2008, only immature and developing ovaries were recorded (Figure 7.15). During July to September 2007 the majority of females collected had developed ovaries. However, no ripe (stage 4) or spent (stage 5) ovaries were recorded. This pattern was consistent with the GSI for females and suggests a winter spawning period for *P. urvillii*.

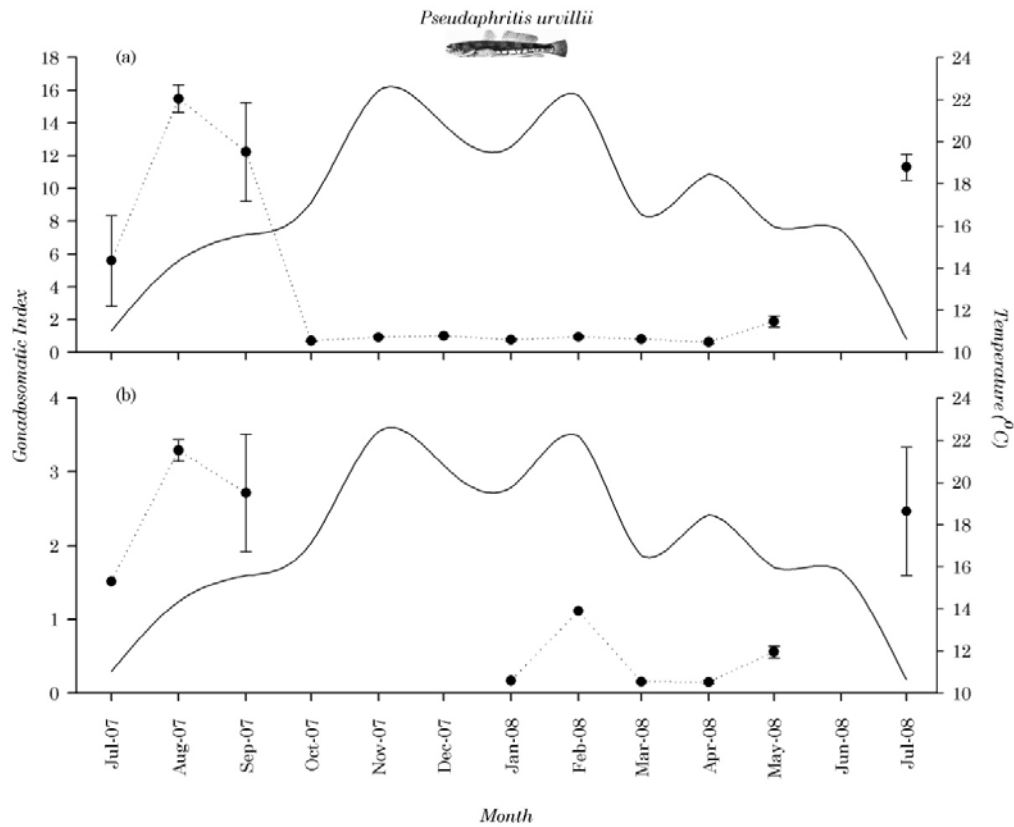


Figure 7.14. Temporal trends in GSI ($\pm$ s.e.) (dotted line) for a) female (n = 364) and b) male (n = 48) *P. urvillii* in the Coorong from July 2007 to July 2008. Solid black line is mean monthly temperature

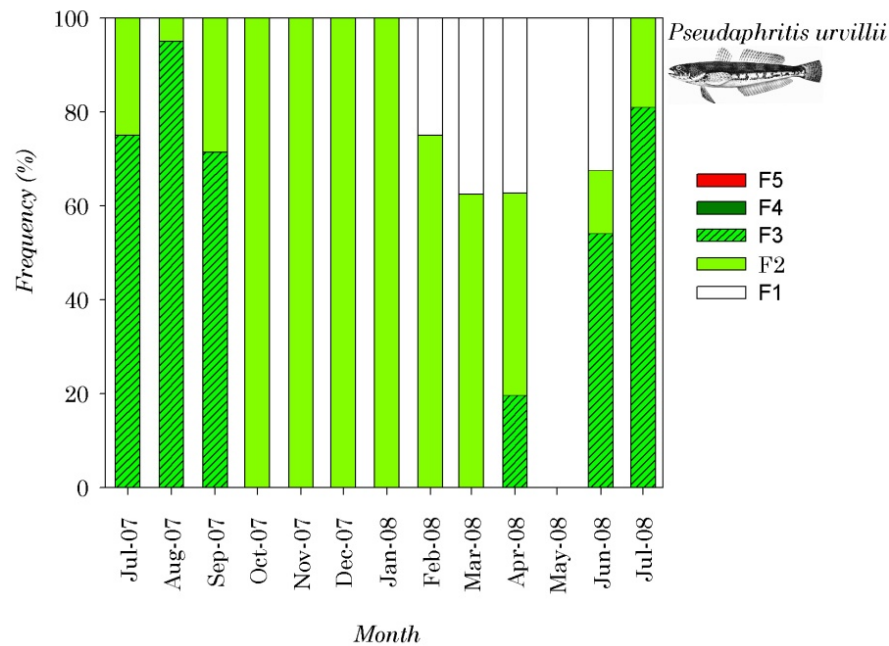


Figure 7.15. Temporal trends in macroscopic stages of gonad development (frequency %) for female *P. urvillii* in the Coorong from July 2007 to July 2008. (n = 364).

On average, female *P. urvillii* were sexually mature at 165 mm TL, the same size of the smallest mature female collected (Table 7.4). There were insufficient numbers of mature males collected to develop a model to estimate size at 50% maturity; the smallest male collected was 103 mm.

Spawning modes

Determination of spawning mode required a comprehensive analysis of the microscopic characteristics of ovaries for individual species. All species were classified as multiple batch spawners (i.e. they release batches of oocytes (eggs) on multiple occasions over a prolonged reproductive period). Full descriptions, including photographs are shown in Cheshire *et al.* (2013).

7.4 Effects of hypersalinity on the survival and distribution of key species

All species displayed tolerance to salinity conditions greater than sea-water (~ 38 ppt), with LC_{50} estimates ranging between 54.4 ppt for *A. hololepidotus* and 100.1 ppt for *P. urvillii* (Figure 7.16; Table 7.5). Relative species tolerances were similar for both temperatures, though lower tolerance values were generally recorded at 23 °C compared to 14 °C. Observed field salinity maxima for each species (Section 7.2), ranged from ~60 ppt for *A. butcheri* to ~130 ppt for *A. microstoma* (Figure 7.16).

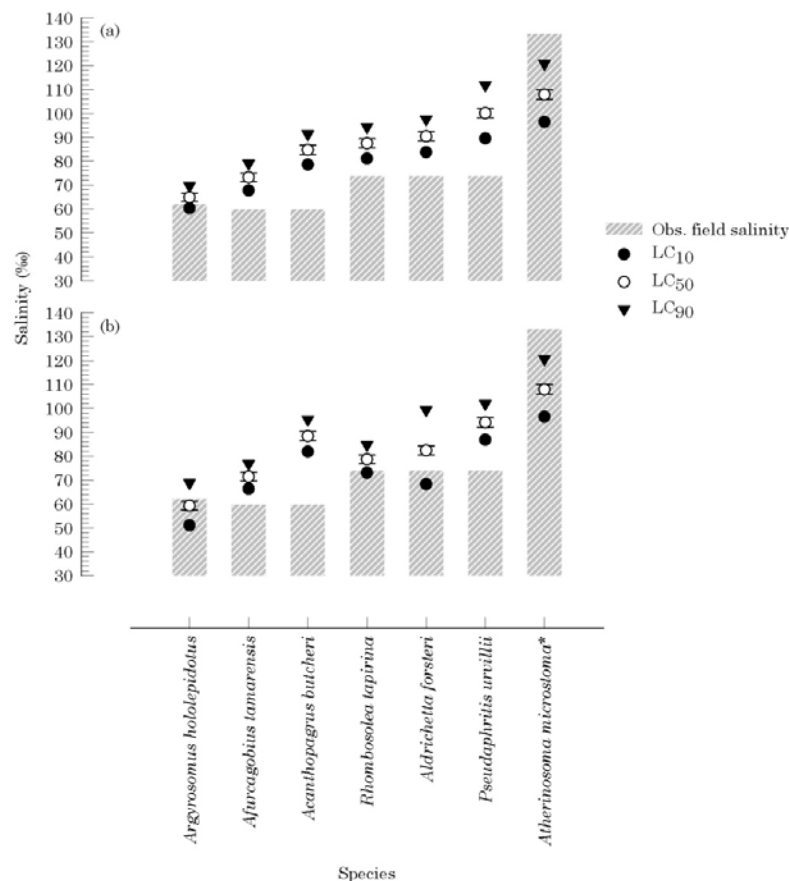


Figure 7.16. Lethal Concentration (LC) range LC_{10} , LC_{50} ($\pm$ standard error) and LC_{90} values for salinity determined at (a) 14 °C and (b) 23 °C for juveniles of six estuarine species of fish, estimated using Probit analysis. Observed field salinity is also shown.

Table 7.5. Summary of LC10, LC50, LC90 estimates (expressed as ppt) and fatal Daily Feeding Response Score (DFRS) for the six key species at 14°C and 23°C temperatures compared to field observations obtained from Section 7.1 and 7.2. *possibly affected by another unknown water quality factor. *from Lui (1969).

Vulnerability to high salinity	Species name	14 °C				23 °C				Maximum observed field salinity
		LC ₁₀	LC ₅₀	LC ₉₀	Fatal DFRS	LC ₁₀	LC ₅₀	LC ₉₀	Fatal DFRS	
Most	<i>Argyrosomus hololepidotus</i>	60.3	64.4	69.6	62	51.1	59.3	68.8	66	62.4
	<i>Afurcagobius tamarensis</i>	67.7	73.2	79.1	72	66.3	71.4	76.8	72	60.1
	<i>Acanthopagrus butcheri</i>	78.6	84.7	91.4	82	81.8	88.4	95.3	86	60.1
	<i>Rhombosolea tapirina</i>	81.1	87.5	94.4	82	72.9	78.6	84.7	78	74.1
	<i>Aldrichetta forsteri</i>	83.8	90.5	97.6	88	68.3	82.4*	99.4	90	74.1
	<i>Pseudaphritis urvillii</i>	89.5	100.1	111.9	88	86.9	94.1	101.9	88	74.1
Least	<i>Atherinosoma microstoma</i> *		108		-		108		-	133.5

Comparative vulnerability to hypersaline conditions

Maximum salinities occupied by individual species based on field observations (Section 7.1 and 7.2) were compared to LC_{50} values for all species as determined in this study (Table 7.5). Estimated relative order of vulnerability to salinity for each species was identified; *A. hololepidotus* was considered to be the most vulnerable, whilst *A. microstoma* the most tolerant.

Salinity tolerance thresholds and relative distribution for individual species

Argyrosomus hololepidotus: At 14 °C, *A. hololepidotus* mortalities occurred between 58 to 70 ppt (Figure 7.17a), with an LC_{50} estimate of 64.4 ppt. At 23 °C, mortalities occurred between 50 to 74 ppt with an LC_{50} estimate of 59.3 ppt (Figure 7.17b). Daily Feeding Response Scores (DFRS) indicated that feeding rates decreased at approximately 53 ppt in both temperature treatments, and had completely ceased at approximately 62 ppt (14 °C) and approximately 66 ppt (23 °C) (Table 7.5). Stress Scores (SS) were initially higher at 14 °C than at 23 °C; but rose in both treatments at approximately 52 to 54 ppt with colouration darkening at approximately 60 ppt and general inactivity occurring at 60 ppt (14 °C) and 64 ppt (23 °C). The field distribution of *A. hololepidotus* was generally within 40 km of the Murray Mouth with occasional catches taken between March and September 2007 in salinity concentrations exceeding the LC_{50} at 23 °C (Figure 7.18).

Afurcagobius tamarensis: At 14 °C, mortalities occurred from 70 to 72 ppt, with an LC_{50} estimate of 73.2 ppt (see McNeil *et al.* (2013) for detailed figure). At 23 °C, mortalities occurred in salinities from 66 to 72 ppt and the estimated LC_{50} was 71.4 ppt (Table 7.5). DFRS decreased at 66 ppt in 14 °C, and 58 ppt in 23 °C, this pattern continued steadily, until feeding ceased entirely in both treatments when ambient salinities reached 72 ppt (Table 7.5). SS initially began to rise at approximately 52 to 54 ppt in both temperatures and change in colouration started to occur at approximately 58 ppt, followed by general inactivity at approximately 70 ppt in both treatments. The observed field distribution of *A. tamarensis* was generally within 20 km of the Murray Mouth within salinity conditions well within their tolerance range.

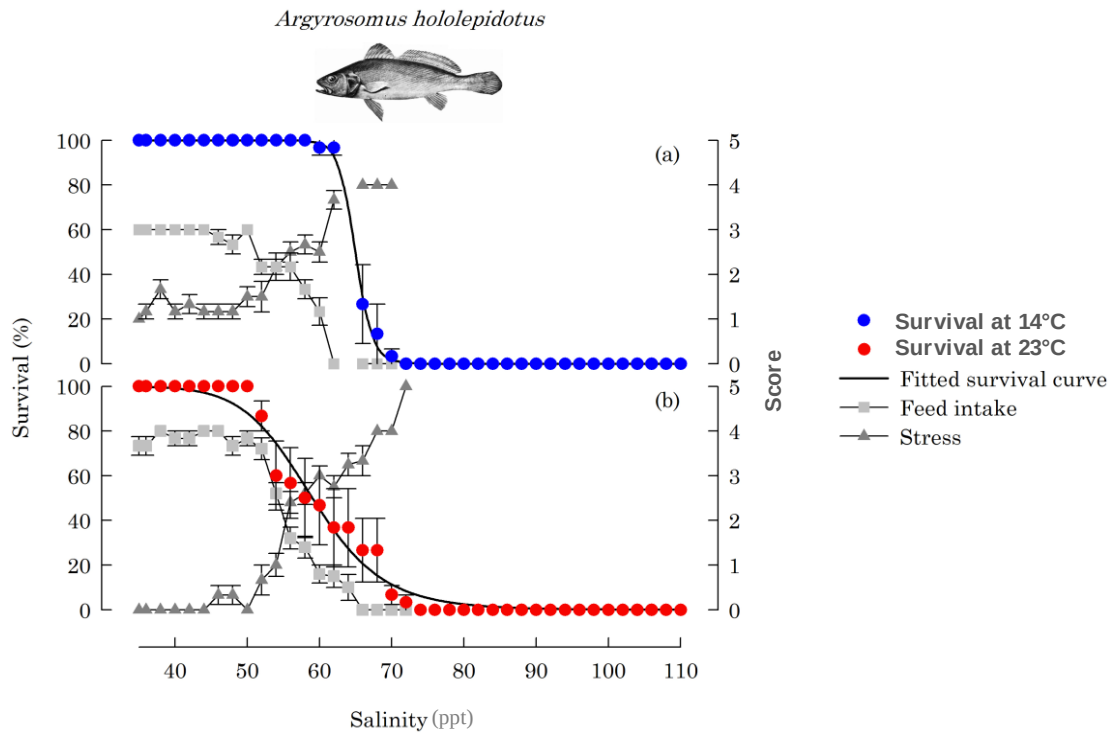


Figure 7.17. Survival, feeding vigour and indications of stress with increasing salinity (a) 14 °C ('winter') and (b) 23 °C ('summer') temperatures for juvenile *A. hololepidotus*.

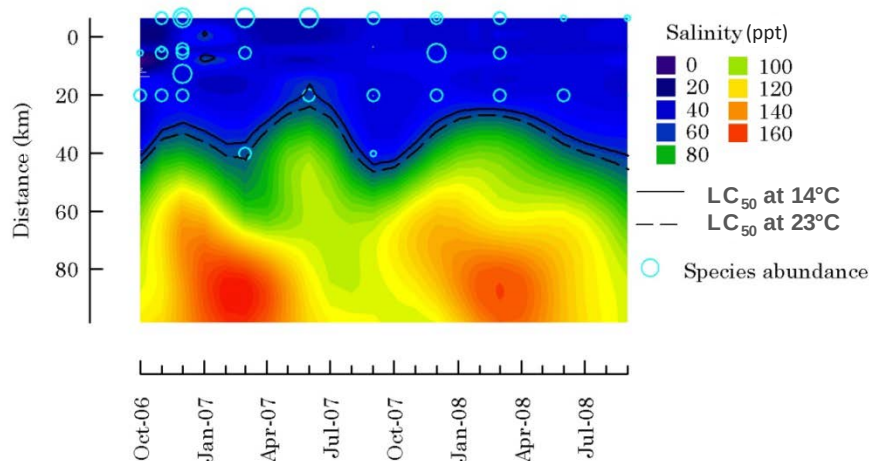


Figure 7.18. Salinity concentration with distance from the Murray Mouth against time; with LC_{50} values determined at 14 °C and 23 °C and field observations ($\circ$ = relative abundance, from Section 6.2) plotted for juvenile *A. hololepidotus*.

Acanthopagrus butcheri: At 14 °C, mortalities occurred at approximately 80 to 86 ppt, the LC_{50} estimate was 84.7 ppt. In contrast, at 23 °C mortalities occurred between 82 and 90 ppt, the estimate of LC_{50} was 88.4 ppt (Table 7.5). DFRS decreased between 76 and 78 ppt for both temperatures, and continued to decline until feeding ceased at 82 and 86 ppt for 14°C and 23° C treatments, respectively (Table 7.5). SS initially began to rise at 74 ppt for both temperature treatments, which included darkening colouration and fish generally became inactive at 74 ppt at 23 °C and 80 ppt at 14 °C. *A. butcheri* was generally collected within 20 km of the Murray Mouth. Field salinities in these areas did not approach LC_{50} estimates. The schematic map showing the temporal variability in distribution and abundance for this species is shown in McNeil *et al.* (2013).

Rhombosolea tapirina: Mortalities of juvenile *R. tapirina* occurred at 14 °C between 78 and 92 ppt, whilst estimated LC_{50} was 87.5 ppt. In 23 °C, mortalities occurred between 68 and 82 ppt, whilst the LC_{50} was 78.6 ppt (Table 7.5). DFRS declined from ~66 to 68 ppt for both temperature treatments, and continued to decrease until 82 ppt at 14 °C and 78 ppt at 23 °C (Table 7.5). SS initially began to rise between 74 and 78 ppt in both temperatures, and general inactivity became apparent in 76 ppt at 14 °C and 82 ppt at 23 °C. *R. tapirina* were frequently caught up to 50 km from the Murray Mouth. Whilst they were often distributed in close proximity to saline waters, they were never caught in salinities exceeding the LC_{50} thresholds identified here, yet they were regularly caught in salinities that exceeded their LC_{10} threshold suggesting that some individuals of this species may enter and tolerate hypersaline waters (Figure 7.19).

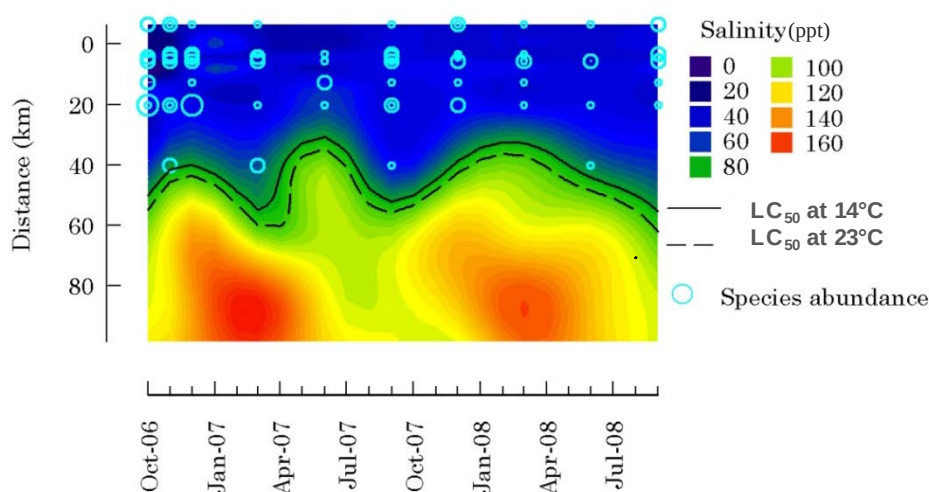


Figure 7.19 Salinity concentration with distance from the Murray Mouth against time; with LC_{50} values determined at 14 °C and 23 °C and field observations (° = relative abundance, from Noell *et al.*, 2009) plotted for juvenile *R. tapirina*.

Aldrichetta forsteri: At 14 °C, mortalities occurred between approximately 82 and 90 ppt, with an LC_{50} estimate of 90.5 ppt. At 23 °C, 20% of mortalities occurred between 50 and 70 ppt, with the majority occurring after 86 ppt, the estimated LC_{50} was 82.4 ppt (Table 7.5). At 14 °C, DFRS started to decline from 84 ppt and continued to decline until feeding ceased completely at 88 ppt. Whilst at 23 °C, DFRS declined from 70 ppt and feeding did not cease until complete mortality at 90 ppt. SS initially began to increase with darkening colouration observed from 74 to 76 ppt at both temperatures and reduced activity was noticeable at approximately 84 to 86 ppt. *A. forsteri* were recorded up to 40 km from the Murray Mouth. In June of 2008, this species was collected near hypersaline waters, but were never caught in salinities matching or exceeding the LC_{50} thresholds. The schematic map showing the temporal variability in distribution and abundance for this species is shown in McNeil *et al.* (2013).

Pseudaphritis urvillii: At 14 °C, mortalities occurred between 92 and 104 ppt and the estimated LC_{50} was 100.1 ppt. At 23 °C, mortalities occurred between 84 and 98 ppt, with an LC_{50} estimate of 94.1 ppt (Table 7.5). DFRS started to decrease at 82 ppt at 14 °C and 78 ppt at 23 °C, and continued to decrease

steadily with exposure. Fish ceased feeding at 88 ppt at both 14 °C and 23 °C. At 14 °C, SS began to rise at 68 ppt and darkening colouration was evident at 70 ppt. At 23 °C, SS began to increase at 74 ppt and darkened colouration was evident at 76 ppt. Reduced activity was noticeable after exposure to 88 ppt at both temperatures. The observed field distribution of *P. urvillii* was within 40 km of the Murray Mouth and largely within 20 km. Ambient salinity was in all cases well below the LC_{50} estimates for this species.

***A. microstoma*:** Juvenile *A. microstoma* were collected up to 90 km from the Murray Mouth under field salinities greatly exceeding the LC_{50} estimates identified by Lui (1969) using direct transfer methodologies (Figure 7.20). The highest abundances were recorded in salinities below the estimated LC_{50} , closer to the Murray Mouth; however, fish were recorded in ambient salinities up to 130 ppt exceeding even the LC_{90} threshold calculated for this species.

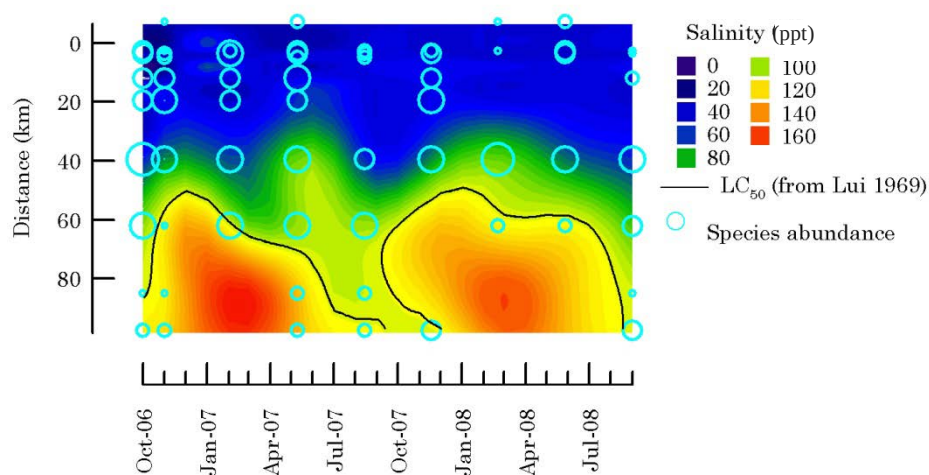


Figure 7.20. Salinity Concentration with distance from the Murray Mouth against time; with LC_{50} values determined at by Lui (1969) and field observations (° = relative abundance, from Section 6.2) plotted for juvenile *A. microstoma*.

7.5 Fishery production relative to freshwater inflows for key fish species

Description of time series

The time series for monthly catch of the species groups between July 1984 and June 2008 and the corresponding number of areas fished are shown in Figure 7.21. Despite the confidentiality provisions applied to the data, monthly catches of the species groups fluctuated greatly in any given year. Periodic peaks in catches suggested seasonality in catches of *A. butcheri*, *A. hololepidotus*, *R. tapirina* and, to a lesser extent, *A. forsteri*. Relatively large catches were taken in October 1984, September 1985 and September 1986 for *A. butcheri* (>8,000 kg), March and December 2001 for *A. hololepidotus* A (>28,000 kg), and April 1991 for *R. tapirina* (>14,000 kg). A general reduction in the number of areas that were fished across the time series is also apparent for each species group (Figure 7.21).

Similarly, the flow time series exhibits large intra-annual variation, and the peak monthly volumes occur on a seasonal basis (Figure 7.22a). Monthly flow volumes were particularly high (>2,500 GL) in

November 1990, and January and December 1993. The study region has been subjected to several droughts (defined here as periods of at least six months with zero flows) over the 24-year time series; however, these have become more frequent and protracted since January 2002. Furthermore, the few flows that intersperse these recent drought periods are relatively low compared to the pre-drought period (i.e. prior to 2002).

It appears that the frequency and magnitude of flows have a direct impact on the spatial extent of the study region that comprises brackish water (0.5-29.9 ppt salinity). Therefore, as a consequence of the extensive drought periods since 2002, brackish areas diminished to the point that the study region almost exclusively comprised saline (30-49.9 ppt) and hypersaline (≥ 50 ppt) waters during this 'drought' phase, with salinities reaching unprecedented levels (i.e. 200 ppt on one occasion) in the South Lagoon (Figure 7.22b).

Mann-Whitney *U*-test results revealed significant differences in underlying distributions of mean monthly catch (using median values as the measure of central tendency) between pre-drought and drought phases for *A. forsteri*, *A. hololepidotus* B and *R. tapirina*, whereby catches for *A. forsteri* and *R. tapirina* were significantly reduced during the drought phase, whilst *A. hololepidotus* B catch significantly increased (Table 7.6). Significant differences were also found for each of the species groups (except *A. hololepidotus* B) with respect to the number of areas fished and number of active licences contributing to catch, all of which were reduced during the drought phase (by 1-2 areas fished and 3-5 active licences).

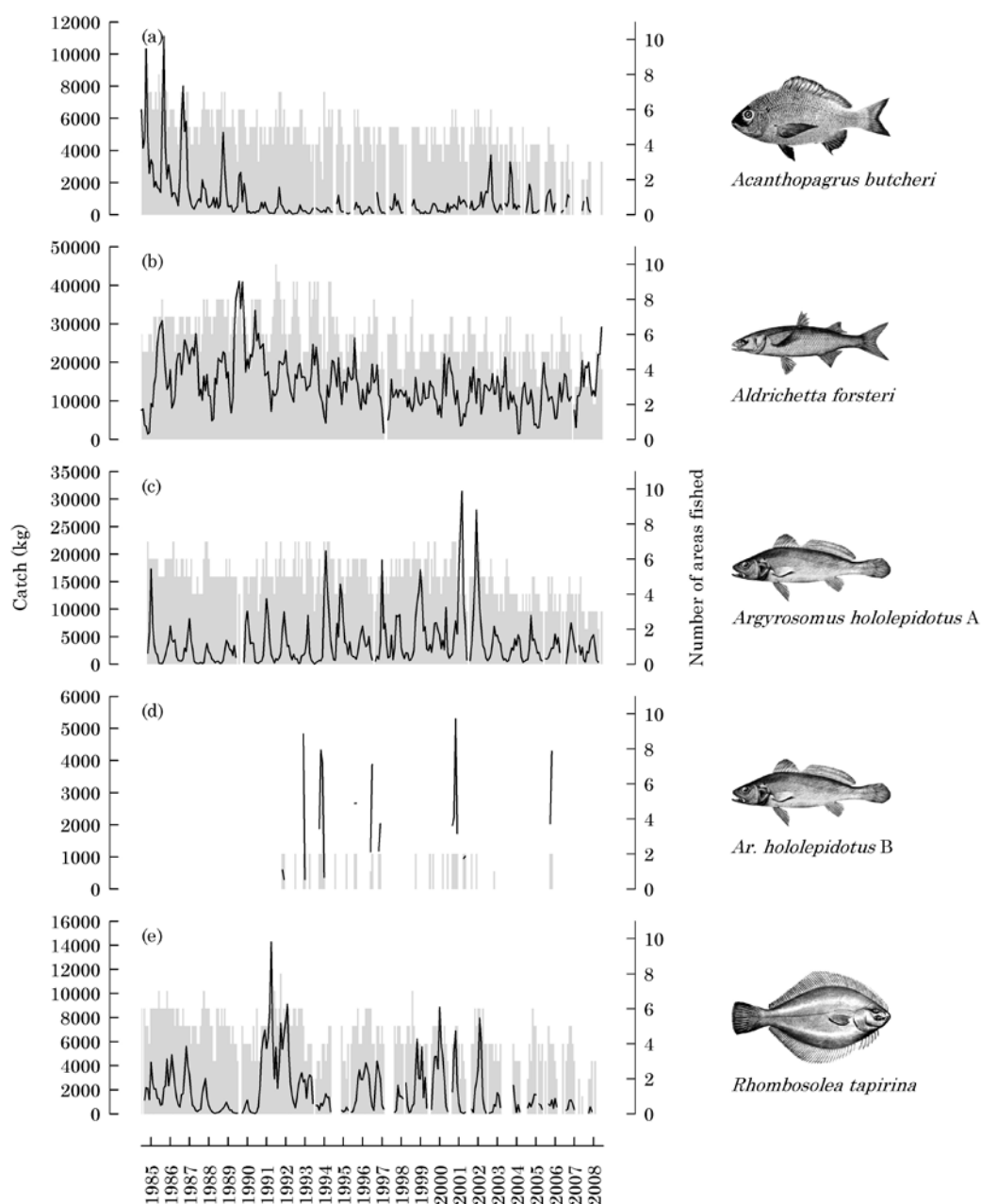


Figure 7.21. Monthly time series of catch (kg) of (a) *Acanthopagrus butcheri*, (b) *Aldrichetta forsteri*, (c) *Argyrosomus hololepidotus* A (inside the Murray Mouth), (d) *A. hololepidotus* B (outside the Murray Mouth) and (e) *Rhombosolea tapirina* from the Lakes and Coorong Fishery between July 1984 and June 2008. Also shown is the number of areas fished (out of a total of 11, except for *A. hololepidotus* A and *A. hololepidotus* B, which are taken from a total of 9 and 2 areas, respectively). Note: where catch represents <5 licence holders, this data is confidential and is therefore omitted from the graph.

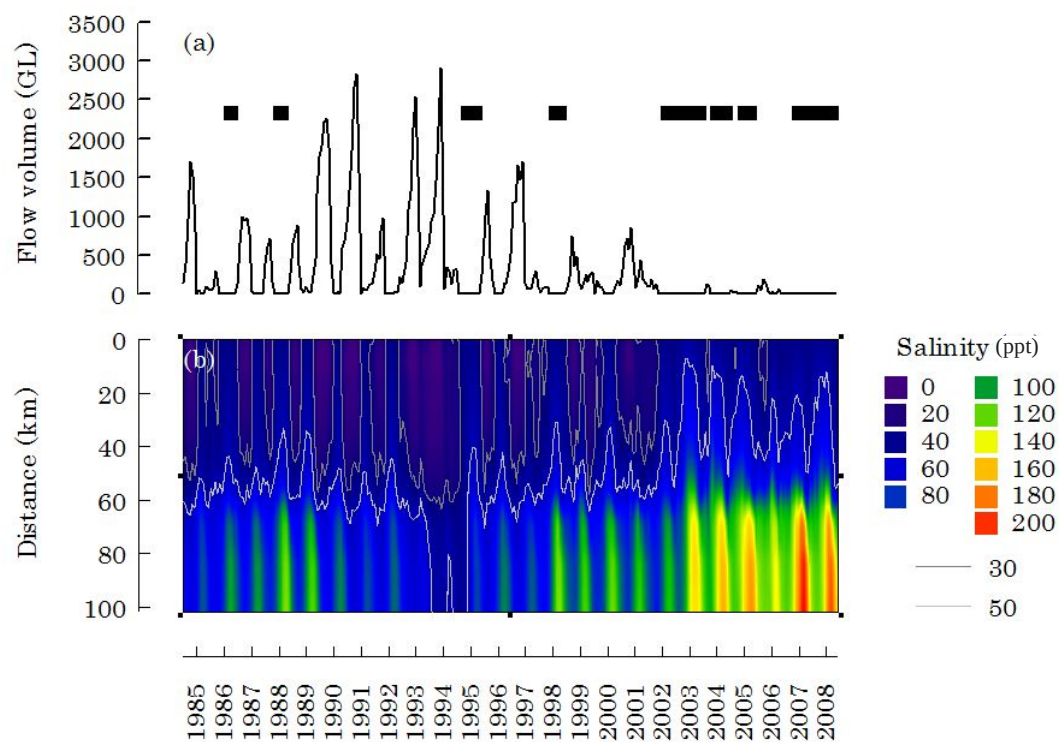


Figure 7.22. Monthly time series of (a) flow volume (GL) across the barrages, with corresponding drought periods ≥ 6 months, and (b) model-interpolated salinities (ppt) throughout the Murray Mouth, North Lagoon and South Lagoons between July 1984 and June 2008. Distance (km) refers to the south-easterly distance along the Coorong from the Murray Mouth. Salinity contours for 30 ppt and 50 ppt are shown to identify brackish (0.5-29.9 ppt), saline (30-49.9 ppt) and hypersaline (≥ 50 ppt) boundaries along the Coorong. Note: The North and South Lagoons are divided by significant reductions in channel width and depth near Parnka Point at ~ 55 km from the Murray Mouth.

Table 7.6. Results of two-sample Mann-Whitney *U*-test for difference in mean monthly catch, number of areas fished and number of active licences between pre-drought (before 2002) and drought (2002 onward) phases from July 1984 to June 2008. Median values are presented. Abbreviations: *n*, number of months; *Z*, *Z*-statistic. Note: the absolute value of the *Z*-statistic is used since *U* is approximately normally distributed for large samples (Zar 2009).

Species group	Median values		Z
	Pre-drought (n = 210)	Drought (n = 78)	
Total catch (kg)			
<i>A. butcheri</i>	397	325	-0.957
<i>A. forsteri</i>	14,191	11,682	-3.355***
<i>A. hololepidotus</i> A	2,246	2,247	-0.345
<i>A. hololepidotus</i> B	117	333	-2.830**
<i>R. tapirina</i>	1,107	343	-5.041***
No. areas fished			
<i>A. butcheri</i>	5	3	-8.858***
<i>A. forsteri</i>	6	5	-8.005***
<i>A. hololepidotus</i> A	5	4	-9.139***
<i>A. hololepidotus</i> B	1	1	-1.257
<i>R. tapirina</i>	5	3	-7.190***
No. licences			
<i>A. butcheri</i>	10	6	-6.553***
<i>A. forsteri</i>	14	10	-6.427***
<i>A. hololepidotus</i> A	12	9	-5.784***
<i>A. hololepidotus</i> B	2	2	-1.760
<i>R. tapirina</i>	10	5	-6.068***

P* < 0.01; *P* < 0.001.

The spectral density plot of monthly catch for each of the species groups reveals a peak at a frequency of 0.083, which corresponds to 12 months (i.e. 1/0.083) (Noell and Ye 2013). We conclude from this that the monthly catch series exhibit periodic behaviour, and that the development of time series models for all species groups should consider seasonal models with a monthly periodicity.

Seasonality of monthly catch for the species groups were suspected from visual examination of the time series plots, and then confirmed through spectral analysis techniques. Details of this seasonality, in terms of distinctiveness and timing, were determined by isolating the seasonal adjustment factor (SAF) of each time series, along with other components, through a seasonal decomposition procedure (refer to Noell and Ye (2013) for a more detailed explanation).

Mean monthly catches were largest in early spring (September) for *A. butcheri*, summer (January) for *A. hololepidotus* A, and late spring (November) for *A. hololepidotus* B and *R. tapirina* (Figure 7.23). Seasonality was pronounced in these species groups, as their maxima were at least 100% greater than the mean monthly catch for the respective species group obtained over the 24-year time series (except for *R. tapirina*, where the November catch was 83% greater than the overall mean). Seasonality was relatively weak for *A. forsteri*, where mean monthly catch only deviated <30% from the overall mean. In comparison, mean monthly flow volumes across the barrages were highest during spring (September to November), and 99% greater than the overall mean.

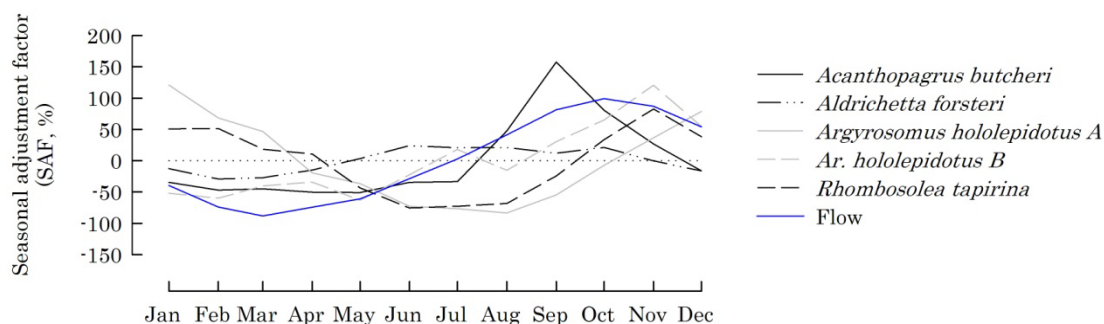


Figure 7.23. Seasonal adjustment factor (SAF, %) of flow and monthly catch of *Acanthopagrus butcheri*, *Aldrichetta forsteri*, *Argyrosomus hololepidotus* A (inside the Murray Mouth), *A. hololepidotus* B (outside the Murray Mouth) and *Rhombosolea tapirina* from the Lakes and Coorong Fishery. The SAF for each calendar month represents the percentage above/below the mean monthly catch obtained between July 1984 and June 2008.

Univariate ARIMA and Transfer Function (TF) models for key species

For the development of a model for any dependent time series, the modelling software ‘Expert Modeler’ only identifies those models whose parameters and coefficients are statistically significant. The best model for that series is then selected based on goodness-of-fit.

Once a univariate ARIMA model (Type A model) was established for catch of a species group, we systematically selected flow volume and catches of other species groups as candidate predictor series’ for the development of TF models (Type B, C, D models). In doing so, we considered the univariate model a baseline to assess whether the inclusion of the predictor series in TF models offer greater predictive power than previous catches of the dependent series alone.

To facilitate the interpretation of models and complement the model descriptions shown below including the differences between model types, comprehensive model output summary tables are arranged for each species group and are shown in Noell and Ye (2013). In addition, all graphical comparisons between observed and model-predicted catches of the different species groups are arranged by model type and are shown in Noell and Ye (2013).

***Rhombosolea tapirina*:** The monthly catch of *R. tapirina* was not modelled successfully using any of the ARIMA time series modelling techniques presented in this study. Either the Type A or D model was not correctly specified by virtue of its significant Q-value or a Type B or C model could not be identified.

***A. butcheri*:** Mean monthly catch for *A. butcheri* was successfully modelled based on previous catches alone (Type A model). The catch time series for *A. butcheri* was natural log-transformed to stabilise variance, and seasonal differencing applied in order to account for the decreasing trend resulting from relatively large periodic catches in the 1980s. Catch at time t is influenced by catch at time $t-1$ as indicated by a non-seasonal AR parameter with an order of 1, and is also affected by the deviation of the series mean at time $t-12$ as indicated by a seasonal term with order 1 (= 12 months).

For the development of Type B and C models, monthly flow was selected as the input series to (partly) predict the catch of a species group (along with previous catches). Both model outputs for *A. butcheri* identified no predictors, which indicate that no model could be identified that improved on the univariate model for this species.

Type D models build upon Type C models with the inclusion of catches of other species groups as potential predictors, particularly given that the Lakes and Coorong Fishery is a multi-species fishery. Whilst the Type D model identified season-specific flows (August–December), and catches of *A. hololepidotus* B and *R. tapirina* as predictors of catch of *A. butcheri*, the coefficients of the model parameters all approached zero, which means they have a negligible effect.

A. forsteri: The Type A model for the *A. forsteri* catch series could not be correctly specified, by virtue of a significant *Q*-statistic.

The Type B model for *A. forsteri* revealed that catch is partly predicted by flows during the same month. Since there is no confounding delay before the predictor series has an influence, the *Num* coefficient (2.423, $P < 0.001$) indicates that, at time t , every 1 GL of freshwater discharged across the barrages leads to an additional catch of *A. forsteri* of 2.4 kg. The catch of *A. forsteri* is also influenced by non-seasonal MA orders of 1–4 and a seasonal AR order of 1. An estimated 63% of the total variation in the series is explained by this model.

No Type C model could be identified for *A. forsteri*.

The Type D model identified that catch of *A. forsteri* is partly predicted by *A. hololepidotus* A catch during the same month. As for the Type B model for *A. forsteri*, this relationship can be quantified. The *Num* coefficient (-0.268, $P < 0.001$) indicates that, at time t , every 1 kg of *A. hololepidotus* A that is caught corresponds with a reduction in catch of *A. forsteri* by 0.3 kg. The Type D model for *A. forsteri* has only a slightly higher r^2 and improved BIC measure compared to the Type B model.

A. hololepidotus A: The Type A model for catch of *A. hololepidotus* A had non-seasonal AR orders of 1 and 2, a seasonal AR order of 1 and a seasonal MA order of 1. This model explains an estimated 86% of the total variation in the *A. hololepidotus* A catch series.

The Type B model for catch of *A. hololepidotus* A indicate that catch is partly predicted by concurrent flows and flows of the 1st and 2nd lagged months (coefficients reveal that the flow-catch relationship is negative at t and $t-1$), and by deviations in the 1st and 2nd lagged months from the series mean. The catch of *A. hololepidotus* A is also influenced by non-seasonal AR orders of 1 and 2 and non-seasonal MA orders of 9 and 10. The Type B model for *A. hololepidotus* A is a poorer fit to the catch series (in terms of r^2 and BIC measure) compared to the Type A model.

Type C models were successfully developed only for *A. hololepidotus* species groups A and B, therefore the season-specific flow data for this species refers to the spawning season of November–March. The catch model for *A. hololepidotus* A indicate that catch is partly predicted by season-specific flow at times t and $t-1$, and by deviations at times $t-1$ and $t-2$ from the series mean. As for the Type B model,

the coefficients for *Num* orders 0 and 1 for *A. hololepidotus* A are both negative. The catch of *A. hololepidotus* A is also influenced by a non-seasonal AR order of 1, a non-seasonal MA order of 9, a seasonal AR order of 1 and a seasonal MA order of 1. The Type C model for *A. hololepidotus* A has only a slightly improved BIC measure compared to the Type A model.

A Type D model for the *A. hololepidotus* A catch series could not be correctly specified.

A. hololepidotus B: The Type A model for catch of *A. hololepidotus* B has a non-seasonal order of 1 and a seasonal AR order of 1. This model explains an estimated 82% of the total variation in the *A. hololepidotus* B catch series.

The Type B model identified that catch of *A. hololepidotus* B indicates that every 1 GL of flow at time t and $t-15$ leads to an increase and reduction in catch by 0.3 kg, respectively. The catch of *A. hololepidotus* B is also influenced by a non-seasonal AR order of 1, a non-seasonal MA order of 10 and a seasonal AR order of 1. The Type B model for *A. hololepidotus* B is a poorer fit to the catch series compared to the Type A model.

The Type C model for catch of *A. hololepidotus* B is similar to the Type B model, but its *Num* coefficient of order 0 (0.405, $P < 0.001$) further specifies that every 1 GL of flow during the spawning season (November–March) at time t leads to an additional catch of 0.4 kg. The catch of *A. hololepidotus* B is also influenced by a non-seasonal AR order of 1 and a seasonal AR order of 1. The Type C model for *A. hololepidotus* B is a better fit to the catch series than the Type B model but is still a poorer fit compared to the Type A model.

The Type D model identified that, in addition to season-specific flows, catch of *R. tapirina* partly predicts catch of *A. hololepidotus* B. Flow has a *Num* order of 1, whereas *R. tapirina* catch has *Num* orders of 0 and 1 and a delay of 4. The combined influence of these predictors, in the absence of *Den* coefficients, is that every 1 GL of flow during the spawning season (November–March) at time t leads to an additional catch of 0.4 kg and every 1 kg of *R. tapirina* that is caught at time t and $t-1$ leads to small reductions in catch of *A. hololepidotus* B by 0.1 and 0.1 kg, respectively. The Type D model was the poorest fitting of all four model types for predicting catch of *A. hololepidotus* B.

Model fit

Only minor improvements to model fit were obtained through the inclusion of predictor series (a poorer fit actually resulted in some cases). Nevertheless, the overall fit of model-predicted values compared to actual catch time series for each of the species groups is satisfactory. This is evident in the comparison plots (see Noell and Ye (2013)) and the r^2 -values, which generally ranged between 0.63 and 0.86 (the exception being the models for *A. butcheri*, which had r^2 -values of almost 0.5).

8. Discussion

8.1 Environmental characteristics: 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 the study period (DWLBC 2008) and as a consequence, only seawater entered the Murray Mouth and Coorong and continued evaporation resulted in increasing salinities along the Coorong. In our study, mean salinities ranged from 30-43 ppt in the Murray Mouth subregion, 61-86 ppt in the North Lagoon, and 105-164 ppt in the South Lagoon. There was no obvious temporal pattern in salinities for either the Murray Mouth or North Lagoon, but there were sharp peaks in salinity each March in the South Lagoon, presumably due to relatively high evaporative water loss during the preceding summer and a lack of water exchange between the lagoons (Geddes 2005b).

Salinity levels recorded in this study, particularly from the South Lagoon, were quite high in comparison to observations made in a previous study undertaken in the Coorong during the 1982 drought, one which included a 16-month period of no freshwater inflows (Geddes and Butler 1984). In that study, salinities in the North Lagoon reached 80 ppt, while salinities in the South Lagoon ranged between 90 and 100 ppt. 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 North Lagoon became brackish (<30 ppt) and the South Lagoon moderately hypersaline (55-70 ppt) (Geddes 1987).

8.2 Composition of fish assemblages

In this study, over 66,000 fish, representing 26 species were collected. 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 and Potter 2002). Unlike the Murray Mouth, which is kept open through ongoing dredging, the mouth of the Wellstead Estuary typically closes-over during summer months and as such the estuary is landlocked for long periods (it occasionally opens at times of high freshwater discharge). Despite this, both regions are similar in that they exhibit a variable salinity gradient with extremely high salinities in some areas. The fish fauna in the Wellstead Estuary is described as 'depauperate' in comparison to other temperate estuaries of south-western Australia (Young and Potter 2002).

The seine net (8 mm mesh size) used in this study was very effective in sampling small-bodied fish species and juvenile fish of large-bodied species. The small-bodied *A. microstoma*, in particular, was very abundant, making up most of the total number of fish collected throughout the study (>60%), and being the only species found in the South 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 (Potter *et al.* 1993; Potter and Hyndes 1994; Valesini *et al.* 1997; Griffiths and West 1999; Young and Potter 2002; Hoeksema and Potter 2006). The second most abundant species, *A. forsteri*, is also consistently abundant in south-western Australian estuaries, particularly as juveniles (see Potter and Hyndes 1999).

From seine net samples, almost the same number of marine species utilised the Murray Mouth and Coorong region as the estuarine group. In terms of numbers of fish, however, the solely-estuarine category was dominant (62%) due to the high abundance of *A. microstoma*, with marine estuarine-opportunists making up approximately 35%. Two catadromous species, *G. maculatus* and *P. urvillii*, collectively made a notable contribution to the total number of fish (1.3%), mainly due to the relative abundance of *G. 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.

Overall, a grand total of 31 fish species were recorded from both seine and gill net samples; this comprised 30 teleost species (bony fishes) and 1 ray species (cartilaginous fish). Of these, 6 species had not been recorded in previous inventories of some 77 species of the region (including freshwater species) (Eckert and Robinson 1990; Higham *et al.* 2002). These additional species were all marine species (i.e. either estuarine opportunists or marine stragglers), i.e. *Heteroclinus heptaeolus*, *Sardinops neopilchardus*, *Ammotretis rostratus*, *Pomatomus saltatrix*, *Stigmatopora argus*, and *Myliobatis australis*. 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 quite low densities.

Link between salinity and fish assemblages

It has been well documented, that salinity is an overwhelmingly important factor in the ecological health of the Coorong (e.g. Geddes and Butler 1984; Geddes 1987, 2003, 2005c).

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 highlight the influence of salinity on the fish assemblages along the length of the Murray Mouth and Coorong region. Specifically, it describes the assemblages during an extended drought period. Further, it provides a comprehensive sampling methodology and baseline data to which future assessments can be compared.

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 and Hernández de Santillana 2004). The utilisation of such opportunities is best exemplified in this study by the dominance of *A. microstoma* in the North Lagoon and its occurrence as the only fish species in the South Lagoon, which place it as a keystone species in the structuring of fish assemblages throughout the Murray Mouth and Coorong region.

Size and growth characteristics for 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.

Atherinosoma microstoma: The broad temporal scale of sampling made the modal progression of cohorts between samples somewhat unclear. Nevertheless, it appears that early-spawned fish from a September-December spawning season (Molsher *et al.* 1994) only just began to appear during November/December. Rapid growth occurs over summer until early autumn, by which time it attains most of its growth and forms a single cohort with a broad size range, probably as a result of multiple spawnings per fish over a protracted spawning period. 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 of the cohort surviving to the second year of growth.

Aldrichetta forsteri: The length-frequency distributions for *A. forsteri* showed a noticeable difference in size structure between subregions, with relatively few fish <170 mm TL occurring in the North Lagoon compared to the Murray Mouth. We are uncertain of the reason for this size-based segregation, although an increase in salinity tolerance with growth does not appear to be a factor, since tank experiments conducted in this study suggest a high salinity tolerance for juveniles. However, one explanation for larger *A. forsteri* mainly occurring in the North Lagoon is that this subregion provides greater refuge from seals or other predators than the Murray Mouth subregion where they are more prevalent. 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.

Rhombosolea tapirina: Adult *R. 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). The distribution of this species in the marine waters adjacent to the Coorong lagoons remains unknown, yet it is believed that the species completes its life cycle within the Murray Mouth and Coorong region (Hall 1984). The growth of juveniles could be detected from a modal size class of 40-50 mm TL in December to 70-80 mm TL in March. However, further growth of this cohort was uncertain, with fish larger than ~110 mm TL occurring only sporadically on most sampling occasions. Most *R. 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 *R. tapirina* population has a more 'complete' size and age distribution.

Afurcagobius tamarensis: This small-bodied species spawns in spring and completes its life cycle in estuaries (Larson and Hoese 1996). Despite the lack of information on age and growth of *A. tamarensis*, this species probably has a short lifespan of perhaps just over one year. Length-frequency distributions show that, after being spawned in spring or summer (Section 6.3), this species first appears in March as small as 20 mm TL and belonging to a cohort with a modal size class of 35-40 mm TL. The progression of this cohort can be traced through to at least November at a modal size of ~70 mm TL and an approximate age of 1 year.

Argyrosomus hololepidotus: The Murray Mouth and Coorong *A. hololepidotus* population is comprised almost exclusively of juveniles (<750 mm TL), whilst the nearshore marine fishery comprises reproductively mature and sub-mature adults (800-1500 mm TL) 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 TL (Hall 1986). The length-frequency distributions obtained in this study conform to these life history descriptions, with juveniles as small as 128 mm TL and belonging to a cohort with a modal size of <200 mm TL appearing in December (approximately one year of age). Modal progression of this cohort indicates that juveniles reach a modal size class of ~350 mm TL over the subsequent 12-month period (at two years of age).

Acanthopagrus butcheri and *Pseudaphritis urvillii*: Only a few *A. butcheri* and *P. urvillii* were collected in this study. 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 *P. urvillii* has also been suggested, which is probably related to the closed barrages and fishways preventing this species undertaking spawning migrations.

This study aimed to sample fish assemblages rather than target individual species. As such, a more species-specific approach in sampling methods is required to sample and comprehensively describe the long-term progression of cohorts of these species more effectively.

Influence of drought on fish assemblages

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.

During the early 2000s 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 condition of the environment during this study was 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.

Given the resumption of a normal, seasonal flow regime to the Murray Mouth and Coorong in 2010, we recommend that this 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.

8.3 Reproductive Characteristics of key species

Sex ratios

Sex ratios for each species varied temporally throughout the sampling period. However, ratios for most species were heavily weighted towards females. Males only dominated the catch in two instances; *A. forsteri* during November and *A. tamarensis* in December 2007. In the current study the most likely factors explaining this result are sampling methodology and habitat variation between the sexes. Sex ratios in the commercially caught species, *A. butcheri*, *A. forsteri* and *R. tapirina* are likely to be influenced in part by the method of collection, whereby commercial fishing methods may hold bias due to the sampling of spawning aggregations. Other species-specific factors that may explain large numbers of females compared to males are discussed in more detail in Cheshire *et al.* (2013).

Temporal variation in spawning behaviour

The timing of the spawning period is an important aspect of fish ecology, as it aims to place eggs, larvae and juveniles into the system under the optimal conditions for growth and survival (Bye 1984; Jobling 1995; Yaron and Sivan 2006). In temperate systems, spawning time is often correlated with day length, temperature and food availability. Seasonal timing of spawning within a year is likely to be driven by these factors, however long term (preferably greater than 5 years) studies are most likely required before environmental correlations for spawning activity can be accurately identified.

Using GSI and macroscopic staging, this study has identified the spawning seasons for the five selected species in the Coorong under drought conditions. Spring and spring/summer spawners included *A. butcheri* and *A. tamarensis*, respectively. A previous investigation into the spawning season of *A. butcheri* in the Coorong suggested a solely summer spawning season (Hall 1984). However,

considerable variation in spawning times between different estuaries has been documented (Newton 1996; Haddy and Pankhurst 1998; Sarre and Potter 2000; Norriss *et al.* 2002). The spring period identified for *A. butcheri* spawning is not localised to South Australian estuaries (Harbison 1974) but has also been observed in Victorian estuaries such as the Glenelg River and Gippsland Lakes (Coutin *et al.* 1997; Norriss *et al.* 2002). *Acanthopagrus butcheri* has been documented to move downstream with freshwater flushes and then move upstream during summer months in order to find the appropriate salinity, dissolved oxygen content and habitat suitable for spawning (Norriss *et al.* 2002). For *A. tamarensis*, this study is the first to comprehensively assess the spawning season in the Coorong region. However, the spawning season identified is consistent with results from Victorian estuaries where they have been seen to spawn from September to November (Cadwallader and Backhouse 1983). Spring and summer spawners are likely to be utilising a time characterised by warmer temperatures, ensuring faster growth and an abundant source of food for developing larvae (Wootton 1998).

A. forsteri was identified as a summer/autumn/winter spawner; whereas *P. urvillii* and *R. tapirina* were found to be winter spawners. Timing of the spawning seasons can also vary depending on location and stock structure. For example, *A. forsteri* can be split into two stocks; eastern and western, whereby eastern populations spawn in late summer to autumn and western populations spawn in winter (Thomson 1957; Chubb *et al.* 1981; Lenanton 1982). The spawning season of *R. tapirina* in Tasmania, based on gonadosomatic indices, occurred from June to October (Kurth 1957; Crawford 1984; Ferguson 2007). Due to the absence of ripe (stage 4) and spent (stage 5) ovaries in female *P. urvillii*, an actual spawning event may not have occurred within the sampling period, however, the spawning season identified in this study is comparable to populations in two estuarine or freshwater habitats in eastern and western Victoria (Crook *et al.* 2010). Crook *et al.* (2010) identified that females started their spawning migration and were in optimum spawning condition between May and June. Female *P. urvillii* have been documented to migrate downstream with the onset of freshwater flows, which historically would have occurred towards the end of winter (Zampatti *et al.* 2011). Both *A. forsteri* and *P. urvillii* are believed to spawn in the marine environment during autumn or winter, developed larvae and juveniles then migrate back into the estuaries during spring (Jenkins 1986; Crook *et al.* 2010). This strategy places well developed larvae and juveniles into the estuaries during spring, allowing them to competitively take advantage of the warmer temperatures and abundant food resources. Complementary larval fish sampling during this study between August and November 2008 collected a very small number of *P. urvillii* larvae in the vicinity of Murray Mouth, however, environmental conditions in this area more resembled the marine environment due to lack of freshwater inflows (Bucater *et al.* 2013).

Size at first maturity

Size at first maturity represents a transitional point in the life of an individual where allocation of time and resources shifts from growth and survival only, to include reproduction (Wootton 1998). Size at first maturity varies between and within species and can be influenced by environmental change or external stressors (Stearns and Crandall 1984; Wootton 1998). Species that exhibit variations in size at

maturity as a result of external pressures are said to demonstrate life history plasticity and is most commonly displayed by a shift to an earlier maturation in faster growing fish (Stearns and Crandall 1984). However, this is not always the case. Three prominent patterns of decreased growth have been reported in the literature, both within and between populations, 1) delayed maturity at a smaller size, 2) delayed maturity at the same size, and 3) delayed maturity at a larger size (Stearns and Crandall 1984).

Female *A. butcheri* matured more rapidly when compared to males, however, some males reached sexual maturity before that of the minimum size (270 mm) of females with ripe or hydrated ovaries. *A. butcheri* within the Coorong lagoons reached first maturity at a size greater than those found in populations in South Victorian and Western Australian estuaries (Sarre 1999; Norriss 2002; Sarre and Potter 2000). This suggests that during periods of drought with no freshwater flushes or flows, sexual maturity in relation to size may slow, due to factors such as the availability of food resources and salinity gradients optimal in the stages of reproductive development for *A. butcheri*.

The results for *A. forsteri* in this study concur with results from Harris' (1968) Coorong study; female *A. forsteri* were found to be sexually mature at 255 mm TL, while males were found to sexually mature at 244 mm TL. This indicates that *A. forsteri*'s reproductive development was not greatly affected by the drought conditions. This is most likely a result of being a marine species, more so than an estuarine species; that is, being less reliant on freshwater inflows or fluctuating salinities for optimum reproductive development.

This is the first study to determine size at maturity for the Coorong population of *R. tapirina*. Size at first maturity has been determined for *R. tapirina* populations in Tasmania where Crawford (1984) found that females reached sexual maturity at sizes ≥ 219 mm whilst males were smaller at 190 mm.

Also, this is the first study to determine size at maturity for *A. tamarensis* and *P. urvillii*, within Australia. Thus, the results indicating that female *A. tamarensis* reaches sexual maturity at ≥ 53 mm and female *P. urvillii* reach sexual maturity at ≥ 165 mm, these results can be used as a basis during drought conditions for future reference. Results indicate that male *A. tamarensis* are likely to take a longer time to mature than their female counter-parts. Contrastingly the results for *P. urvillii* indicate that males would mature more rapidly than females. However, in both these cases and in the absence of a model to determine size at 50% maturity for males (due to low sample size), this claim requires further verification.

Impacts of drought on reproduction

Previous studies on Coorong spawning of *A. butcheri* suggested a summer spawning season (Hall 1984), rather than a spring spawning season as identified in this study. Summer spawning may have resulted following periods of high spring rainfalls whereby *A. butcheri* move downstream with freshwater flushes and then move upstream during summer months to find appropriate salinity, dissolved oxygen levels and habitat suitable for spawning (Norriss et al. 2002). However, in periods of

drought fish may have been cued to spawn via increasing water temperatures and minor freshwater releases during the winter months, causing fish to spawn during spring.

Aldrichetta forsteri are known to move into freshwater on rising tides (Thomson 1996), however, they are still predominately a marine estuarine-opportunistic species which can complete their entire lifecycle in a marine environment (Potter and Hyndes 1994). This suggests that whilst freshwater flows would not hold much significance in terms of cueing a spawning event, they may be important in maintaining suitable spawning habitat. Access to suitable habitat will influence the timing for spawning, for example in the western population of *A. forsteri*, during summer there is a tendency for estuaries to close over by the formation of sandbars at the mouth which effectively prevents the movement of fish in spawning condition into the estuary (Chubb *et al.* 1981). Subsequently the opening of estuaries by heavy freshwater discharge during winter, permits spawning and supports the movement of juveniles into the protected estuaries for their first year of life.

Salinity levels also play a key role in the reproductive biology of *R. tapirina*, with optimum fertilisation rates occurring at salinities of 35-45 ppt (Hart and Purser 1995). Eggs of *R. tapirina* are said to be positively buoyant at salinities above 28 ppt and after fertilisation were tolerant of a wide range of salinities (15-45 ppt) (Hart and Purser 1995). Although adult *R. tapirina* are said to be tolerant to a wide range of salinities (Kailola *et al.* 1993), specific threshold values are still unknown.

Increased GSI and developed gonads were also associated with low water temperatures for some species (i.e. *P. urvillii* which is a winter spawner). However, there was no direct evidence of recent spawning for *P. urvillii*, suggesting that an actual spawning event may not have occurred within the sampling period and hence during drought conditions. As such, there is still some uncertainty in regards to the spawning mode of *P. urvillii* and whether it varies in response to environmental conditions. If spawning did not occur during the sample period, it could be directly attributed to the loss of fish passage from freshwater to estuarine habitats in the region, whereby females are unable to move into the Coorong lagoon area to disperse their eggs for fertilisation..

In summary the low flow conditions in the Coorong may have direct impacts on the reproductive biology of the key species present. This may require interventions to ensure that the Murray Mouth stays open, ensuring the salinity in the Coorong remains within a reasonable range for survival of eggs and larvae and that the passage between fresh and salt waters remains accessible.

8.4 Influence of salinity on the survival and distribution of key species

Tolerance to hypersaline conditions

Controlled tank experiments were conducted at summer (23 °C and) winter (14 °C) temperature regimes, to assess the salinity tolerance thresholds of key fish species that inhabit the Murray Mouth estuary and Coorong lagoons. All fish species (juveniles) tested tolerated high salinity levels approximately twice the concentration of seawater. There was a gradient of relative tolerance across species with the highest tolerances recorded by *A. microstoma*, followed by *P. urvillii*, and *A. forsteri* which were tolerant of

salinities greater than 80 ppt regardless of water temperature. Although differentially effected by water temperature, *R. tapirina* and *A. butcheri* also recorded high tolerances (> approximately 80 ppt). Slightly less tolerant, *A. tamarensis* and *A. hololepidotus* recorded tolerances between approximately 60 and 72 ppt. *A. butcheri* was the only species tested to record a higher tolerance value under summer water temperatures (23 °C) than the cooler 14 °C treatment.

The maximum field salinities at which species were caught more clearly divide these species into two groups with *A. microstoma*, *P. urvillii*, *A. forsteri* and *R. tapirina* captured in salinities of over 74 ppt and *A. butcheri*, *A. tamarensis* and *A. hololepidotus* found only at salinities below approximately 60 ppt. These field patterns suggest that the winter temperature tolerance thresholds for these species are more closely related to their distribution throughout the Coorong during 2006 to 2008 (Section 6.2).

Relating tolerance thresholds to ecological distribution

A key outcome of the current study is the application of experimentally derived tolerance thresholds to the distribution of wild fish across a natural salinity gradient. The results suggest that threshold values, in particular LC₁₀ and LC₅₀, can approximate the maximum field distribution of species with moderate accuracy. In general, species tended to be caught in salinities far lower than threshold limits which concurs with results from Kefford *et al.* (2004). This is a reasonable result considering the range of chronic impacts that sub-lethal concentrations of salinity may have on the homeostasis of estuarine fish. Respiratory efficiency, energetic budgets, growth and immune responses are impacted at levels far below those directly lethal to individual fish (Geddes 1979; Hart *et al.* 1991; Haddy and Pankhurst 2000; Boeuf and Payan 2001; Akin and Neill 2003).

By exception, two species (i.e. *A. hololepidotus* and *A. microstoma*) were observed occupying habitats more saline than their tolerance limits would suggest. *A. hololepidotus* recorded LC₁₀ and LC₅₀ thresholds under 23 °C that were lower than salinities at which they were recorded in the field. However, the catches of *A. hololepidotus* at these salinities only occurred during the cooler months and therefore the summer temperature threshold does not apply. Instead the winter (14 °C) threshold would apply and whilst salinity levels may still be high enough to restrict <10% of individuals, trials suggest most members of this species could survive under these salinity and temperature conditions.

Tolerance estimates were lower than habitat field salinities for *A. microstoma* and this was the only species not tested using gradual acclimation tolerance trials. Instead, threshold values were re-calculated from published data (Lui 1969) that used a direct transfer methodology. Direct transfer methods do not allow for any degree of acclimation to increasing salinities and can often under-estimate the ability of fish to physiologically adapt to rising salinity levels, leading to lower estimates of LC₅₀ (McNeil *et al.* 2010a; 2010b; 2010c). This result emphasises the importance of comprehensive and comparative assessments of species' tolerances when addressing the impacts of water quality extremes on fish health and survival, as the application of previously or variously derived estimates may not allow valid comparisons across species.

If comparable methods were used for *A. microstoma*, as were used for other species in the current study, it is likely that LC estimates may more closely approximate field distribution limits. This would also render *A. microstoma* the most tolerant of all Coorong fish species as indicated by the field results, and we hypothesise that the gradual acclimation derived LC_{50} for this species is likely to approximate 140 ppt. This suggests that *A. microstoma*, alongside *Cyprinodon variegatus*, is one of the most salt-tolerant fish species in the world (Gunther 1956).

Ecological and management significance

These results have significant implications for the provision of freshwater inputs into the Coorong and Lower River Murray. They indicate that freshwater inflows of subsequent size and duration to push back or break down the hypersaline mass will almost certainly result in the expansion of key marine and estuarine species southward into the Coorong lagoon, expanding from remaining source populations that persist within marine environments close to the Murray Mouth. Furthermore, the data suggests that salinity levels do not need to be significantly fresh to facilitate the re-distribution of most fish species back into the lagoon, assuming that ecological fidelity also recovers and the ecological processes necessary to support fish populations is also able to recover from hypersaline conditions.

The distributional data also shows that the true estuarine species, *A. butcheri* and *A. tamarensis*, are perhaps the least likely to respond quickly to improvements in saline conditions due to their apparent reluctance to move toward a hypersaline mass, even during seasonal retreats southward. It is likely that these species are persisting within sub-optimum marine environments around the Murray Mouth. These species have relatively low tolerances and are likely to be most impacted by any further expansion of the hypersaline mass into the Murray Mouth subregion. Whilst also relatively intolerant, *A. hololepidotus* is also highly mobile and therefore able to retreat rapidly to marine environments to which they are well adapted.

8.5 Influence of freshwater flows on fishery production

Time series analysis was identified as a potentially useful tool to investigate the influence of freshwater discharge across barrages (flow volume) as a predictor of catch of key species groups in the Lakes and Coorong Fishery. Specifically, it is hypothesised that flow has an influence on the spawning and recruitment (*A. butcheri*, *A. hololepidotus*, *R. tapirina*) or spawning aggregation (*A. hololepidotus*) of most of these species, although it is unclear what effect flow has, if any, on *A. forsteri*.

The basic premise of this study was that these biological processes have a causal effect on fish production, which is reflected (concurrently or some time later) in the catches of the species concerned. Catches in another multi-species fishery in the northwest Mediterranean Sea were typically found to correspond to either the time of spawning or recruitment to the gear (Lloret et al. 2000).

Importantly, the development of time series models to investigate these relationships accounts for any inherent seasonality and underlying trends and periodicity in the time series before the final model is

developed. The specific nature of the relationships can then be inferred from the model parameters and their coefficients.

As the Lakes and Coorong Fishery is a multi-species fishery, the licensed net fishers are able to target different species under different circumstances (season, time of day, weather, etc.). Therefore, the catch of any species is not independent of the catch of another species. To allow for any confounding influence of catches of other species, further models were developed to include these catches as potential predictors (in addition to flow).

The univariate ARIMA model (Type A) described the catch series for *A. butcheri* and *A. hololepidotus* B better than any TF model (Types B, C, D). Both models exhibited a positive autoregressive component, which indicates that catch is predominantly influenced by catch in the previous month. No valid model was produced for *R. tapirina*. The catches of *A. forsteri* and *A. hololepidotus* A, were best described using TF models, some of which can be explained by biological process or fisher behaviour.

The TF model identified for catch of *A. forsteri* indicated that increases in flow lead to additional catch taken during the same month. If we assume that catch of *A. forsteri*, in this case, is a proxy for abundance, then this model could be explained by their: 1) aggregation to take advantage of an increased food supply from the nutrient-enriched freshwater discharge; 2) immigration from the sea into the Murray Mouth and Coorong to shelter from predation in more turbulent water; or 3) immigration from the sea to occupy the increasing area available that comprises preferred lower salinities or other optimal conditions (Geddes 1987). The latter of these explanations is supported by Hall's (1984) observation of a general southward expansion of the range of fish species when salinities fall. The latter explanation is supported by the observation that larger catches of *A. forsteri* generally corresponded to more fishing areas being fished, and *vice versa*.

With the inclusion of catches of other species groups as potential predictors, an alternative TF model that described catch of *A. forsteri* was developed. This model indicated that *A. forsteri* catch was inversely related to catch of *A. hololepidotus* A (taken from inside the Murray Mouth). This model may be explained by licensed net fishers targeting one species at a time, particularly since *A. forsteri* are predominantly caught using small-mesh gill nets, whereas *A. hololepidotus* A are caught using large-mesh gill nets.

The TF model identified for catch of *A. hololepidotus* A indicated that catch was inversely influenced by flows during the spawning season 1 and 2 months earlier or, in other words, catches of *A. hololepidotus* A during December–May are reduced with increasing flows 1 or 2 months earlier during its spawning season (November–March). However, this model is difficult to interpret as there is no conceivable explanation for this relationship.

Despite the hypothesised relationship between flow and catch of species groups, it was difficult to establish these relationships in this study. Transfer Function (TF) models, which included flow as a

predictor series, offered only slight improvements in predictive power to the univariate ARIMA models, in which catch is modelled on previous catches alone.

The lack of predictive models does not preclude that these relationships actually exist. However, without knowing the level of impact, it is worth considering that there are a number of possible reasons that have interfered with model development. These reasons are listed below, but are comprehensively discussed in the context of this study in Noell and Ye (2013).

- Catch is delayed to detect flow-recruitment signal;
- Catch does not accurately reflect production;
- Time series intervals conceal important information;
- Errors in model-derived series.

With careful planning of further research, some of these limitations may be overcome. Fishery-independent sampling, for instance, may be employed to sample and estimate abundance of earlier life stages of the species concerned. This would reduce the opportunity for external factors (other than flow) to interfere with the relationship, as well as provide an improved measure of fish production. Since there must be at least 50 observations required to develop a reliable time series model, the research sampling may be undertaken monthly over at least four years or more frequently with intensive sampling, but this depends on the timescale that the relationship under investigation is likely to exist.

Although this study identified limitations of time series modelling when applied to commercial catch data of the Lakes and Coorong Fishery, it remains a potentially useful tool to describe the influence of flows on fishery production, as has been demonstrated in other fisheries.

9. Benefits

Sectors of the fishing industry, government and community that will benefit directly from this research include:

- Commercial fishers operating in the South Australian Lakes and Coorong Fishery.
- Interstate commercial fisheries (NSW, TAS, VIC, WA).
- Local and interstate recreational fishers (SA, NSW, TAS, VIC, WA).
- Department of Primary Industries and Resources of South Australia (PIRSA): Fisheries – managers of the Lakes and Coorong Fisheries.
- Managers of South temperate estuarine environments and natural resources.
- Department of Environment, Water and Natural Resources (DEWNR).
- Murray-Darling Basin Authority (MDBA): water policy makers and river managers.
- South Australian Murray-Darling Basin Authority Natural Resources Management Board (SA MDBANRMB).
- Agricultural industries irrigating in the vicinity of the Lower Lakes.
- Traditional fishers of the Ngarrindjeri Aboriginal group.
- South Australian Eco-Tourism Industry: *Spirit of the Coorong*.
- South Australian Tourism Commission.

The benefits and beneficiaries are similar to those listed in the original application. The new major beneficiaries are the local fishing and tackle retailers in the Fleurieu Peninsula region, South Australian Tourism Commission and SA Eco-tourism industry operators in the South Fleurieu region, especially those conducting daily eco-tours from Goolwa, through the Murray Mouth region and into the Coorong's North Lagoon.

10. Further Development

The results of this study further highlight the need for a more integrated and strategic approach to restore and maintain improved ecological health in the Coorong and Murray Mouth, and other estuaries in southeastern Australia, through better knowledge of the role of freshwater in estuarine processes and functions and improved management of water resources. Research and other activities that should be undertaken to further develop the results of this research and facilitate more integrated management strategies include:

Dissemination of results and outputs to relevant stakeholders including: resource managers and policy makers preparing water and fisheries management plans in South Australia and south-eastern Australia, i.e. PIRSA, DEWNR, SA MDB NRM Board, MDBA, DSEWPaC, commercial, recreational and indigenous sectors of the Lakes and Coorong Fishery, Fisheries and other NRM committees; and the scientific and broader communities. Dissemination of the results has and will involve:

- presentations to the Project Stakeholders and Traditional Owners Committee, and at scientific forums and relevant meetings of government agencies (PIRSA, DEWNR, SA MDB NRMB, MDBA, etc);
- media releases where appropriate, e.g. radio or TV interviews and newspaper articles;
- oral presentations to the broader scientific community at relevant conferences; and
- publication of scientific papers in international journals.

Development of quantitative models of ecological performance: The collaborative approach with the CLLAMMecology team has ensured that key outputs of this project be incorporated in the development of quantitative models to evaluate and maintain ecological performance, which will be integrated into a decision support system framework for the region. This collaboration emphasises the importance of differing freshwater input and flow regimes to the maintenance of fish populations, estuarine health and productivity, and highlights the importance and linkage of key levers (barrage operation, releases from upstream storages, Murray Mouth opening and releases from the Upper South East Drainage Scheme) to the ecosystem health for the CLLAMM region.

Further research on flow-related fish and fisheries ecology for key species is required to better understand the role and influence of freshwater inflows and the importance of estuarine habitats on the population dynamics of individual species. Future research should investigate habitat requirements and resource use for individual species; predator/prey interactions; early life history including factors that influence recruitment; and immigration and emigration to and from the estuarine system. Further monitoring and fishery dependent research is required to better understand sustainable fishing rates and the influence of fishing on broader populations.

Data management after the project's completion: The data were entered onto a database (ACCESS), being managed by the PI at SARDI Aquatic Sciences. The data can be provided to the FRDC on request.

11. Planned outcomes

The project outputs have contributed to the following outcomes by:

- Providing baseline data and ecological information on the impacts of no freshwater inflows to the estuary and management actions on the abundance and distribution of fish populations and fisheries for the region.
- Providing the collaborative opportunity to incorporate fishery and ecological considerations through the CSIRO Flagship CLLAMMecology program into a decision-support system framework for the region that can be used to quantify the environmental, socio-economic tradeoffs of water use in the Murray-Darling Basin.
- Facilitating improved ecological health in the Coorong and Murray Mouth, and other estuaries in southeastern Australia, through better knowledge of the role of freshwater in estuarine processes and functions and improved management of environmental flows.
- Increasing awareness and promoting sustainable production of both the Lower Lakes irrigation agriculture and estuarine fisheries from the water resources available as a consequence of a better understanding of the relative importance of freshwater flows to these industries.
- Providing key biological and ecological information that is relevant to fisheries in southern temperate estuaries because the importance of freshwater flows to estuarine fisheries remains poorly understood.
- Facilitating well informed ecosystem-based environmental and fishery management by PIRSA and other partner agencies in the CLLAMM region (DEWNR and SA MDB NRMB) by providing a better understanding of flow related fish ecology.
- Encouraging Water Management Plans and other related Natural Resource Management Plans to allocate water in an ecologically sustainable manner that will help restore and maintain ecological processes and sustainable production.
- Highlighting the importance of freshwater flow to fish habitats and recruitment in estuaries, emphasising that maintaining a salinity gradient and connectivity between the freshwater, Coorong and marine system is paramount to the ecological health of the Coorong fish community and the fishery. The communication of results from this study will increase stakeholder and community awareness about the environmental and economic benefits of providing freshwater flows to estuaries.
- In addition to the FRDC final report, communication of the project results has been and will be conducted through publications in scientific journals and presentations to the Stakeholders and Traditional Owners Committee (involving PIRSA, DEWNR, commercial and recreational fishing industry and Ngarrindjeri Traditional Owners) and other NRM committees (e.g. CLLMM Science Advisory Group), and to the broader scientific community at relevant workshops and conference.

12. Conclusion

Reduced freshwater inflows to the Murray Mouth and Coorong estuary due to the over-exploitation and diversion of freshwater resources in the Murray-Darling Basin has been identified as a major threat to the local estuarine ecosystem including fish populations and the productivity of the commercial and recreational fisheries. While a number of environmental flow options/scenarios have been considered to help improve the social, economic and environmental value of the system, there is a lack of biological and ecological knowledge which is required to identify the environmental flow requirements and assess and predict the potential environmental benefits of the different management options. Knowledge gaps include flow-related fish ecology, which is critical for water management to enhance spawning, recruitment and habitat availability for native fish, thus supporting ecologically sustainable fisheries in the region.

The South Australian Lakes and Coorong Fishery Management Plan identified flows as an important issue impacting key commercial and recreational fish species. However, there has been little research on specific flow and habitat requirements of these fish. This led to the present study, aiming to address flow-related ecology of key fish species of commercial, recreational, conservation or ecological significance (*A. butcheri*, *R. tapirina*, *A. forsteri*, *P. urvillii* and *A. tamarensis*) in the Murray Estuary and Coorong. The lack of freshwater flows during the study period precluded any *in-situ* investigation of ecological response to flow events in the Coorong. Nevertheless, a strong north-south salinity gradient that increased with distance from the Murray Mouth persisted throughout the study, allowed us to study the impact of 'lack of flows' on fish assemblages and various aspects of biology and ecology in the region.

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 influenced the composition of fish assemblages observed in this study. These conditions may have negative implications for *R. tapirina*, *A. hololepidotus*, *A. butcheri* and *P. urvillii* based on knowledge of the life histories of these species and low densities recorded in the current study. The decline in species diversity with distance from the mouth is likely a response to the greater osmoregulatory stress and diminishing food resources, thus providing limited opportunities for only the few highly salt-tolerant species to extend their ecological niche. We recommend that the results of this study be treated as a baseline by which future quantitative assessments are made, particularly under non-drought conditions.

The reproductive biology for the five key species during drought conditions was examined. Sex ratios for all species, were heavily weighted towards females. Most species, with the exception of *A. forsteri*, exhibited plasticity in size at maturity either between different regions or as a result of environmental change or external stressors. Seasonal spawning guilds were identified for all species, consisting of spring (*A. butcheri*), spring/summer (*A. tamarensis*), summer/autumn/winter (*A. forsteri*) and winter (*R. tapirina* and *P. urvillii*) spawners. Microscopic analysis of gonads suggested spawning for *P. urvillii* may not have occurred in the Coorong during this study. It is highly likely that the reduction in the

amount of available habitat induced by the low flow conditions and the absence of flow-induced spawning cues during the study period had direct impacts on the reproductive biology of the key species examined. Maintaining appropriate salinity ranges and connectivity between fresh, estuarine and marine waters is integral for the spawning and recruitment of many of the key Coorong species.

An experimental approach investigating the influence of hypersalinity on juveniles of the key fish species was conducted to assess the influence of hypersaline conditions on early life survival. Juveniles of all species trialled tolerated high salinity levels approximately twice the concentration of seawater. There was, however, a gradient of relative tolerance across species. Behavioural response measures during gradual salinity increase provided additional insight into the sub-lethal impacts. The maximum field salinities at which species were caught in the fish assemblage study divided species into two groups, with species captured in salinities of over 74 ppt and those below 60 ppt. These field patterns suggest that the tolerance thresholds for the species at 14 oC were closely related to their distribution throughout the Coorong during 2006 to 2008. A key outcome of the current study is the application of experimentally derived tolerance thresholds to the distribution of fish across a natural salinity gradient in the field. The results suggest that threshold values, in particular LC for 10% and 50% mortalities, can approximate the maximum salinity extent of field distribution of species with moderate accuracy.

Finally, we used time series analysis to explore the relationships between freshwater flow and monthly commercial catches of key species in the South Australian Lakes and Coorong Fishery between July 1984 and June 2008. For *A. butcheri* and large *A. hololepidotus* (taken from outside the Murray Mouth), catches were best predicted by univariate models (i.e. catches in the previous year alone). For *A. forsteri* and small *A. hololepidotus* (taken from inside the Murray Mouth), multivariate models slightly improved predictive power when accounting for the effects of flow and other species catch. For example, it was indicated that increased flow leads to additional catch of *A. forsteri* during the same month, whereas catch of this species had a negative relationship with the catch of *A. hololepidotus* outside the Murray Mouth, suggesting a fisher targeting behaviour influence. No model could be specified for *R. tapirina*. Although this study identified limitations of time series modelling when applied to commercial catch data of the Lakes and Coorong Fishery, some of these limitations may be overcome with careful planning of further research. It therefore remains a potentially useful tool to describe the influence of flows on fishery production, as has been demonstrated in other fisheries.

Despite the preclusion of any *in-situ* investigation on the ecological response of fish ecology to freshwater flows to the Coorong, this project has successfully delivered upon its four research objectives. The findings of this research provides important baseline information in fish and fisheries ecology in the Murray Mouth and Coorong that can be used to compare the effect of various flow regimes and management scenarios or actions on the fish populations and fisheries for the region. The outcomes of the project also provide a unique opportunity to incorporate fishery and ecological information through collaboration with the CSIRO Flagship CLLAMMecology Program that can be used to develop a decision-support system framework for the region. The findings of this study facilitate

the development of management strategies that will contribute to improved ecological health in the Coorong and Murray Mouth, and other estuaries in southeastern Australia.

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Appendix 2: Companion studies

The five companion studies for the FRDC Project No. 2006/045 were:

Bucater L. B., Livore J. P., Noell C. J. and Ye Q. (2013). Temporal variation of larval fish assemblages of the Murray Mouth in prolonged drought conditions. Marine and Freshwater Research. <http://dx.doi.org/10.1071/MF12278>.

Cheshire K. J. M., Ye Q., Fredberg J., Short D. and Earl J. (2013). Aspects of reproductive biology of five key fish species in the Murray Mouth and Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-3. SARDI Research Report Series No. 699. 63pp.

McNeil D. G., Westergaard S., Cheshire K. J. M., Noell C. J. and Ye Q. (2013). Effects of hypersaline conditions upon six estuarine fish species from the Coorong and Murray Mouth. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-4. SARDI Research Report Series No. 700. 27pp.

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

Noell C. J. and Ye Q. (2013). An investigation into the relationship between freshwater flow and production of key species in the South Australian Lakes and Coorong Fishery. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-5. SARDI Research Report Series No 701. 64pp.

Appendix 3: Intellectual Property

All intellectual property arising from this research project has been made publicly available.