

## Conceptual food-web models for the Coorong: A focus on fishes and the influence of freshwater inflows



G. C. Giatas and Q. Ye

SARDI Publication No. F2016/000124-1  
SARDI Research Report Series No. 892

SARDI Aquatics Sciences  
PO Box 120 Henley Beach SA 5022

June 2016

# **Conceptual food-web models for the Coorong: A focus on fishes and the influence of freshwater inflows**

**G. C. Giatas and Q. Ye**

**SARDI Publication No. F2016/000124-1  
SARDI Research Report Series No. 892**

**June 2016**

This publication may be cited as:

Giatas, G. C. and Ye, Q. (2016). Conceptual food-web models for the Coorong: A focus on fishes and the influence of freshwater inflows. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2016/000124-1. SARDI Research Report Series No. 892. 77pp.

### **South Australian Research and Development Institute**

SARDI Aquatic Sciences  
2 Hamra Avenue  
West Beach SA 5024

Telephone: (08) 8207 5400

Facsimile: (08) 8207 5406

<http://www.pir.sa.gov.au/research>

### **DISCLAIMER**

The authors warrant that they have taken all reasonable care in producing this report. The report has been through the SARDI internal review process, and has been formally approved for release by the Research Chief, Aquatic Sciences. Although all reasonable efforts have been made to ensure quality, SARDI does not warrant that the information in this report is free from errors or omissions. SARDI does not accept any liability for the contents of this report or for any consequences arising from its use or any reliance placed upon it. The SARDI Report Series is an Administrative Report Series which has not been reviewed outside the department and is not considered peer-reviewed literature. Material presented in these Administrative Reports may later be published in formal peer-reviewed scientific literature.

### **© 2016 SARDI**

This work is copyright. Apart from any use as permitted under the *Copyright Act* 1968 (Cth), no part may be reproduced by any process, electronic or otherwise, without the specific written permission of the copyright owner. Neither may information be stored electronically in any form whatsoever without such permission.

Printed in Adelaide: June 2016

SARDI Publication No. F2016/000124-1

SARDI Research Report Series No. 892

Author(s): George Giatas and Qifeng Ye

Reviewer(s): Chris Bice (SARDI) and Paul McEvoy (DEWNR)

Approved by: Prof Xiaoxu Li  
Science Leader - Aquaculture

Signed: 

Date: 6 June 2016

Distribution: SAASC Library, SARDI Waite Executive Library, Parliamentary Library, State Library and National Library

Circulation: Public Domain

## TABLE OF CONTENTS

LIST OF FIGURES .....	IV
LIST OF TABLES.....	IV
ACKNOWLEDGEMENTS .....	V
EXECUTIVE SUMMARY .....	1
1. INTRODUCTION .....	4
1.1 Background.....	4
1.2 The Coorong and current understanding of trophic dynamics .....	5
1.3 Aims and objectives .....	10
2. MODEL DEVELOPMENT .....	11
2.1 Identifying model components .....	11
2.2 Establishing trophic links.....	16
3. RESULTS .....	18
3.1 Overall Coorong model (Model CM).....	18
3.2 Coorong model – Low inflow period .....	22
3.2.1 Model CML.....	22
3.2.2 Model CMLE .....	25
3.2.3 Model CMLN .....	27
3.2.4 Model CMLS .....	29
3.3 Coorong model – High inflow period .....	31
3.3.1 Model CMH .....	31
3.3.2 Model CMHE .....	34
3.3.3 Model CMHN.....	37
3.3.4 Model CMHS.....	40
4. DISCUSSION .....	42
4.1 Food-web responses to variable inflows .....	42
4.2 Model limitations.....	45
4.3 Further research and development of models.....	47
5. CONCLUSION AND MANAGEMENT IMPLICATIONS .....	49
6. REFERENCES .....	51
APPENDICES.....	61

## LIST OF FIGURES

Figure 1. Map of the Coorong showing the three regions: the Murray Estuary, North Lagoon and South Lagoon.....	6
Figure 2. Annual freshwater inflow through barrages from 1984-85 to 2013-14 (DEWNR).....	7
Figure 3. Semi-quantitative food-web structure for the Coorong at Pelican Point (taken from Geddes and Francis 2008). .....	8
Figure 4. Guild-specific food-webs in the Coorong at different salinity levels (taken from Deegan <i>et al.</i> 2010). .....	9
Figure 5. Legends for conceptual food-web models. ....	16
Figure 6. Overall conceptual model of the Coorong food-web. ....	21
Figure 7. Low inflow conceptual model of the Coorong food-web.....	24
Figure 8. Low inflow conceptual model of the Coorong food-web for the Murray Estuary.....	26
Figure 9. Low inflow conceptual model of the Coorong food-web for the North Lagoon. ....	28
Figure 10. Low inflow conceptual model of the Coorong food-web for the South Lagoon.....	30
Figure 11. High inflow conceptual model of the Coorong food-web.....	33
Figure 12. High inflow conceptual model of the Coorong food-web for the Murray Estuary. ....	36
Figure 13. High inflow conceptual model of the Coorong food-web for the North Lagoon.....	39
Figure 14. High inflow conceptual model of the Coorong food-web for the South Lagoon. ....	41

## LIST OF TABLES

Table 1. Information from monitoring reports used to construct food-web models for the Coorong (2003–2013).....	12
Table 2. Biotic groupings for the construction of the Coorong conceptual food-web models.....	14

## ACKNOWLEDGEMENTS

This project is a component of the broader project ‘Fish monitoring in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region for 2013-14 and 2014-15’. It is part of the South Australian Government’s Murray Futures program, funded by the Australian Government’s *Water for the Future* initiative, and supported by *The Living Murray* program. *The Living Murray* is a joint initiative funded by the New South Wales, South Australian, ACT and Commonwealth governments, coordinated by the Murray–Darling Basin Authority (MDBA).

Thanks to Paul McEvoy, Adam Watt, Rebecca Quin and Adrienne Rumbelow of the Department of Environment, Water and Natural Resources (DEWNR), for providing management and support to this project. Associate Professor Simon Goldsworthy, Sarah Reinhold and Dr Alice Mackay (SARDI) provided seal scat data (FRDC Project No. 2013-011). Afzal Hossain and Luke Silvester (Flinders University) provided access to unpublished fish diet data. Stomach-content data from Deegan *et al.* (2010) was re-evaluated to include all prey items originally identified, including rare ones. We would like to thank Dr Sébastien Lamontagne, Dr Brian Deegan (CSIRO) and Julianne Francis (The University of Adelaide) for providing access to this data.

We would like to thank Dr Mike Geddes for providing preliminary comments on an earlier version of this report. We would also like to thank Chris Bice (SARDI) and Paul McEvoy (DEWNR) for reviewing this report and providing constructive feedback. This report was approved for release by Professor Xiaoxu Li.

## EXECUTIVE SUMMARY

The Coorong, South Australia, was listed as a Wetland of International Importance under the 1985 *Ramsar* convention due to its significant ecological and cultural value. Critical to the management of the Coorong is an understanding of trophic dynamics of the system and, in particular, the influence of variability in freshwater inflow. Considerable monitoring of ecological patterns (e.g. biotic distribution and abundance) and investigation of the diets of several fishes occurred over the period 2003–2016; a period which encompassed highly variable freshwater inflow to the Coorong. This presented an opportunity to investigate food-web structure in the Coorong, under variable hydrology, with a particular focus on fishes.

To improve our understanding of how freshwater inflow affects food-web structure in the Coorong, conceptual models were constructed for two different hydrological periods: 1) years of ‘low inflow’ (<1,200 GL/yr); and 2) years of ‘high inflow’ (>5,000 GL/yr) based on information from 2003–2010 and 2010–2013, respectively. Food-web models were developed using: 1) species composition, abundance and distribution information from monitoring programs in the Coorong; and 2) all relevant dietary and trophic information from various gut-content and stable isotope studies conducted within and outside of the Coorong. A total of nine food-web models were created for the Coorong, which included an overall model and further levels of division by inflow (low and high) and spatial units (Murray Estuary, North Lagoon and South Lagoon regions).

These conceptual models suggest the Coorong food-web is both temporally (i.e. low vs high inflow periods) and spatially (i.e. Murray Estuary vs North Lagoon vs South Lagoon) variable. General comparison of low and high inflow models suggested a greater contribution of pelagic components of the food-web towards production in the Murray Estuary and North Lagoon during years of high freshwater inflows, i.e. phytoplankton → zooplankton → sandy sprat and juvenile bony herring → Australian salmon, mulloway, piscivorous birds and long-nosed fur seal. Enhanced pelagic productivity was likely a result of increased zooplankton abundance (dominated by freshwater species) during high inflows, presumably due to transportation from the Lower Lakes to the Coorong or increased primary productivity stimulated from allochthonous nutrient input. Conversely, benthic production appeared to play the dominant role in transferring energy to higher trophic levels during low inflows, e.g. detritus and benthic algae/macrophytes → benthic invertebrates → smallmouthed hardyhead and yellow-eye mullet → mulloway, Australian salmon

and piscivorous birds, particularly in the North and South Lagoon where the pelagic loop was almost absent.

During low inflows and high salinities, contraction of suitable habitat was reflected in food-web structure. Diversity and abundances of macroinvertebrates and fishes were highest in the Murray Estuary region where salinities were marine (~30–45 ppt), but declined when progressing into the North and South Lagoons. Correspondingly, food chain length also decreased along this gradient. In contrast, favourable habitat (i.e. <~55 ppt) was widespread during high inflows and extended far into the North Lagoon where fish and macroinvertebrate diversities remained high, implying enhanced food-web complexity and greater resilience to environmental or biotic disturbances. Furthermore, unlike the low inflow period, the South Lagoon fish community during high inflow was represented by multiple species (e.g. yellow-eye mullet and gobies), along with highly abundant smallmouthed hardyhead. The benthic macroinvertebrate community also was comprised of multiple taxonomic groups.

#### Management implications and further research

Freshwater inflows are considered to be highly beneficial to the Coorong food-web; they lead to a reduction in salinities along the longitudinal gradient of the Coorong and subsequent expansion of suitable habitat for biota. Freshwater inflows also promote productivity, reflected by increased zooplankton abundance, benefiting zooplanktivorous species (e.g. sandy sprat and juvenile bony herring) and consequently supporting higher level predators. Specific management considerations relating to maintaining or promoting food-web stability and structure include:

- Maintaining regular inflows into the Coorong to expand favourable habitat and enhance productivity is critical for improving food-web complexity and maintaining ecosystem resilience.
- Maintaining freshwater–estuarine and estuarine–marine connectivity is essential for food-web function in the Coorong. Many diadromous and marine fishes, which are important prey or predators in the Coorong, have life history stages that depend on habitat connectivity.
- Low volume deliveries of water may provide localised temporary ecological benefits to the food-web and are recommended during adverse conditions (e.g. extended drought).

The conceptual food-web models focused on interactions involving fishes and are based on singular low (drought) and high inflow events. There is opportunity for these models to be further refined by including data from other disciplines (e.g. organic matter and microbial processes) and integrating information from other drought/flood events in the future. Furthermore, a better understanding of the diets of understudied biotic groups (e.g. piscivorous birds) and knowledge on the abundance and distribution of large epi-benthic invertebrates (e.g. the crab *Paragrapsus gaimardii*) in the Coorong is required to improve models and our understanding of food-web dynamics.

# 1. INTRODUCTION

## 1.1 Background

Estuaries are unique and dynamic environments. As the interface between marine and freshwater environments, estuaries are subject to variability in both tidal and freshwater inputs. Freshwater inflow dictates the transport of organic matter and nutrients to estuaries (Nedwell *et al.* 1999), and influences salinity, which, in turn, may affect the distribution and abundance of biota (Drinkwater and Frank 1994; Alber 2002; Kimmerer 2002). Consequently, estuarine food-webs are typically variable and influenced by freshwater inflow.

In estuaries, nutrients and organic matter (the energy supplied to heterotrophs) can be from autochthonous (locally produced, e.g. phytoplankton and plants) or allochthonous sources (externally produced, e.g. terrestrial, freshwater or marine origin). Both autochthonous and allochthonous material may be present at any given time, with their relative importance influenced by hydrology. Ultimately, this organic carbon (energy) is produced and supplied to aquatic food-webs through two main pathways: 1) pelagic production; and 2) benthic production. The pelagic-based (phytoplankton) component of the food-web becomes more important during periods of high riverine input (Allanson and Read 1995), where transportation of allochthonous material (e.g. inorganic nutrients and organic matter) or zooplankton promotes estuarine zooplankton biomass and consequently supports higher trophic organisms such as zooplanktivorous and predatory fishes (de Sylva 1975).

In contrast, detritus (benthic-based component), which is mainly locally derived from aquatic macrophytes and macroalgae, is available year-round and an important and dependable source of carbon in many estuaries (Whitfield 1999). During conditions of low freshwater inflow, detritus is essential for the supply of carbon to estuarine food-webs (Marais 1984; Allanson and Read 1995). Benthic invertebrates (e.g. polychaetes and amphipods) are abundant in most estuaries and many are deposit-feeders or benthic predators that derive their carbon from the benthic (detritus-based) food-web. These invertebrates, in turn, play important roles as key food sources for many fishes (e.g. Edgar and Shaw 1995). Furthermore, detritus provides a direct food supply for detritivorous fishes (e.g. mugilids), which are common in some temperate estuaries (Marais 1984).

Understanding where energy is derived (e.g. externally vs internally) and how it is transferred from one organism to another ('trophic structure') can highlight the importance of different trophic

pathways and sensitivity of trophic links (e.g. the dependence of particular species on a specific prey species) and is important for understanding ecosystem function. Both gut-content analyses and stable isotope techniques can provide insight into the trophic structure of estuarine food-webs. While either method can be used in isolation, their complementary application provides greater power to understand food-web structure (Post 2002). Stable isotope analyses in food-web studies typically involve the use of ratios of isotopic carbon ( $\delta^{13}\text{C} = {}^{13}\text{C}:{}^{12}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N} = {}^{15}\text{N}:{}^{14}\text{N}$ ) from the tissues of biota. While carbon isotopic signatures of prey are relatively similar to those of their consumers (DeNiro and Epstein 1978), nitrogen is more enriched in the consumer (Fry and Sherr 1984; Peterson and Fry 1987). Carbon can, therefore, be used as an indication of the trophic pathway, while nitrogen can be used to identify trophic positions and levels of species, confirming consumers and prey.

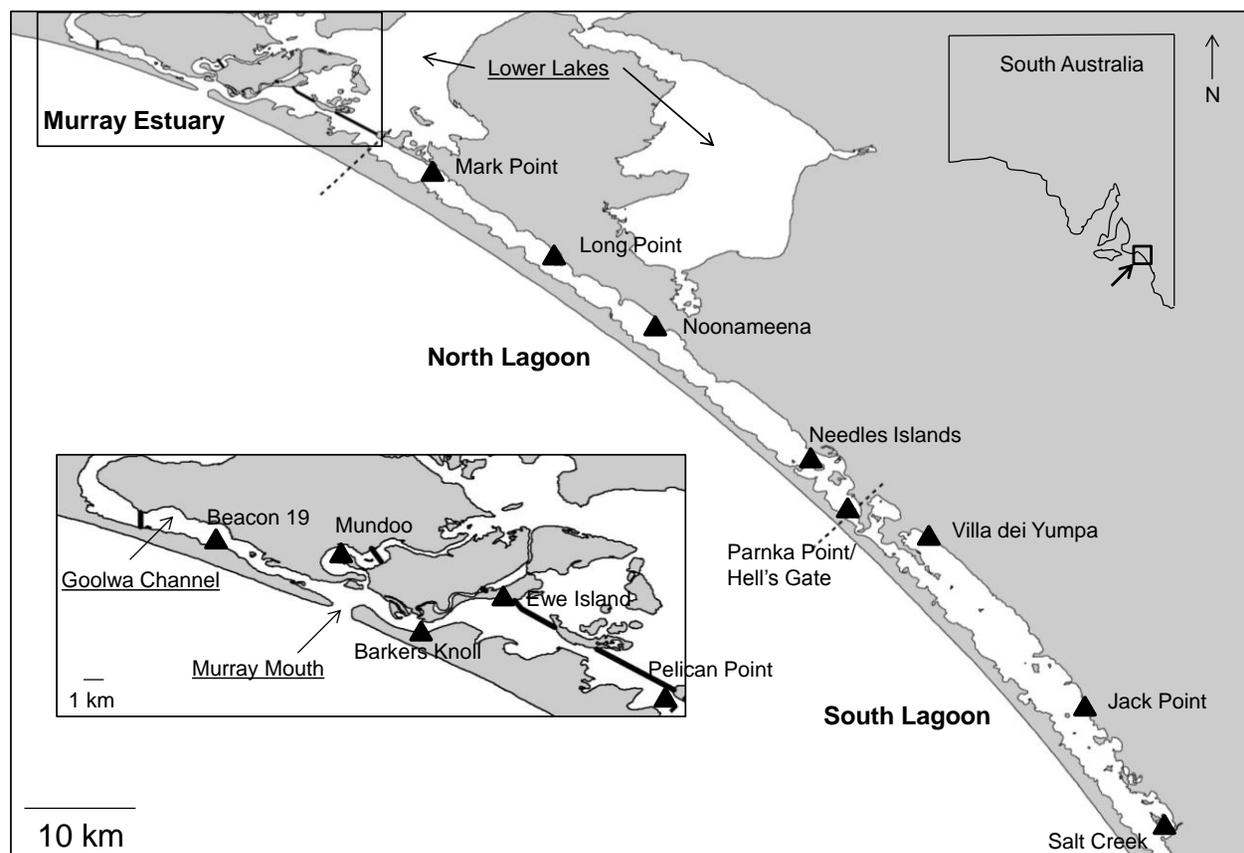
## 1.2 The Coorong and current understanding of trophic dynamics

The River Murray estuary and Coorong Lagoon (herein, collectively referred to as the 'Coorong') is an estuarine–lagoonal system that is located at the terminus of the River Murray, South Australia (SA), which connects to the Southern Ocean through the Murray Mouth. The Coorong can be divided into three geographical regions: the Murray Estuary, North Lagoon and the South Lagoon – based on distinct physical features and salinity properties, generally with increasing salinity from the barrages into the South Lagoon (Figure 1). The Coorong is heavily influenced by freshwater inflow from the River Murray, which enters the system through the barrages at the Lake Alexandrina–Coorong interface. In recent years, the southern end of the South Lagoon has also received small volumes of water from a network of drains (the Upper South East Drainage Network) through Salt Creek.

The Coorong is considered a wetland of international importance under the Ramsar Convention, due to its ecological significance (Phillips and Muller 2006), and supports a diverse biotic assemblage including the macrophyte *Ruppia tuberosa*, benthic invertebrates, fishes, waterbirds and shorebirds, with many of the latter being migratory. The benthic invertebrate community is made up of several species/genera of annelids, most of which are polychaetes (e.g. *Capitella capitata* and *Simplisetia aequisetis*), crustaceans, represented principally by amphipods and the crab *Paragrapsus gaimardii*, molluscs and insect larvae (Dittmann *et al.* 2006b; 2010; 2013). The fish assemblage is characterised by a spatio-temporally variable mix of estuarine (e.g. smallmouthed hardyhead *Atherinsoma microstoma* and black bream *Acanthopagrus butcheri*), marine (e.g. sandy sprat *Hyperlophus vittatus*, mulloway *Argyrosomus japonicus* and yellow-eye

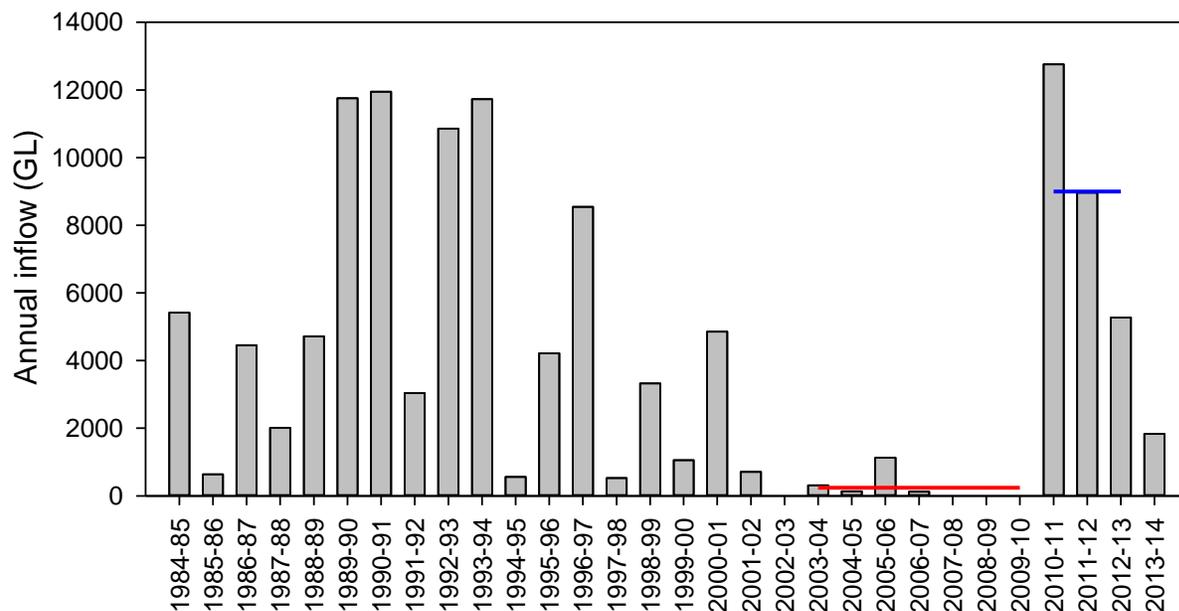
mullet *Aldrichetta forsteri*), freshwater (e.g. bony herring *Nematalosa erebi*) and diadromous species (e.g. congolli *Pseudaphritis urvillii*) (Noell *et al.* 2009; Zampatti *et al.* 2011; Ye *et al.* 2012; Livore *et al.* 2013).

Waterbirds include the Australian pelican (*Pelecanus conspicillatus*), cormorants (*Phalacrocorax* spp.), grebes, gulls, ducks, geese, black swan (*Cygnus atratus*), terns, herons and allies (Geddes 2005; Paton and Rogers 2009; Paton and Bailey 2011). Abundant shorebird (wader) species are the red-neck stint (*Calidris ruficollis*), banded stilt (*Cladorhynchus leucocephalus*), sharp-tailed sandpiper (*Calidris acuminata*), black-winged stilt (*Himantopus himantopus*), red-capped plover (*Charadrius ruficapillus*) and red-necked avocet (*Recurvirostra novahollandiae*) (Geddes 2005; Dittmann *et al.* 2006; Paton and Rogers 2009). Many of the fish and bird species present are conservationally, culturally (i.e. Ngarrindjeri people) and economically important to the area (Phillips and Muller 2006).



**Figure 1. Map of the Coorong showing the three regions: the Murray Estuary, North Lagoon and South Lagoon. Major sampling sites for fish, macroinvertebrate and zooplankton monitoring projects are represented by black triangles. Dotted lines represent the boundaries of the regions. Solid black lines represent barrages.**

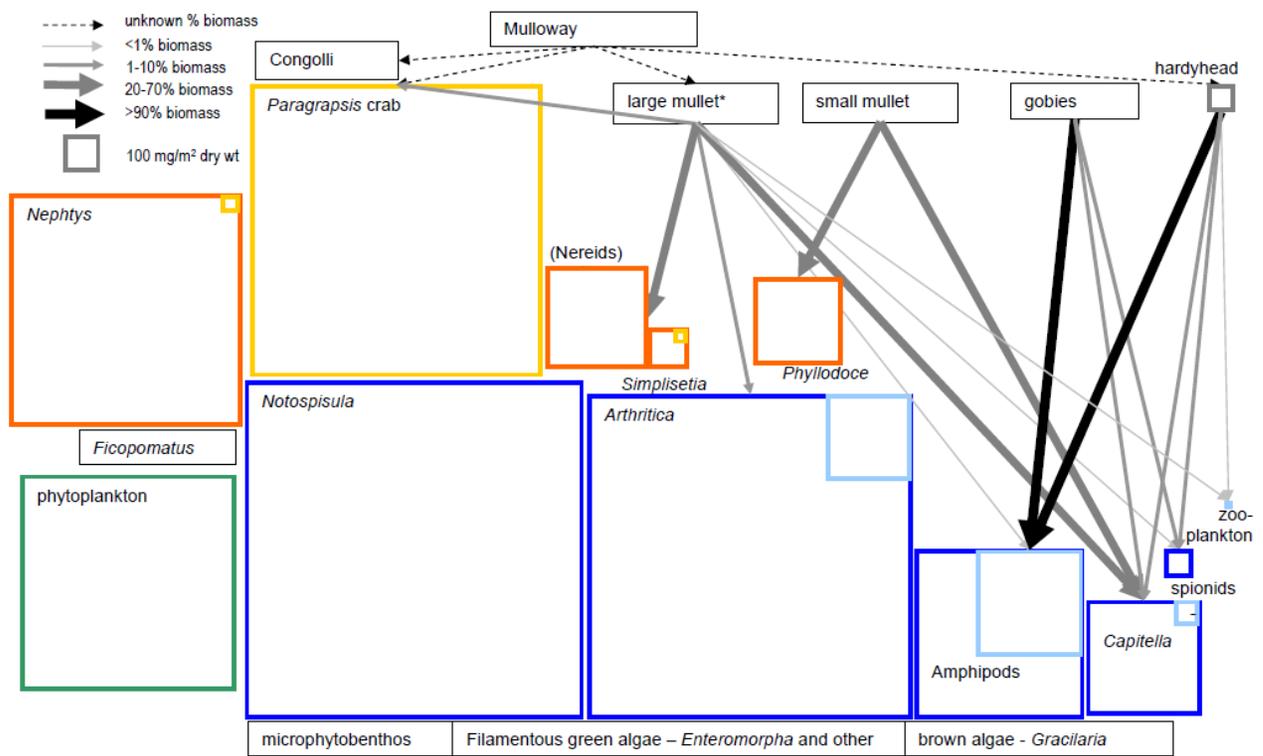
Freshwater inflows (hereafter 'inflows') to the Coorong over the last decade were variable and characterised by extremes. From 2003–2010, drought and water abstraction in the Murray–Darling Basin were accompanied by low inflows to the Coorong (<1,200 GL/yr, mean 242 GL/yr) (Figure 2) and marine–hypermarine salinities (Appendix 1). In contrast, heavy rainfall and flooding in the upper reaches of the Murray–Darling Basin during late 2010 resulted in the 2010–2013 period being characterised by relatively high inflows (>5,000 GL/yr, mean 8,997 GL/yr) (Figure 2) and brackish–hypermarine salinities (Appendix 1). Inflow decreased the following year (2013–14, ~1,800 GL, Figure 2), although salinities were similar to that of 2010–2013 (Appendix 1). For the purpose of this study and hereafter, the 2003–2010 period will be referred to as the 'low inflow' period and the 2010–2013 period will be referred to as the 'high inflow' period. It is acknowledged that 'high inflows' described in this report during regulated conditions are considerably less than those expected under natural conditions, where mean annual discharge into the Southern Ocean is ~12,233 GL/yr (Puckridge *et al.* 1998).



**Figure 2. Annual freshwater inflow through barrages from 1984-85 to 2013-14 (DEWNR). Red line represents the mean annual inflow (242 GL/yr) between 2003-04 and 2009-10 (low inflow period). Blue line represents the mean annual inflow (8,997 GL/yr) between 2010-11 and 2012-13 (high inflow period).**

Since 2005, our understanding of food-web structure in the Coorong has greatly improved as a result of targeted investigations into fish diet and trophic structure. Geddes and Francis (2008) conducted a trophic ecology pilot study at Pelican Point in the Murray Estuary region (Figure 1) during low inflows and marine salinities in March 2005. They used invertebrate prey abundances

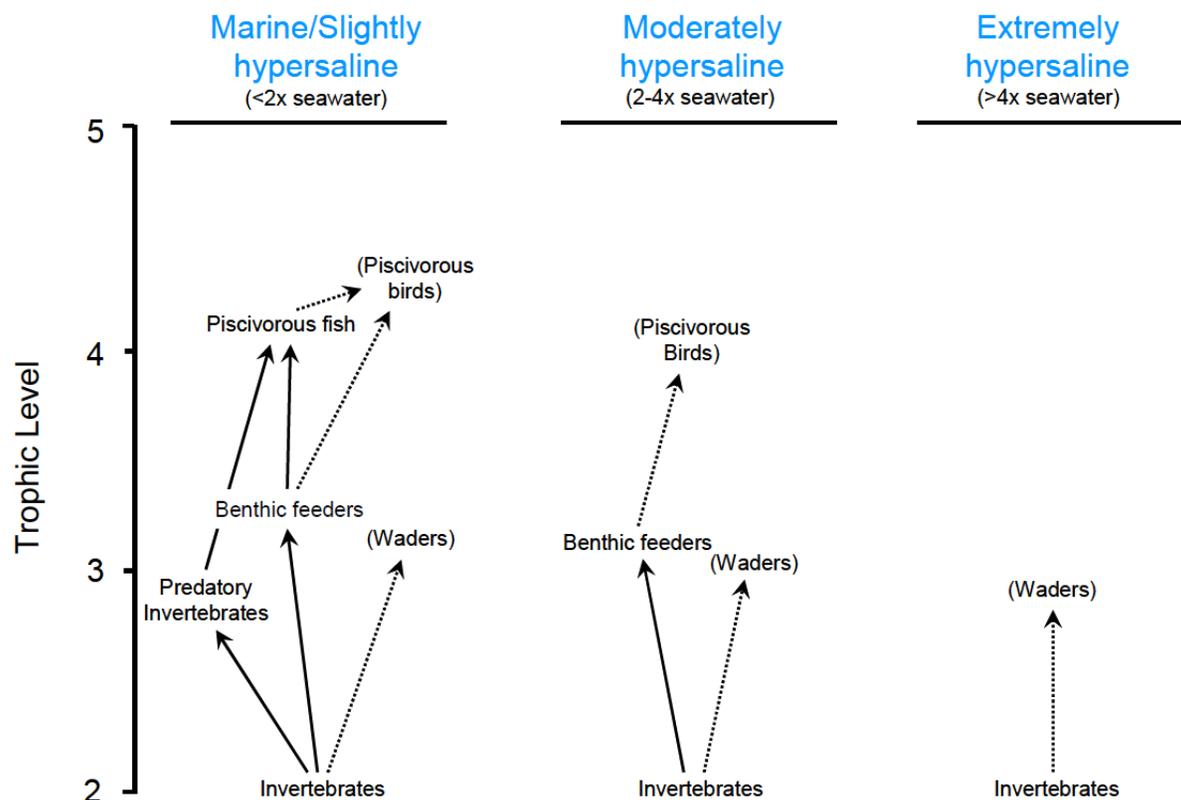
and their estimated biomass, along with diet results from two key small-bodied fish families (Atherinidae and Gobiidae) and two key large-bodied fishes (yellow-eye mullet and mulloway), to construct a semi-quantitative food-web (Figure 3). This food-web model provided considerable insight into the contribution of prey to important fishes in the Coorong; however, it had limited spatial (conducted in a small area) and temporal (information from one sampling event) resolution. The Coorong food-web is likely to vary considerably across the salinity gradient of the system, and is also likely to differ temporally during different environmental conditions. Similarly, as the predator–prey links were based on a snapshot gut-content study, it is expected that trophic links will be much more complex when other literature is considered.



**Figure 3. Semi-quantitative food-web structure for the Coorong at Pelican Point (taken from Geddes and Francis 2008). Size of each taxon box represents biomass (mg m<sup>-2</sup> dry wt). The smaller rectangular boxes are for species where there is no estimate of biomass. For each item, darker boxes represent total biomass and lighter boxes inside them are the proportion of the food item that is epibenthic/nektonic. The diet of the target four species is represented by the arrows with the width and darkness of the arrow representing the importance of the food item in terms of % biomass in the diet.**

A trophic study of the Coorong was undertaken in detail by Deegan *et al.* (2010) during low inflows in March 2007 using a combination of stable isotope and gut-content data, which focused on the food-web leading to fishes and the trophic guilds of prey and predator species. This study was

conducted over a much broader spatial scale (Goolwa Channel in the Murray Estuary region to Jack Point in the South Lagoon, Figure 1) as compared to the previous pilot investigations in the system (Lamontagne *et al.* 2007; Geddes and Francis 2008). Food-web structure along the salinity gradient of the system (Murray Mouth to Nooannameena, Figure 1) changed considerably, reflecting a loss of prey diversity and specific trophic guilds (e.g. piscivorous fish) with increasing salinity. Figure 4 shows a simplistic food-web model of the system by trophic guilds under different salinities derived from Deegan *et al.* (2010).



**Figure 4. Guild-specific food-webs in the Coorong at different salinity levels (taken from Deegan *et al.* 2010). Guilds are: “invertebrates” = primary consumers (grazers, filter feeder, etc); “predatory invertebrates” = larger omnivorous or predatory invertebrate species (e.g. *Aglaophamus* and *Macrobrachium*); “benthic feeders” = smaller fishes (e.g. smallmouthed hardyhead and Tamar goby), or smaller size-classes of larger fishes; “piscivorous fish” = black bream and mulloway. Also included is the hypothesised trophic position and trophic relation (dashed lines) for “waders” (various species of shorebirds) and “piscivorous birds” (including terns, Australian Pelican, etc).**

Since the return of freshwater inflows in late 2010, a number of gut-content and/or stable isotope-based studies have examined the diets of fishes including greenback flounder (*Rhombosolea tapirina*) (Earl 2014), smallmouthed hardyhead (A. Hossain unpublished data; L. Silvester unpublished data), Tamar goby (*Afurcagobius tamarensis*) (A. Hossain unpublished data;

L. Silvester unpublished data), yellow-eye mullet (Giatas 2012), mulloway (Giatas and Ye 2015), Australian salmon (*Arripis truttaceus* and *A. trutta*) (Giatas and Ye 2015), congolli (Johnson 2014; Giatas and Ye 2015) and sandy sprat (Bice *et al.* 2016; A. Hossain unpublished data). Findings from these studies during high inflow, together with the aforementioned studies during low inflow, provide a basis to develop a greater understanding of food-web interactions and variability in the Coorong. To date there has been no synthesis of this information, nor has there been a comparison of food-web function in the Coorong among different hydrological periods.

### **1.3 Aims and objectives**

The primary aim of this project was to improve our understanding of how freshwater inflow affects food-web structure in the Coorong. This was achieved by creating conceptual models for the Coorong food-web (with a primary focus on fishes), based on information from past monitoring programs and diet/trophic studies, for two different hydrological periods: 1) 'low inflows' (i.e. <1,200 GL/yr, 2003–2010); and 2) 'high inflows' (i.e. >5,000 GL/yr, 2010–2013).

Specific objectives were to:

- Develop a conceptual model of the food-web in the Coorong for low inflow and high inflow periods; and
- Identify differences in the food-web structure and diet between low inflow and high inflow periods.

## 2. MODEL DEVELOPMENT

A literature review was conducted to collect information for input into conceptual food-web models for the Coorong. Literature included monitoring reports, diet and trophic/food-web studies. Monitoring reports were reviewed to: 1) identify species or taxonomic groups present in the Coorong that should be incorporated into food-web models; and 2) identify abundant species or taxonomic groups that characterised low (2003–2010) and high (2010–2013) inflow periods to enable further division of food-web models by inflow. Gut-content studies were reviewed to create trophic links (arrows) from prey to predators, while information from stable isotope-based food-web/trophic studies (e.g. Deegan *et al.* 2010; Johnson 2014) was used to establish hierarchy in trophic structure (i.e. trophic positions of biota) for food-web models. In addition to models being divided by levels of inflow (low and high), models were further divided by region (Figure 1), as food-web function is likely to be different at these spatial scales, driven primarily by salinity. A total of nine food-web models were developed:

- An ‘overall Coorong model’ (Model CM).
- ‘Coorong low inflow model’ (Model CML), which was subdivided by region into three further models:
  - ‘Low inflow Murray Estuary model’ (Model CMLE);
  - ‘Low inflow North Lagoon model’ (Model CMLN); and
  - ‘Low inflow South Lagoon model’ (Model CMLS).
- ‘Coorong high inflow model’ (Model CMH), which was subdivided by region into three further models:
  - ‘High inflow Murray Estuary model’ (Model CMHE);
  - ‘High inflow North Lagoon model’ (Model CMHN); and
  - ‘High inflow South Lagoon model’ (Model CMHS).

### 2.1 Identifying model components

Long-term sampling programs allow information to be gathered on spatio-temporal variability in species-specific distribution and abundance. Species-specific distribution and relative abundance data for primary producers, zooplankton, benthic macroinvertebrates, fish and birds from recent (last decade) monitoring reports were analysed (Table 1). Information from older studies (e.g. Geddes and Butler 1984; Geddes 1987) was omitted due to significant changes in the presence, abundance and distribution of some biota over the past 30 years (e.g. disappearance of the

macrophyte *Ruppia megacarpa*). Species assemblage information for 2013-14 was not incorporated as inflow and salinities during this year were intermediate between the low and high inflow periods (Figure 2; Appendix 1).

**Table 1. Information from monitoring reports used to construct food-web models for the Coorong (2003–2013). For more information refer to Appendices 2 and 3. Sampling programs are generally more biased towards spring/summer months and were not consistently conducted throughout the 2003–2013 period. Nutrients and organic matter measurements have not been taken into account for the food-web model due to patchy data and because the food-web model has a primary focus on trophic links involving fish.**

Biological group	Information	Low-inflow period (2003-04 to 2009-10)	High-inflow period (2010-11 to 2012-13)
Phyto-plankton	Taxonomic composition	Sampling from 2003-04 (Geddes 2005), 2004-05 (Geddes and Tanner 2007), 2005 (Geddes and Francis 2008) and 2007–2009 (Leterme <i>et al.</i> 2015).	Sampling from 2011–2013 (Leterme <i>et al.</i> 2015).
Macroalgae and macrophytes	Macroalgal species composition	Observations from other projects from 2003–2005 (Geddes 2005; Geddes and Tanner 2007; Lamontagne <i>et al.</i> 2007) and from <i>Ruppia tuberosa</i> monitoring from 2003–2008 (Rogers and Paton 2009a).	Observations from other projects during 2012 (Giatas 2012) and from <i>Ruppia tuberosa</i> monitoring from 2011–2013 (Frahm <i>et al.</i> 2012; Paton and Bailey 2013a; 2014).
	Distribution ( <i>Ruppia tuberosa</i> only)	<i>Ruppia tuberosa</i> monitoring from 2003-2008 (Rogers and Paton 2009a).	<i>Ruppia tuberosa</i> monitoring from 2011–2013 (Frahm <i>et al.</i> 2012; Paton and Bailey 2013a; 2014).
Zooplankton	Species composition, relative abundances and distribution	Zooplankton monitoring (pelagic net tows and Haney trap samples) from 2003–2005 (Geddes 2005; Geddes and Tanner 2007; Geddes <i>et al.</i> 2016).	Zooplankton monitoring (pelagic net tows and Haney trap samples) from 2010–2013 (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b).
Macro-invertebrates	Species composition, relative abundances and distribution	Macrobenthic invertebrate monitoring (benthic core and grab sampling) from 2003–2010 (Geddes 2005; Dittmann <i>et al.</i> 2006a; 2006b; Geddes and Tanner 2007; Dittmann <i>et al.</i> 2008; Geddes and Francis 2008; Baring <i>et al.</i> 2009; Rolston and Dittmann 2009; Dittmann <i>et al.</i> 2010). Bird food resource assessment in the South Lagoon (Paton and Rogers 2008; Paton and Rogers 2009).	Macrobenthic invertebrate monitoring (benthic core and grab sampling) from 2010–2013 (Dittmann <i>et al.</i> 2011; 2012; 2013). Bird food resource assessment in the South Lagoon (Paton and Bailey 2011; 2012; 2013b).

Biological group	Information	Low-inflow period (2003-04 to 2009-10)	High-inflow period (2010-11 to 2012-13)
Fish	Species composition, relative abundances and distribution	Fish monitoring using seine and multi-panel gill netting during 2006-07 (Noell <i>et al.</i> 2009). Fish assemblage monitoring and fishway movement from 2006–2010 (Jennings <i>et al.</i> 2008; Zampatti <i>et al.</i> 2010; Zampatti <i>et al.</i> 2011).	Fish monitoring using seine and gill netting from 2010-11 to 2012-13 (Ye <i>et al.</i> 2011; 2012; Livore <i>et al.</i> 2013). Fish assemblage monitoring and fishway movement from 2010–2012 (Bice <i>et al.</i> 2012; Zampatti <i>et al.</i> 2012).
Birds	Species composition	Information from various Coorong bird monitoring survey reports (e.g. Geddes 2005; Paton and Rogers 2009; Rogers and Paton 2009b; Paton and Bailey 2012; 2013b).	
Other chordates	Species composition	Personal observations and incidental catches through other monitoring programs.	

Models were constructed using the biotic groupings shown in Table 2. Whilst many fishes have been recorded in the Coorong, only abundant species were included in the models, i.e. >1% of total seine or gill net numerical catch for small and large-bodied fishes, respectively, for 2006-07, 2010-11, 2011-12 and 2012-13 (data from Livore *et al.* 2013). Benthic invertebrates were initially grouped based on feeding modes, habitat use, morphology and broad taxonomic groupings, but were later grouped together into one category (i.e. benthic invertebrates) to simplify final models (Table 2). Consequently, some suspension feeding bivalves (e.g. *Arthritica helmsi*) have been grouped with deposit-feeding benthic invertebrates. The crab *Paragrapsus gaimardii* was separated from other benthic invertebrates due to its substantially larger size (maximum carapace width 55 mm), while the tubeworm *Ficopomatus enigmaticus* was separated from other benthic invertebrates as this species forms calcareous reefs and has a different feeding biology in comparison to the other polychaetes (Fauchald and Jumars 1979). Benthic algae and plants were compiled into one group as there was insufficient data to separate these in the models. Fish were analysed as species, except for where similar diet, habitat and morphology enabled a broader grouping (i.e. gobies) (Table 2).

**Table 2. Biotic groupings for the construction of the Coorong conceptual food-web models. Feeding mode functional descriptions for invertebrates and vertebrates, and the literature from which classifications were derived, are in Appendix 4. Fish feeding modes for large juveniles/adults are presented. Colour patterns of biota follow those in Figure 5.**

Group	Taxa included	Feeding mode(s)
Mulloway	<i>Argyrosomus japonicus</i>	Piscivore
Yellow-eye mullet	<i>Aldrichetta forsteri</i>	Omnivore
Greenback flounder	<i>Rhombosolea tapirina</i>	Facultative invertivore
Australian salmon	<i>Arripis truttaceus</i> and <i>Arripis trutta</i>	Piscivore
Black bream*	<i>Acanthopagrus butcheri</i>	Omnivore
River garfish	<i>Hyporhamphus regularis</i>	Facultative herbivore
Australian herring	<i>Arripis georgianus</i>	Facultative invertivore
Congolli	<i>Pseudaphritis urvillii</i>	Facultative invertivore
Bony herring	<i>Nematolosa erebi</i>	Facultative herbivore/detritivore
Common carp	<i>Cyprinus carpio</i>	Detritivore/omnivore
Sandy sprat	<i>Hyperlophus vittatus</i>	Zooplanktivore
Smallmouthed hardyhead	<i>Atherinosoma microstoma</i>	Obligate invertivore
'Gobies'***	<i>Afurcagobius tamarensis</i> , <i>Tasmanogobius lasti</i> , <i>Arenigobius bifrenatus</i> , <i>Pseudogobius olorum</i> and <i>Favonigobius lateralis</i>	Facultative invertivore
Australian smelt	<i>Retropinna semoni</i>	Zooplanktivore
Flathead gudgeon	<i>Philypnodon grandiceps</i>	Facultative invertivore
Benthic invertebrates	Bivalvia: <i>Arthritica helmsi</i> , <i>Spisula (Notospisula) trigonella</i> and <i>Soletellina alba</i>	Suspension feeder
	Gastropoda: Hydrobiidae, <i>Salinator fragilis</i> and <i>Coxiella striata</i>	Herbivorous grazer
	Polychaeta: <i>Capitella capitata</i> , <i>Australonereis ehlersi</i> , <i>Boccardiella limnicola</i> ; Oligochaeta; Sipuncula	Deposit feeder/suspension feeder
	Polychaeta: <i>Aglaophamus australiensis</i> and <i>Phyllodoce novaehollandiae</i>	Predator
	Polychaeta: <i>Simplisetia aequisetis</i>	Omnivorous scavenger/deposit feeder
	Amphipoda: Gammaridea, Corophiidae, <i>Melita</i>	Deposit feeder/herbivorous grazer
	Mysidacea	Predator/suspension feeder
	<i>Macrobrachium</i>	Omnivorous scavenger/browser
	<i>Amarinus laevis</i> and <i>Helograpsus haswellianus</i>	Omnivorous scavenger/browser
	Hexapoda: Chironomidae, Ceratopogonidae, Ephydriidae, Dolichopodidae and Hydrophilidae	Deposit feeder/predator/herbivorous grazer
Hexapoda: Notonectidae and Corixidae	Omnivorous scavenger/predator	
Calcareous tubeworm	<i>Ficopomatus enigmaticus</i>	Suspension feeder
Large crab	<i>Paragrapsus gaimardii</i>	Omnivorous scavenger/predator
Zooplankton	Copepoda: Calanoida e.g. <i>Boeckella</i> , <i>Calmoecia</i> , <i>Acartia</i> , <i>Gladioferens</i> ; Harpacticoida e.g. <i>Mesochra</i>	Various

Group	Taxa included	Feeding mode(s)
	Cladocera e.g. <i>Daphnia</i> , <i>Moina</i> , <i>Bosmina</i> , <i>Alona</i>	Suspension feeder
	Ostracoda	Suspension feeder
	Rotifera e.g. <i>Synchaeta</i> , <i>Branchionus</i> , <i>Keratella</i> ; Protista e.g. <i>Stenosemella</i>	Suspension feeder
	Meroplankton e.g. crab, bivalve, polychaete and gastropod larvae	Various
	Other: <i>Parartemia</i>	Suspension feeder
Phytoplankton (incl. bacteria)	Chlorophytes, diatoms, dinoflagellates, cryptomonads and cyanobacteria.	N/A
Benthic macro- and microalgae, and macrophytes	Filamentous algae: <i>Ulva/Enteromorpha</i> , <i>Cladophora</i> , <i>Rhizoclonium</i> and <i>Polysiphonia</i>	N/A
	Non-filamentous algae: <i>Gracilaria</i> , <i>Hypnea</i> and <i>Caloglossa</i>	N/A
	Macrophytes: <i>Ruppia tuberosa</i>	N/A
	Microalgae: e.g. benthic diatoms	N/A
Detritus	Fine and coarse detritus/organic material (animal or algal/plant origin)	N/A
Seals	<i>Arctocephalus forsteri</i>	Piscivore
Piscivorous birds***	e.g. <i>Pelecanus conspicillatus</i> , <i>Phalacrocorax</i> spp. and <i>Sterna</i> spp.	Piscivore
Carnivorous shorebirds***	e.g. <i>Calidris canutus</i> , <i>Cladorhynchus leucocephalus</i> , <i>Calidris acuminata</i> , <i>Himantopus himantopus</i> , <i>Charadrius ruficapillus</i> and <i>Recurvirostra novahollandiae</i>	Facultative invertivore
Herbivorous waterbirds***	e.g. <i>Cygnus atratus</i>	Obligate herbivore

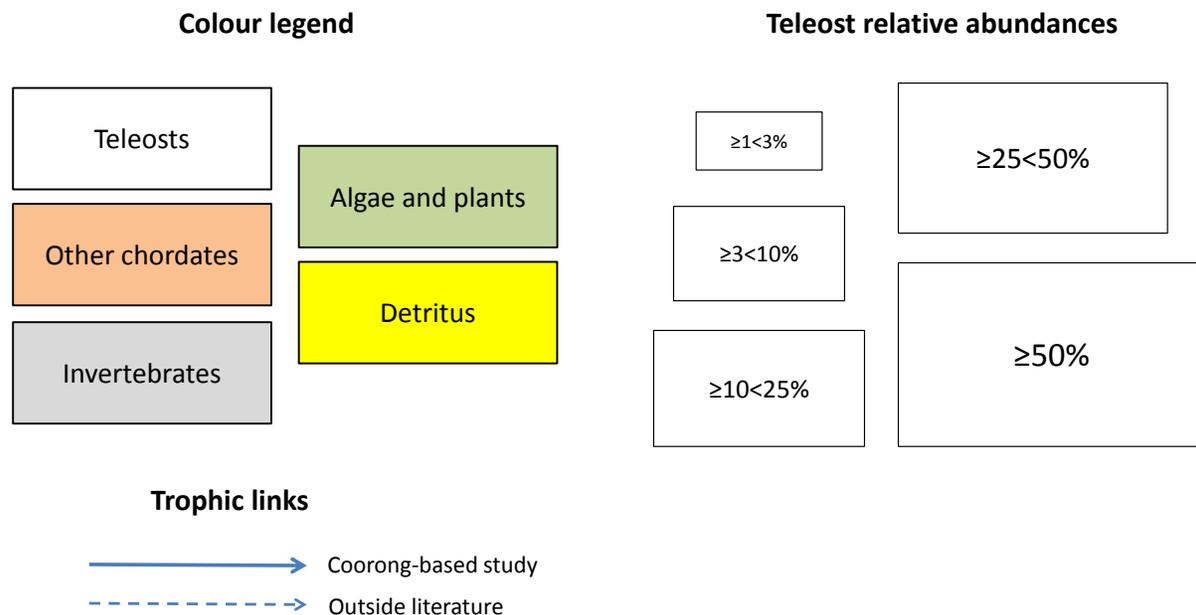
\*Despite contributing <1% by total gill net catch, black bream (*Acanthopagrus butcheri*) was included in the overall model as it is a commercially important species that was previously abundant.

\*\*Trophic links for gobies were derived from one species (Tamar goby), but represented lagoon goby (*Tasmanogobius lasti*), bridled goby (*Arenigobius bifrenatus*), bluespot goby (*Pseudogobius olorum*) and longfin goby (*Favonigobius lateralis*).

\*\*\*Birds have been grouped into the most appropriate categories: piscivorous, carnivorous or herbivorous groups. It is acknowledged that some bird species grouped under these categories may not strictly reside within them.

In order to determine those taxa likely to be of greatest importance during the two periods of inflow under investigation (low and high) and within particular regions, relative abundances of fishes, and to a lesser extent plankton and macroinvertebrates, were incorporated into models. Percentage contribution (by number) of fishes to overall seine net (for small-bodied species) or gill-net (for medium- and large-bodied species) catches (data from Livore *et al.* 2013) were used to represent the importance of fish in the food-web during particular inflow phases and/or in particular regions. Data from 2006-07 were used to represent the low inflow period and the mean data from 2010-11, 2011-12 and 2012-13 were used to represent the high inflow period (Table 1). Fishes that contributed <1% of the total seine or gill net catches for small and large-bodied fishes, respectively, were excluded from the models. For those fishes that were  $\geq 1\%$  of total catches, they are represented in models by boxes that are scaled in size proportional to their

relative abundance categories, i.e.:  $\geq 50$ ,  $\geq 25 < 50$ ,  $\geq 10 < 25$ ,  $\geq 3 < 10$  and  $\geq 1 < 3\%$  contribution (Figure 5). Catch % of fishes can be viewed in Appendices 5 and 6.



**Figure 5. Legends for conceptual food-web models. Fish abundances have been incorporated into the models and represent the percentage catch (by number) of the total seine or gill net catches for small and large-bodied species, respectively (see Appendices 5 and 6). Detritus is of animal (not shown by links in models) and plant origin.**

The relative abundances of macroinvertebrates, zooplankton and phytoplankton were not graphically represented in models. Instead, dominant groups/species during particular inflow phases/regions were provided in the text summary of the model based on information from monitoring reports (Appendices 2 and 3). Appearance of *F. Enigmaticus* and *P. gaimardii* in models was determined by salinity tolerance information, i.e. 3–80 ppt for *F. enigmaticus* (Geddes and Butler 1984; Dittmann *et al.* 2009) and 0–80 ppt for *P. gaimardii* (Brookes *et al.* 2009). This was because benthic coring, the method in which macroinvertebrates were sampled, was deemed unsuitable for assessing the occurrence of these species.

## 2.2 Establishing trophic links

Trophic links to fishes were primarily based on gut-content studies conducted within the Coorong (Hall 1986; Geddes and Francis 2008; Deegan *et al.* 2010; Giatas 2012; Earl 2014; Giatas and Ye 2015; Bice *et al.* 2016; L. Silvester unpublished data; A. Hossain unpublished data), but also included studies conducted outside of the Coorong, where Coorong-specific diet information was poor or absent (Appendix 4). Trophic links for these understudied species must be viewed with

caution as potential predator and prey species within the Coorong may not co-occur in the geographic areas from which data were derived. Trophic links from Coorong-based studies were represented by solid lines in the models, while those based on literature outside of the Coorong were represented by dotted lines (Figure 5), with Coorong-based links overriding those based on outside literature.

Information from dietary studies in the Coorong, regardless of whether they were conducted during low or high inflow periods, were pooled to develop a general food-web model (Model CM). Specific models were developed for different inflow periods and regions based on contemporary data collected through the aforementioned studies (Section 2.1). To reduce complexity in food-web models, only trophic links from 'major' diet items (i.e. >~10% by volumetric contribution or importance indices from literature) were included for fishes and the long-nosed fur seal (*Arctocephalus forsteri*). Coorong-based trophic links for the long-nosed fur seal were based on major prey items (reconstructed biomass) from both scat and stomach-content analyses (SARDI unpublished data, Table A2, Appendix 4). Mulloway was included as a major prey item for the long-nosed fur seal based on results from the stomach-content analysis, which was represented by low sample size ( $n = 2$ ). Detailed diet studies were not available for birds; therefore, any prey species reported in their diet were linked in the model (Appendix 4). For birds and seals, models represent the trophic links and estimated proportions of Coorong prey only and do not consider outside foraging (i.e. birds and seals feeding in lacustrine, terrestrial or marine environments).

Basic trophic links from primary producers to primary consumers (i.e. most benthic invertebrates and zooplankton) were created based on feeding mode information from various feeding ecology studies, which were mostly conducted outside of the Coorong (Appendix 4). In the food-web models, zooplankton feeding was generalised to phytoplankton. The zooplankton group included benthic and pelagic species and thus, it is acknowledged that this group may also be supported by benthic microalgae or detritus. Decomposers (i.e. bacteria and fungi) are represented by the trophic link from benthic algae/macrophytes to detritus.

### 3. RESULTS

#### 3.1 Overall Coorong Model (Model CM)

Figure 6 is a simple qualitative representation of the food-web for the entire Coorong that has not been divided by geographical area/flow periods. Key information is summarised below:

- Carbon (energy) is provided to the Coorong food-web through benthic (i.e. detritus and benthic algae/macrophytes) and pelagic (i.e. phytoplankton) production.
- Phytoplankton (e.g. chlorophytes, diatoms and dinoflagellates) act as a food source for the tubeworm *Ficopomatus enigmaticus* and zooplankton (e.g. rotifers, cladocerans, copepods, ostracods and meroplankton), which, in turn, are important food sources for smaller-bodied pelagic fishes such as sandy sprat (Bice *et al.* 2016), Australian smelt (*Retropinna semoni*) (Lieschke and Gloss 1999), juvenile bony herring (Atkins 1984) and river garfish (*Hyporhamphus regularis*) (Tibbets and Carseldine 2005). Zooplankton is also likely to be important food source for the larval stages of many fishes (not shown in model).
- Benthic macroalgae (e.g. filamentous green algae, *Ulva*, *Cladophora* and *Rhizochlonium*), microalgae and macrophytes (i.e. *Ruppia tuberosa*) provide food for grazing benthic macroinvertebrates (e.g. amphipods and gastropods), herbivorous waterbirds (e.g. black swan) (Marchant and Higgins 1990) and omnivorous fishes (e.g. yellow-eye mullet) (Giatas 2012).
- After decomposition, algae and plants are converted to detritus, which is important in the diet of many benthic macroinvertebrates (e.g. deposit feeding polychaetes and amphipods) and omnivorous fishes, i.e. yellow-eye mullet (Giatas 2012), common carp (*Cyprinus carpio*) (Hall 1981) and sub-adult/adult bony herring (Atkins 1984).
- While most benthic invertebrates (e.g. amphipods, most annelids, insect larvae, gastropods and bivalves) in the Coorong are primary consumers, a number of species/groups are omnivorous (e.g. nereid polychaete *Simplisetia aequisetis* and mysid shrimp) or carnivorous (e.g. nephtyid polychaete *Aglaophamus australiensis*) (Deegan *et al.* 2010; Giatas 2012; Johnson 2014).
- Benthic invertebrates form important components of the diet of many benthic-feeding fishes such as greenback flounder (Earl 2014), congolli (Johnson 2014; Giatas and Ye 2015), smallmouthed hardyhead (Geddes and Francis 2008; Deegan *et al.* 2010; L. Silvester unpublished data; A. Hossain unpublished data) and gobies (Geddes and Francis 2008; L. Silvester unpublished data; A. Hossain unpublished data), as well as

shorebirds (Higgins and Davies 1996). Whilst gobies and smallmouthed hardyhead may also feed on zooplankton, they primarily feed on benthic invertebrates (Geddes and Francis 2008; L. Silvester unpublished data; A. Hossain unpublished data).

- Shorebirds such as red-neck stint, banded stilt, sharp-tailed sandpiper, black-winged stilt, red-capped plover and red-necked avocet) may feed on a variety of benthic invertebrates (e.g. polychaetes, oligochaetes, insect larvae and molluscs), *Ruppia tuberosa* seeds and turions, and brine shrimp (Higgins and Davies 1996).
- Sandy sprat, smallmouthed hardyhead and gobies are important prey species in the diet of larger fishes (i.e. mulloway, black bream and Australian salmon) (Hall 1986; Geddes and Francis 2008; Deegan *et al.* 2010; Giatas and Ye 2015).
- Large-bodied yellow-eye mullet and black bream are omnivorous and have a diverse prey range. Black bream diet may include teleosts (gobies and hardyhead), benthic invertebrates (e.g. crabs, polychaetes and bivalves) and filamentous algae (Weng 1970; Deegan *et al.* 2010). Yellow-eye mullet may feed on benthic invertebrates (polychaetes, amphipods, shrimp and crabs), diatoms, detritus and filamentous algae (Geddes and Francis 2008; Deegan *et al.* 2010; Giatas 2012).
- Mulloway is the highest level teleost in the Coorong food-web, feeding on a variety of teleosts including yellow-eye mullet, sandy sprat, smallmouthed hardyhead, congolli, bony herring and gobies (Hall 1986; Geddes and Francis 2008; Deegan *et al.* 2010; Giatas and Ye 2015). The large crab *Paragrapsus gaimardii* is also likely to be an important food source for medium-sized mulloway (400–700 mm in total length, TL) (Giatas and Ye 2015), while benthic invertebrates such as mysid shrimp and amphipods are important for small mulloway (<400 mm TL) (Hall 1986; Giatas and Ye 2015).
- Piscivorous birds such as Australian pelican (*Pelecanus conspicillatus*), cormorants (*Phalacrocorax* spp.) and terns (Family Sternidae) are capable of feeding on a variety of benthic and pelagic teleost prey (Marchant and Higgins 1990; Higgins and Davies 1996).
- The long-nosed fur seal, when present, is the apex predator of the Coorong and may feed on a variety of teleost prey including common carp, bony herring and mulloway (SARDI unpublished data).
- Other fishes present in low abundances in the Coorong (i.e. <1% of total large-bodied or small-bodied fish abundances by number), that are not shown in the diagram include longsnout flounder (*Ammotretis rostratus*), other mugilids (e.g. goldspot mullet *Liza argentea* and sea mullet *Mugil cephalus*), small-bodied marine species (e.g. Australian anchovy *Engraulis australis*), common galaxias (*Galaxias maculatus*), striped grunter

(*Pelated octolineatus*), toadfishes, redfin perch (*Perca fluviatilis*), golden perch (*Macquaria ambigua*), yellowfin whiting (*Sillago schomburgkii*), goldfish (*Carassius auratus*) and soldier (*Gymnapistes marmoratus*). Cartilaginous fishes include the southern eagle ray (*Myliobatis australis*).

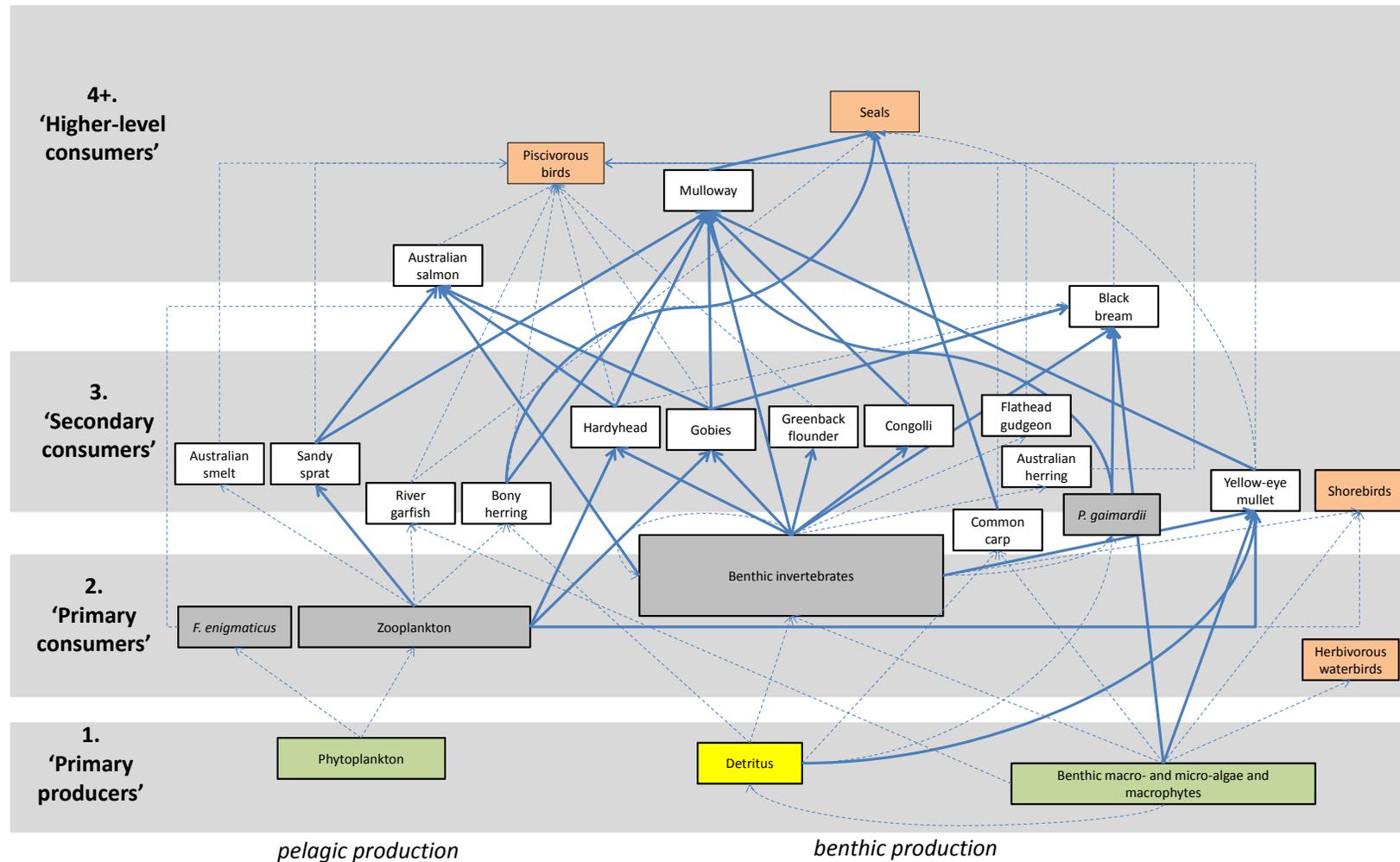


Figure 6. Overall conceptual model of the Coorong food-web (Model CM). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts. Despite contributing <1% by total gill net catch, black bream was included in the overall model as it is a commercially important species that was previously abundant.

## 3.2 Coorong model – Low inflow period

### 3.2.1 Model CML

A food-web model was constructed (Figure 7) for the Coorong during low freshwater inflows (i.e. <1,200 GL/yr). Refer to the following three models (Figure 8; Figure 9; Figure 10) for further breakdown by region. Key information is summarised below:

- Mulloway, Australian salmon and yellow-eye mullet are abundant large-bodied fishes during low inflows. Smallmouthed hardyhead is the most abundant small-bodied fish, followed by sandy sprat.
- Smallmouthed hardyhead, yellow-eye mullet and sandy sprat are likely to be the most important prey species for mulloway and piscivorous birds in the Coorong. Mulloway diet may also include the crab *P. gaimardii*, while Australian salmon is also likely to be important in the diet of piscivorous birds.
- The marine species Australian herring (*Arripis georgianus*) and freshwater species bony herring are present in low to moderate abundances.
- Other fishes present in low abundance during low inflows in the Coorong, but not shown in the diagram, are gobies, longsnout flounder, Australian anchovy, common galaxias, congolli, Australian smelt, striped grunter, other mugilids, toadfishes and black bream.
- Diatoms and dinoflagellates are the most abundant phytoplankton in the Coorong during low inflows (Leterme *et al.* 2015).
- Zooplankton that are likely to be present and abundant during low inflows include halotolerant rotifers (e.g. *Synchaeta*), various estuarine meroplankton (crab, bivalve, polychaete and gastropod larvae) and halotolerant/estuarine calanoid and harpacticoid copepods, copepodites and nauplii (Geddes 2005; Geddes and Tanner 2007; Geddes *et al.* 2016). Small barrage releases during low inflows may have the potential to transfer freshwater species (e.g. calanoid copepod, *Boeckella* spp.); however, abundances of these species are confined to close proximity of the barrages (Geddes 2005; Geddes *et al.* 2016).
- The deposit-feeding polychaete *Capitella capitata*, the omnivorous nereid polychaete *S. aequisetis* and the bivalve *Arthritica helmsi* are the benthic macroinvertebrates that characterised the Coorong during low inflows (Dittmann *et al.* 2014). Abundances and distributions of most benthic invertebrates are likely to be restricted to the Murray Estuary and the northern end of the North Lagoon (Dittmann *et al.* 2013).

- Zooplankton abundances during low freshwater inflows are likely to be low (Geddes 2005; Geddes and Tanner 2007; Geddes *et al.* 2016). Productivity in the Coorong during these inflows would, therefore, be more dependent upon the benthic-detritus component of the food web, supporting primary consumers such as benthic invertebrates, and in turn secondary consumers such as smallmouthed hardyhead and yellow-eye mullet.
- *R. tuberosa*, the most common macrophyte in the system, is likely to be distributed between the southern part of the North Lagoon and the most northern part of the South Lagoon during low inflows (Paton and Bailey 2014).

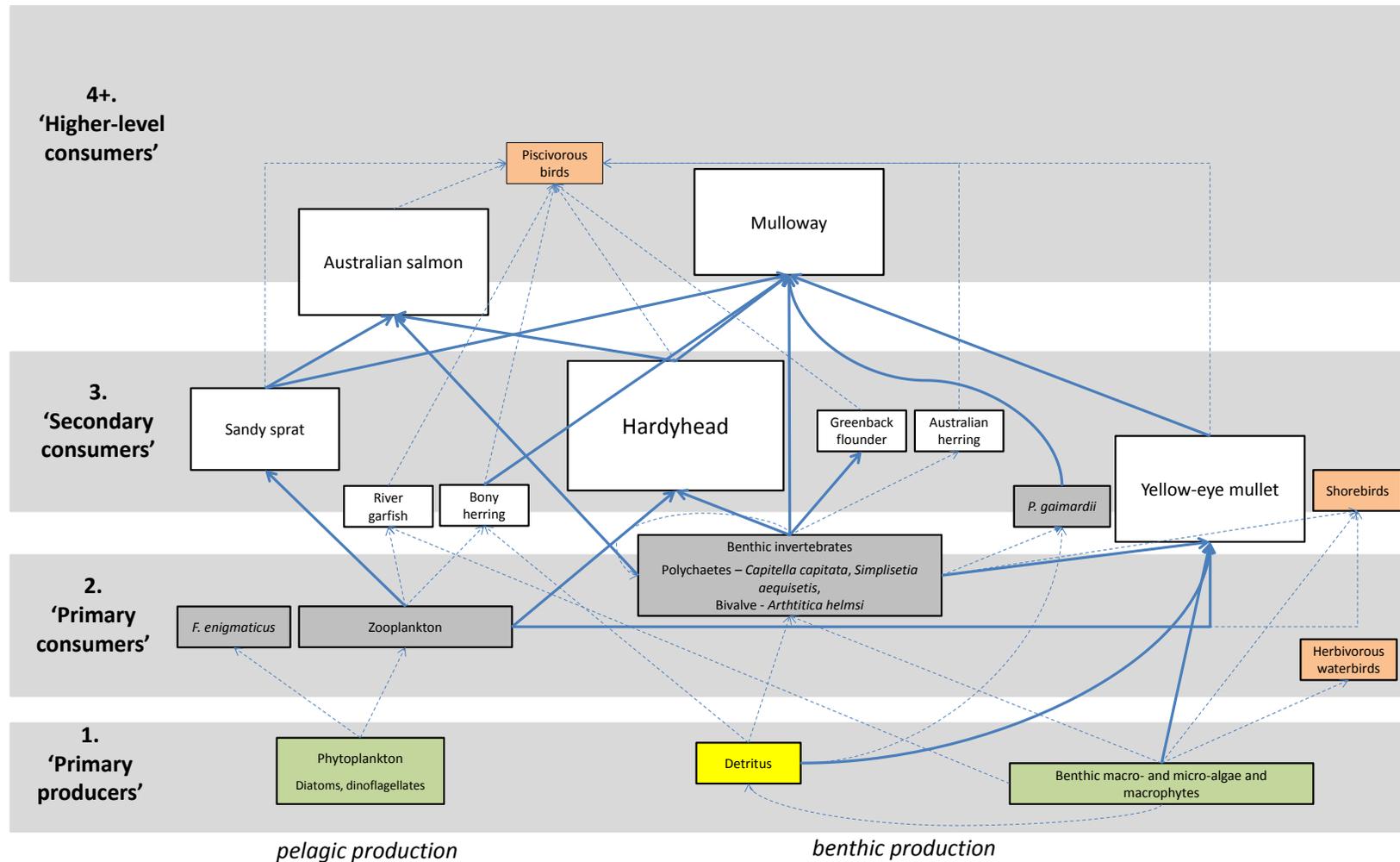


Figure 7. Low inflow conceptual model of the Coorong food-web (Model CML). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts. Seals are likely to be rare in the Coorong during low inflows.

### 3.2.2 Model CMLE

A food-web model was constructed (Figure 8) for the Murray Estuary during low freshwater inflows where salinities are marine (~30–45 ppt). Key information is summarised below:

- Sandy sprat and smallmouthed hardyhead are the two most abundant small-bodied fishes in the Murray Estuary region during low inflows, while Australian salmon, mulloway and yellow-eye mullet are the most abundant large-bodied fishes.
- Mulloway diet is likely to be comprised mostly of sandy sprat, yellow-eye mullet and smallmouthed hardyhead. Mulloway diet may also include the crab *P. gaimardii*.
- Sandy sprat and smallmouthed hardyhead are likely to be the most important prey species for Australian salmon.
- Piscivorous bird diet is likely to be comprised of mainly sandy sprat, Australian salmon, smallmouthed hardyhead and yellow-eye mullet.
- Other fishes present in low abundance in the Murray Estuary during low inflows, but not shown in the diagram, are longsnout flounder, gobies, Australian anchovy, common galaxias, congolli, Australian smelt, striped grunter, black bream and other mugilids.
- Dinoflagellates and diatoms are the most abundant phytoplankton in the Murray Estuary during low inflows (Leterme *et al.* 2015).
- Zooplankton that are likely to be abundant include calanoid copepodites, nauplii and adults (*Gladioferens* spp. and *Boeckella*), halotolerant rotifer *Synchaeta*, and meroplankton (crustacean, bivalve and gastropod larvae) (Geddes 2005; Geddes and Tanner 2007; Geddes *et al.* 2016).
- The benthic macroinvertebrate assemblage in the Murray Estuary during low inflows is characterised by the deposit-feeding polychaete *C. capitata*, the small bivalve *A. helmsi*, amphipods and the omnivorous nereid polychaete *S. aequisetis* (Dittmann *et al.* 2013). These species are likely to be important in the diet of shorebirds, yellow-eye mullet, smallmouthed hardyhead, small Australian salmon (<100 mm TL), small mulloway (<400 mm TL), greenback flounder and Australian herring.
- Both benthic and pelagic production appears to be important for higher-level consumers during low inflows in the Murray Estuary, i.e. 1) detritus and benthic algae/macrophytes → benthic invertebrates → smallmouthed hardyhead and yellow-eye mullet → mulloway, Australian salmon and piscivorous birds, 2) phytoplankton → zooplankton → sandy sprat, river garfish and juvenile bony herring → Australian salmon, mulloway and piscivorous birds.

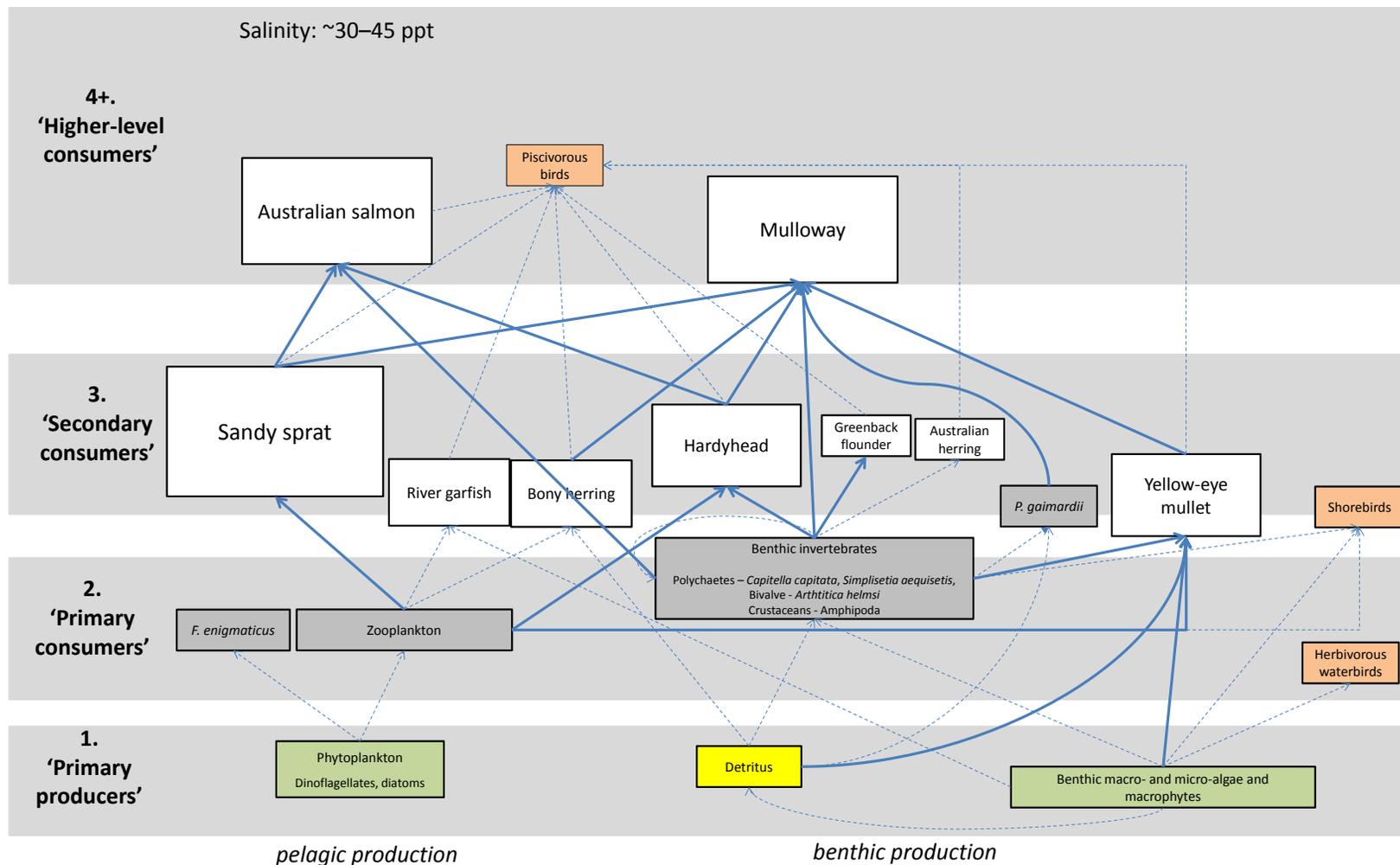


Figure 8. Low inflow conceptual model of the Coorong food-web for the Murray Estuary (Model CMLE). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts. Seals are likely to be rare in the Coorong during low inflows.

### 3.2.3 Model CMLN

A food-web model was constructed (Figure 9) for the North Lagoon during low freshwater inflows where salinities are marine to hypermarine (~45–120 ppt). Key information is summarised below:

- Smallmouthed hardyhead and yellow-eye mullet are the two most abundant small- and large-bodied fishes, respectively, in the North Lagoon region during low inflows.
- Mulloway and piscivorous bird diet is likely to be comprised mostly of smallmouthed hardyhead and yellow-eye mullet. Mulloway diet may also include the crab *P. gaimardii*.
- Other fishes present in low abundance in the North Lagoon during low inflows, but not shown in the diagram, are longsnout flounder, gobies, river garfish, congolli, greenback flounder, other mugilids, toadfishes and bony herring.
- Diatoms and dinoflagellates are the most abundant phytoplankton in the North Lagoon during low inflows (Leterme *et al.* 2015).
- Zooplankton that are likely to be abundant include the halotolerant rotifer *Synchaeta*, meroplankton (mainly bivalve larvae) and halotolerant harpacticoid copepods, copepodites and nauplii (Geddes 2005; Geddes and Tanner 2007; Geddes *et al.* 2016).
- The benthic macroinvertebrate assemblage in the North Lagoon during low inflows is characterised by insect larvae (Chironomidae) and the deposit-feeding polychaete *C. capitata* (Dittmann *et al.* 2013), which are likely to be important in the diet of shorebirds, yellow-eye mullet and smallmouthed hardyhead. Shorebirds may also feed on *R. tuberosa* seeds and turions, which may be present in the southern part of the North Lagoon (Paton and Bailey 2014).
- Benthic production appears to be the most important means of production for higher level consumers during low inflows in the North Lagoon, i.e. detritus and benthic algae/*R. tuberosa* → *C. capitata* and chironomid larvae → smallmouthed hardyhead and yellow-eye mullet → mulloway and piscivorous birds.

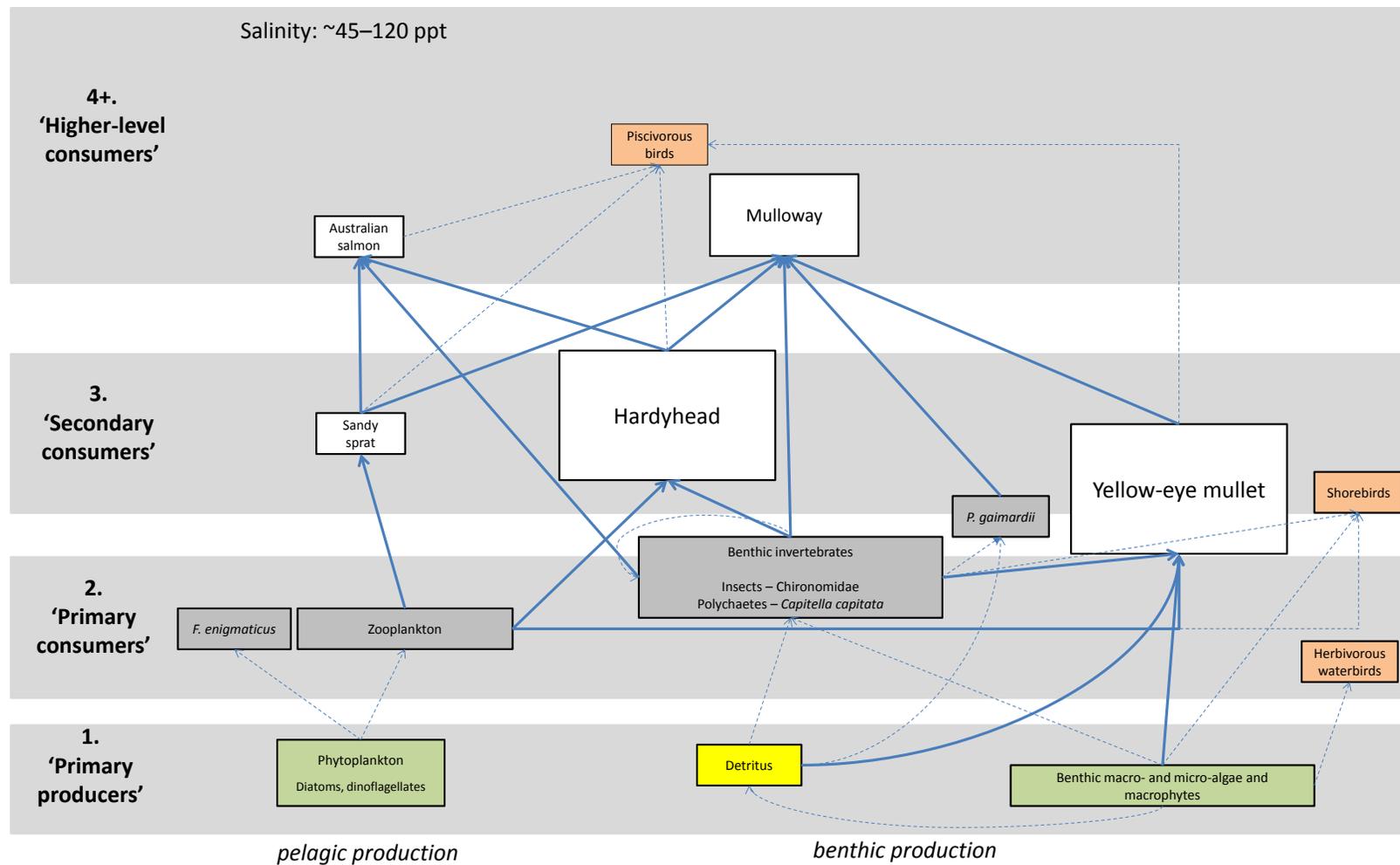


Figure 9. Low inflow conceptual model of the Coorong food-web for the North Lagoon (Model CMLN). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts. Seals are likely to be rare in the Coorong during low inflows.

### 3.2.4 Model CMLS

A food-web model was constructed (Figure 10) for the South Lagoon during low freshwater inflows where salinities are extremely hypermarine (>120 ppt). Key information is summarised below:

- Despite exceeding the species' threshold (LD<sub>50</sub>) of 108 ppt (Lui 1969), smallmouthed hardyhead is expected to occur in low abundance in the most northern part of the South Lagoon (Noell *et al.* 2009). The distribution of foraging by piscivorous birds is likely to be restricted to this area given that no other fishes will be present in the South Lagoon during low inflows.
- Diatoms and dinoflagellates are the most abundant phytoplankton in the South Lagoon during low inflows (Leterme *et al.* 2015).
- Benthic macroinvertebrate diversity is low and characterised by chironomid larvae and pupae (*Tanytarsus barbitarsis*). Other benthic macroinvertebrates present include gastropods (Dittmann *et al.* 2013). Ostracods are likely to be abundant, while brine shrimp may also be abundant (Paton and Rogers 2008). Chironomids are likely to be the main food source for shorebirds and smallmouthed hardyhead.
- *R. tuberosa* may be present in the northern part of the South Lagoon, which may provide shorebirds with an additional food source (i.e. seeds and turions) (Rogers and Paton 2009a).
- Benthic production appears to be the most important means for higher-level consumers during low inflows in the South Lagoon, i.e. detritus and benthic algae/*R. tuberosa* → chironomid larvae → smallmouthed hardyhead and shorebirds → piscivorous birds.

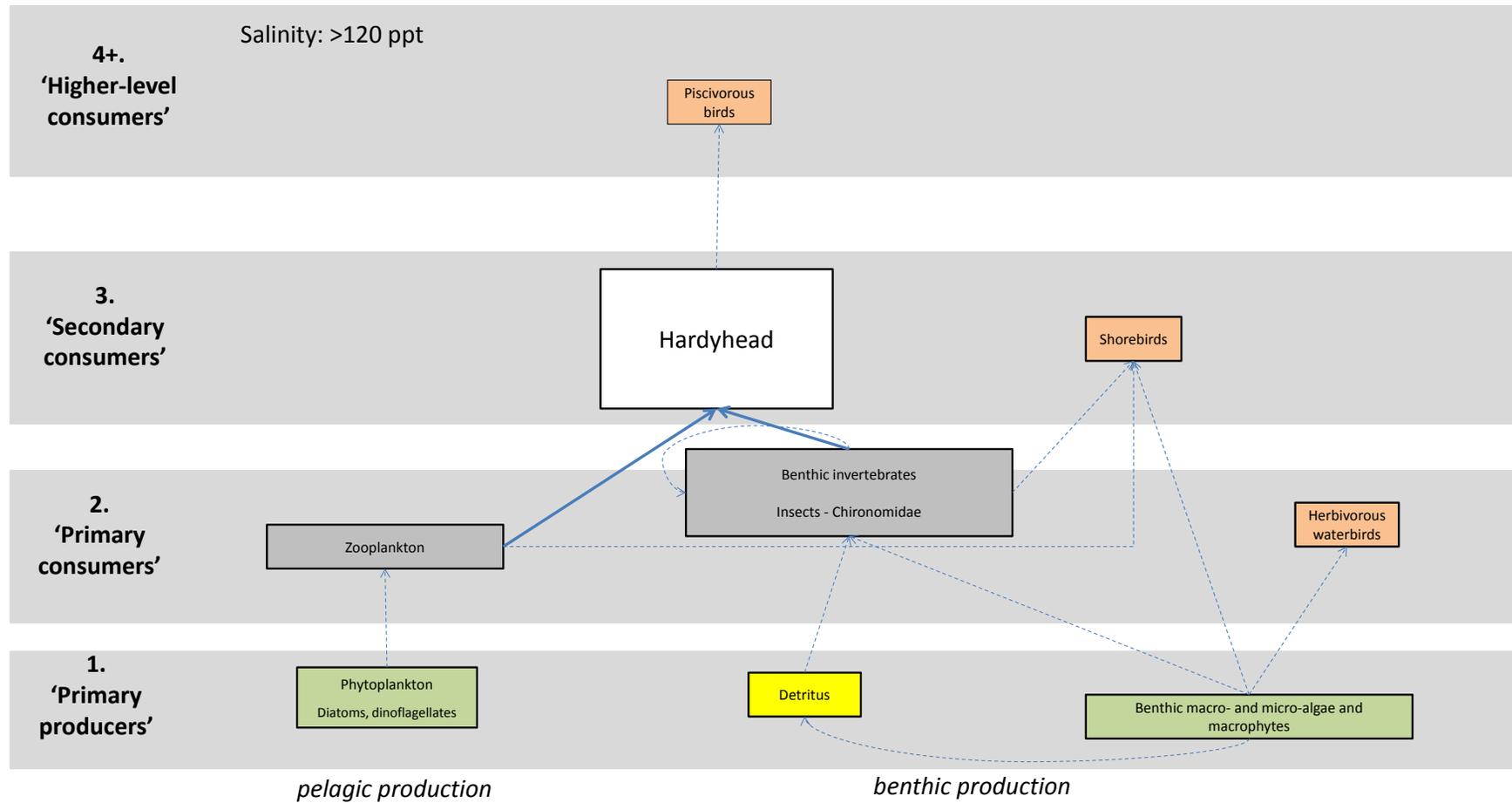


Figure 10. Low inflow conceptual model of the Coorong food-web for the South Lagoon (Model CMLS). Benthic invertebrates include insect larvae. Trophic levels of biota are shown using shaded bands. Hardyhead = smallmouthed hardyhead.

### 3.3 Coorong model – High inflow period

#### 3.3.1 Model CMH

A food-web model was constructed (Figure 11) for the Coorong during high freshwater inflows (i.e. >5,000 GL/yr). Refer to the following three models (Figure 12; Figure 13; Figure 14) for further breakdown by region. Key information is summarised below:

- Bony herring and yellow-eye mullet are the most abundant large-bodied fishes during high inflows, while smallmouthed hardyhead and sandy sprat are the most abundant small-bodied fishes.
- Mulloway diet is likely to be comprised of various teleosts including bony herring, smallmouthed hardyhead, sandy sprat, yellow-eye mullet and gobies. Mulloway diet may also include the crab *P. gaimardii*.
- Smallmouthed hardyhead and sandy sprat are likely to be the most important prey species for Australian salmon, but diet may also include gobies.
- The freshwater species bony herring and common carp are present in high and low to moderate abundance, respectively, during high inflows.
- Piscivorous bird diet is likely to be comprised of mainly bony herring, smallmouthed hardyhead and sandy sprat, while long-nosed fur seal diet is mainly comprised of bony herring.
- Other fishes present in low abundance in the Coorong, but not shown in the diagram, are Australian smelt, congolli, flathead gudgeon (*Philypnodon grandiceps*), common galaxias, longsnout flounder, river garfish, redfin and golden perch, other mugilids, greenback flounder, black bream, Australian herring and yellowfin whiting.
- During high inflows, chlorophytes are the most abundant phytoplankton in the Coorong below 20 ppt, while diatoms are abundant over 20 ppt (Leterme *et al.* 2015).
- The zooplankton assemblage will be dominated by freshwater species during high inflows (Shiel and Tan 2013a). Zooplankton that are likely to be abundant in the Murray Estuary and North Lagoon include protists (e.g. the tintinnid *Stenosemella*), rotifers (*Keratella* and *Synchaeta*), cladocerans (*Daphnia* and *Moina*) and the calanoid copepod *Boeckella* (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b). Halophilic/halotolerant zooplankton such as tintinnids, rotifers, harpacticoid and calanoid (e.g. *Acartia*) copepods, and meroplankton (bivalve and crab larvae) will also be abundant, particularly further into

the salinity gradient from Mark Point into the South Lagoon (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b).

- Insect larvae (Chironomidae) and amphipods are the benthic macroinvertebrates that characterised the Coorong during high inflows (Dittmann *et al.* 2014). Abundances and diversity of macroinvertebrates are greatest in the North Lagoon where the range of salinities is broad, i.e. freshwater to hypermarine (Dittmann *et al.* 2013). Mysid shrimp are also likely to be more abundant when compared to their presence under low inflows (Dittmann *et al.* 2014), which is considered to be highly beneficial for juvenile mullet food supply (Marais 1984; Griffiths 1997; Taylor *et al.* 2006; Giatas and Ye 2015).
- Zooplankton abundance during high freshwater inflows is higher compared to that during low inflows (Shiel and Aldridge 2011; Shiel and Tan 2013a); therefore, the pelagic component of the food-web plays a greater role in the energy transfer, through zooplankton, to secondary consumers such as juvenile bony herring and sandy sprat. The relative contribution of zooplankton in the diet of smallmouthed hardyhead and gobies is likely to increase.
- Freshwater inflows may also be responsible for directly translocating freshwater zooplankton from the freshwater habitat (Lower Lakes) into the Coorong (Shiel and Tan 2013a).
- *R. tuberosa* is likely to be distributed throughout most of the South Lagoon and may be present at the most southern part of the North Lagoon (Frahm *et al.* 2012; Paton and Bailey 2014).

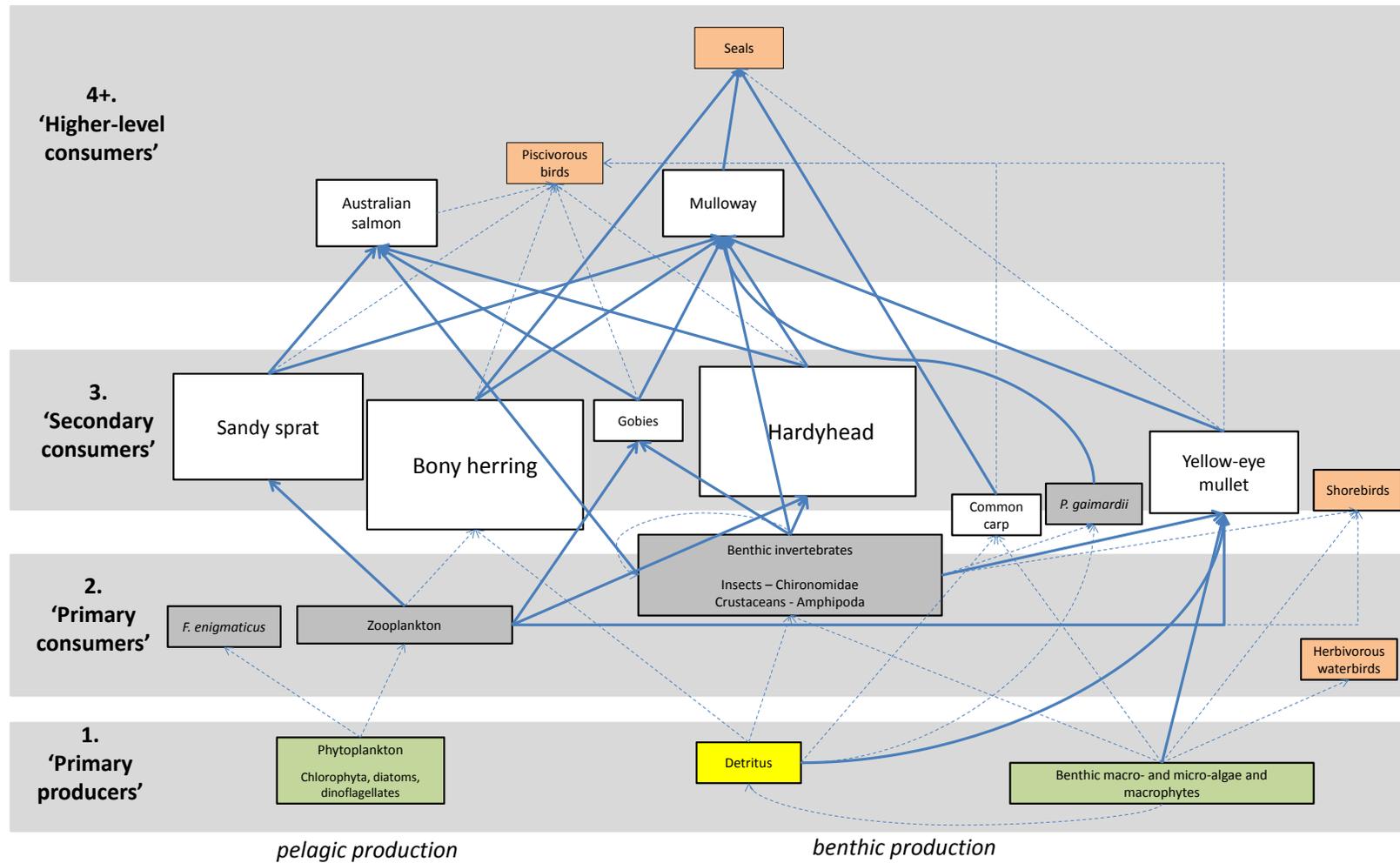


Figure 11. High inflow conceptual model of the Coorong food-web (Model CMH). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts.

### 3.3.2 Model CMHE

A food-web model was constructed (Figure 12) for the Murray Estuary region during high freshwater inflows where salinities are fresh to brackish (~0–15 ppt). Key information is summarised below:

- The fish assemblage in the Murray Estuary during high inflows is diverse and includes greater contributions by freshwater species (i.e. bony herring, common carp, flathead gudgeon and Australian smelt) compared to low inflows.
- Bony herring and sandy sprat are the two most abundant large- and small-bodied fishes, respectively.
- Mulloway diet is likely to be comprised mostly of sandy sprat, bony herring and yellow-eye mullet. Mulloway diet may also include the crab *P. gaimardii*, smallmouthed hardyhead and gobies.
- Sandy sprat and smallmouthed hardyhead are likely to be the most important prey species for Australian salmon.
- Piscivorous bird diet is likely to be comprised of mainly bony herring and sandy sprat, while long-nosed fur seal diet is mainly comprised of bony herring.
- Other fishes present in low abundance in the Murray Estuary during high inflows, but not shown in the diagram, are congolli, common galaxias, longsnout flounder, river garfish, redfin and golden perch, other mugilids, black bream, goldfish and yellowfin whiting.
- Chlorophytes are the most abundant phytoplankton in the Murray Estuary during high inflows (Leterme *et al.* 2015).
- During high inflows, the Murray Estuary zooplankton assemblage will be dominated by freshwater species (Shiel and Tan 2013a). Zooplankton that are likely to be present and abundant include protists (e.g. the tintinnid *Stenosemella*), rotifers (*Keratella* and *Synchaeta*), cladocerans (*Daphnia* and *Moina*) and the calanoid copepod *Boeckella* (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b).
- The benthic macroinvertebrate assemblage in the Murray Estuary during high inflows is characterised by amphipods and chironomid insect larvae (not *T. barbataris*) (Dittmann *et al.* 2013), which are likely to be important in the diet of shorebirds, yellow-eye mullet, smallmouthed hardyhead, gobies, flathead gudgeon, small Australian salmon (<100 mm TL) and small mulloway (<400 mm TL).
- Pelagic production appears to be the most important means of production for higher level consumers during high inflows in the Murray Estuary, i.e. phytoplankton → zooplankton

→ sandy sprat and juvenile bony herring → Australian salmon, mulloway, piscivorous birds and long-nosed fur seal.

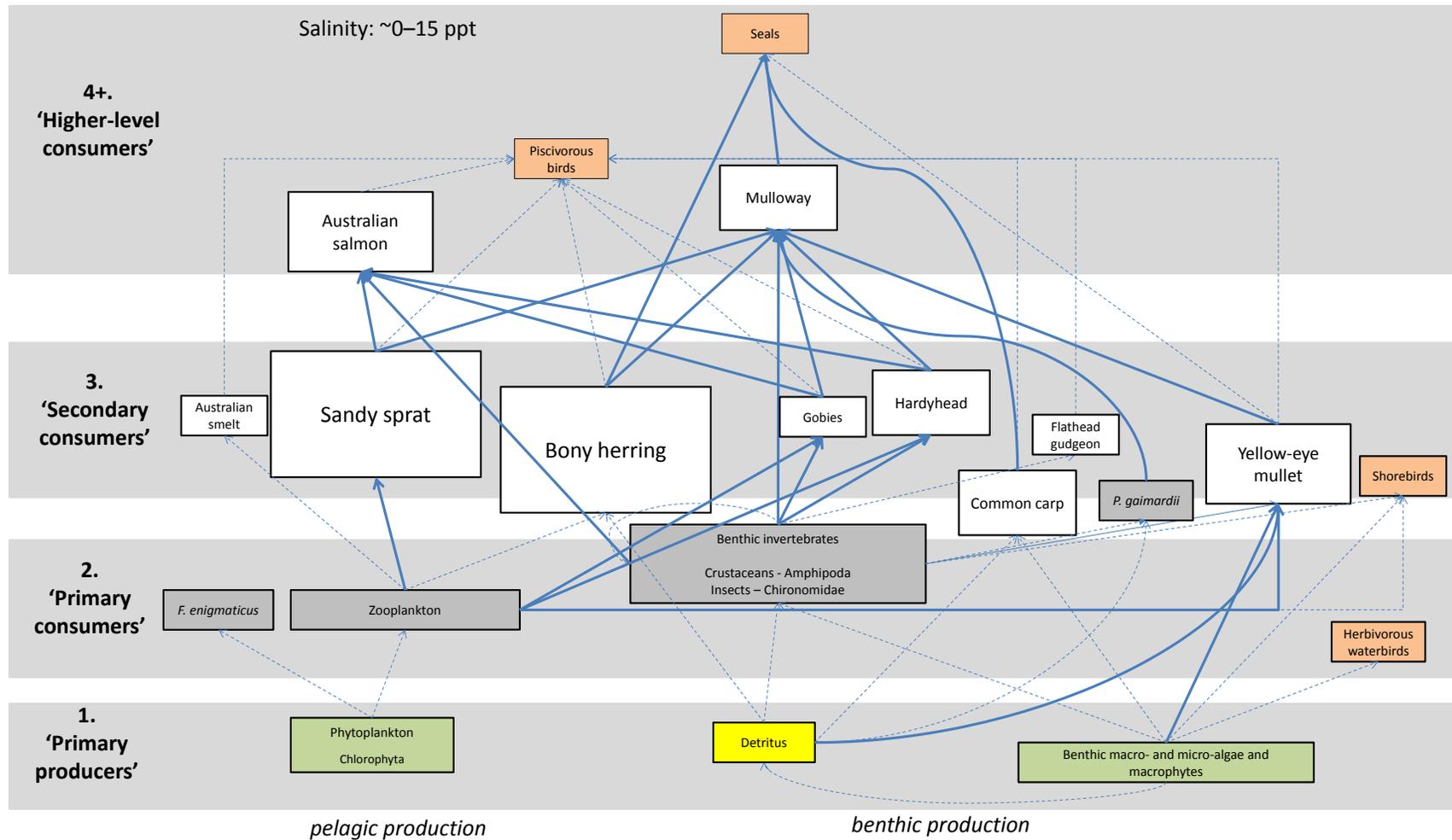


Figure 12. High inflow conceptual model for the Coorong food-web in the Murray Estuary (Model CMHE). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts.

### 3.3.3 Model CMHN

A food-web model was constructed (Figure 13) for the North Lagoon region during high freshwater inflows where salinities are brackish to hypermarine (~15–75 ppt). Key information is summarised below:

- In terms of the fish assemblage, the North Lagoon model during high inflows is similar to the Murray Estuary model during high inflows (Figure 12), although it lacks the presence of some freshwater fishes and there is a greater relative abundance of smallmouthed hardyhead.
- Bony herring is the most abundant large-bodied species and smallmouthed hardyhead and sandy sprat are the two most abundant small-bodied fishes in the North Lagoon during high inflows.
- Mulloway diet is likely to be comprised mostly of smallmouthed hardyhead, bony herring, sandy sprat and yellow-eye mullet. Mulloway diet may also include the crab *P. gaimardii* and gobies.
- Smallmouthed hardyhead and sandy sprat are likely to be the most important prey species for Australian salmon.
- Piscivorous bird diet is likely to be comprised mainly of smallmouthed hardyhead, bony herring and sandy sprat, while long-nosed fur seal diet is mainly comprised of bony herring.
- Other fishes present in low abundance in the North Lagoon during high inflows, but not shown in the diagram, are congolli, Australian smelt, river garfish, common galaxias, longsnout flounder, flathead gudgeon, common carp, redfin and golden perch, greenback flounder, other mugilids and Australian herring.
- Chlorophytes are the most abundant phytoplankton in the northern part of the North Lagoon during high inflows where salinities are <20 ppt (Leterme *et al.* 2015). Diatoms are more abundant in the southern part of the North Lagoon where salinities are higher (>20 ppt).
- During high inflows, the zooplankton assemblage of the North Lagoon will be dominated by freshwater species (Shiel and Tan 2013a). Zooplankton that are likely to be present and abundant include protists (e.g. the tintinnid *Stenosemella*), rotifers (*Keratella* and *Synchaeta*), cladocerans (*Daphnia* and *Moina*) and the calanoid copepod *Boeckella* (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b). Halophilic/halotolerant zooplankton such as tintinnids, rotifers, harpacticoid and calanoid (e.g. *Acartia*) copepods,

and meroplankton (bivalve and crab larvae) are likely to increase in abundance along the salinity gradient towards the South Lagoon.

- The benthic macroinvertebrate assemblage in the North Lagoon during high inflows is characterised by insect larvae (Chironomidae), amphipods and the deposit-feeding polychaete *C. capitata* (Dittmann *et al.* 2013), which are likely to be important in the diet of shorebirds, smallmouthed hardyhead and yellow-eye mullet, gobies, small Australian salmon (<100 mm) and small mulloway (<400 mm).
- Both benthic and pelagic production appears to be important for higher level consumers during high inflows in the North Lagoon, i.e. 1) detritus and benthic algae/macrophytes → benthic invertebrates → smallmouthed hardyhead and yellow-eye mullet → mulloway, Australian salmon and piscivorous birds; 2) phytoplankton → zooplankton → sandy sprat and juvenile bony herring → Australian salmon, mulloway, piscivorous birds and long-nosed fur seal.
- Filamentous green algae (e.g. *Enteromorpha*) is likely to be the most dominant benthic algae/plant in the North Lagoon during high inflows. *R. tuberosa* may be present at the most southern end of the North Lagoon (Frahm *et al.* 2012; Paton and Bailey 2014).

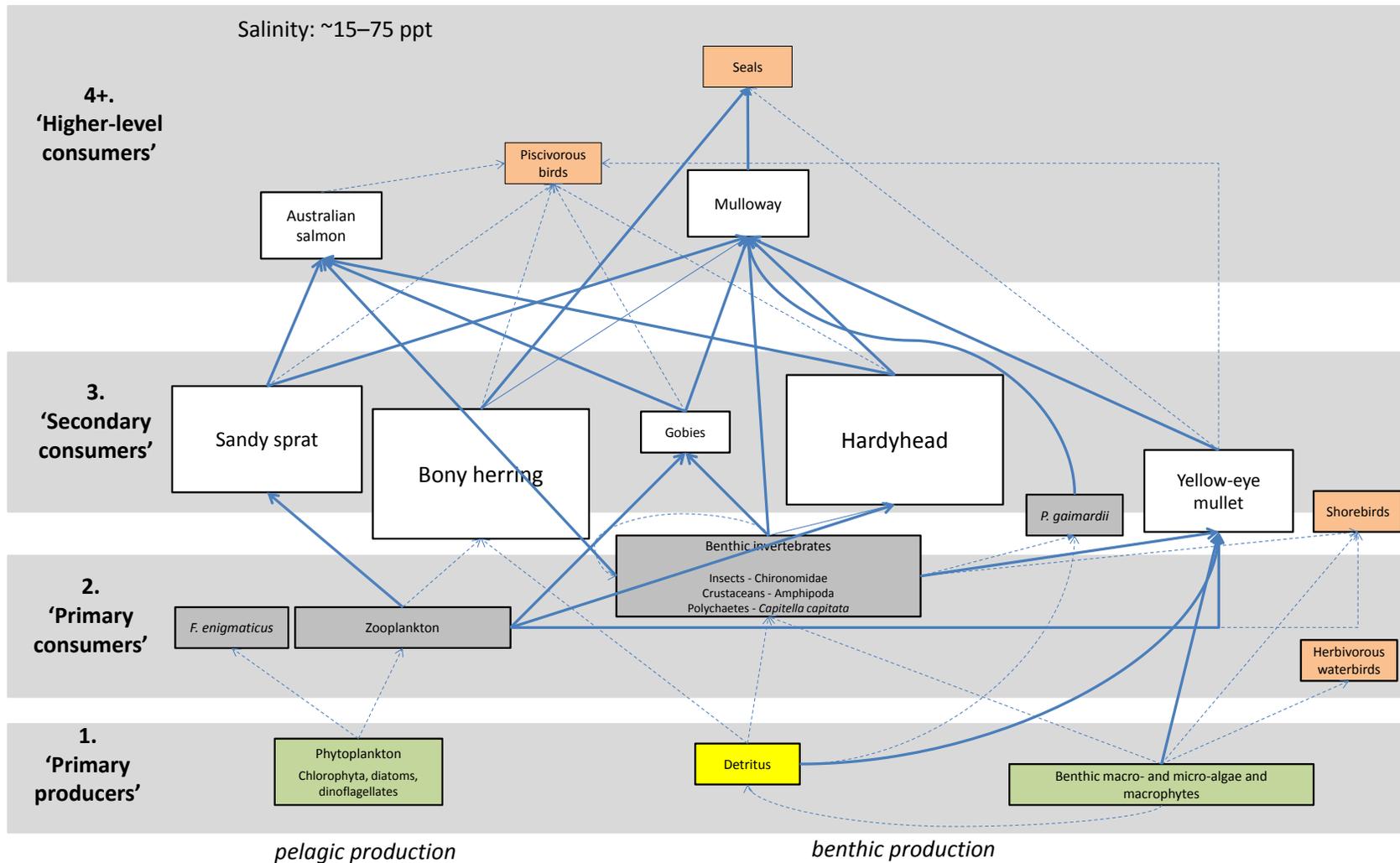


Figure 13. High inflow conceptual model of the Coorong food-web for the North Lagoon (Model CMHN). Benthic invertebrates include amphipods, polychaetes, insect larvae, shrimp, small crabs, bivalves and gastropods. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead. Diet of *Paragrapsus gaimardii* (shore crab) may include teleosts.

### 3.3.4 Model CMHS

A food-web model was constructed (Figure 14) for the South Lagoon during high freshwater inflows where salinities are hypermarine (~75–100 ppt). Key information is summarised below:

- Smallmouthed hardyhead is considerably more abundant during high inflows in the South Lagoon (Livore *et al.* 2013) and likely to occur throughout the region as salinities are below the species' threshold (Lui 1969). In addition to the presence of this species in the region, congolli, gobies, yellow-eye mullet, black bream and bony herring are also present. While only recorded in low abundances, the presence of these species increases the complexity of the food-web structure and provides greater prey diversity for piscivorous birds. Nevertheless, smallmouthed hardyhead is still the dominant fish species in the South Lagoon region during high inflows and is considered to be the most important prey item for piscivorous birds.
- Benthic macroinvertebrate diversity is low and characterised by halophilic chironomid larvae (i.e. *T. barbitarsis*) and amphipods (Dittmann *et al.* 2013). Chironomids are likely to be the main food source for smallmouthed hardyhead and shorebirds.
- Diatoms are the most abundant phytoplankton in the South Lagoon during high inflows (Leterme *et al.* 2015).
- Zooplankton diversity and density in the South Lagoon is likely to be low and include species such as halophilic rotifers (e.g. *Synchaeta*) in the northern part of the South Lagoon (Shiel and Tan 2013b).
- *R. tuberosa* is likely to be present and patchy throughout most of the South Lagoon, which may provide shorebirds with an additional food source (i.e. seeds and turions) (Paton and Bailey 2014).
- Benthic production appears to be the most important means of production for higher level consumers during high inflows in the South Lagoon, i.e. detritus and benthic algae/*R. tuberosa* → chironomid larvae and amphipods → smallmouthed hardyhead and shorebirds → piscivorous birds.

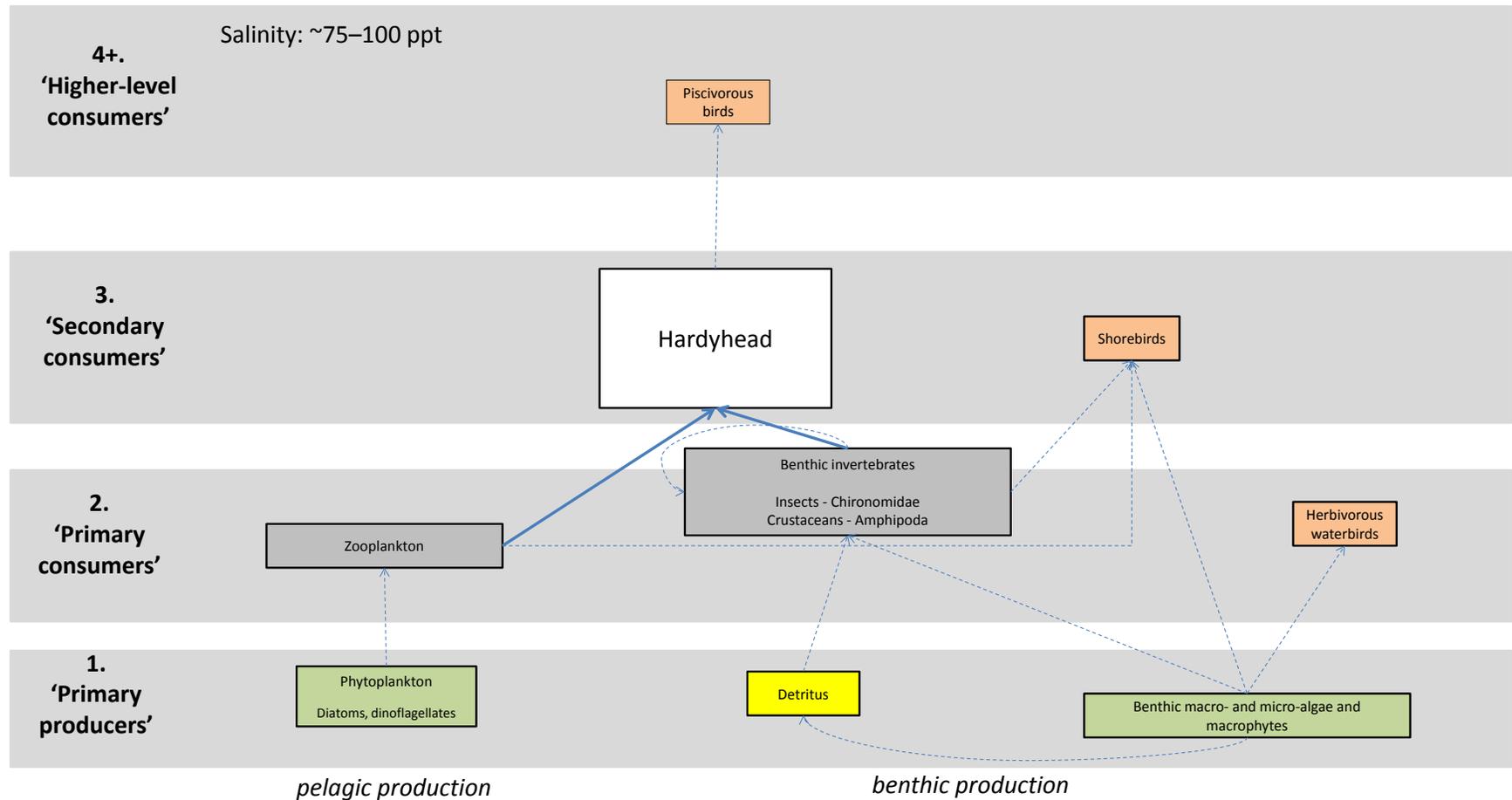


Figure 14. High inflow conceptual model of the Coorong food-web for the South Lagoon (Model CMHS). Benthic invertebrates include amphipods, polychaetes and insect larvae. Trophic levels of biota are shown using shaded bands. Those taxa that occupy intermediate trophic levels (e.g. omnivorous species between level 2 and 3) are situated in the zones of overlapping trophic levels. Some benthic invertebrates are omnivorous or carnivorous so they may extend to the secondary consumers group. Hardyhead = smallmouthed hardyhead.

## 4. DISCUSSION

Conceptual models developed in this study represent our current understanding of the Coorong food-web and how variability in freshwater inflow affects food-web structure, especially in relation to fishes. Models suggest food-web structure is both temporally/hydrologically (i.e. low vs high inflow) and spatially (among regions) variable, driven primarily by salinity, but also differing sources of organic matter under varying hydrology. Development of the food-web models allowed for the identification of key taxonomic groups or species facilitating transfer of energy to higher trophic levels. Amphipods, insect larvae (Family Chironomidae) and the deposit-feeding polychaete *Capitella capitata* appear to be the most abundant benthic invertebrate species and those that are most responsible for the transfer of energy to higher trophic levels through the benthic pathway (e.g. detritus and benthic algae/macrophytes → amphipods, chironomid larvae, *C. capitata* → smallmouthed hardyhead, yellow-eye mullet, gobies, congolli → Australian salmon, mulloway, piscivorous birds and long-nosed fur seal), which dominated in the North and South Lagoons, irrespective of flow conditions.

Relative abundances of fishes were used as an indicator of their importance in the food-web. Smallmouthed hardyhead, sandy sprat and yellow-eye mullet were the most abundant prey fishes in the Coorong food-web during both high and low inflow periods. In addition, the freshwater bony herring was abundant during the high inflow period. Smallmouthed hardyhead and yellow-eye mullet have wide salinity tolerances (McNeil *et al.* 2013) and, accordingly, are distributed throughout the Coorong (Noell *et al.* 2009; Ye *et al.* 2011; 2012; Livore *et al.* 2013). Given their distribution and abundance, these two species are arguably the most important secondary consumers in the Coorong food-web, supporting larger predators such as predatory fishes (e.g. mulloway and Australian salmon) and piscivorous birds (e.g. Australian pelican and terns).

### 4.1 Food-web responses to variable inflows

#### Shift in pelagic vs. benthic coupling

The most noticeable difference in the food-web structure of the Coorong between the two inflow periods was a shift in pelagic–benthic coupling. It was inferred, from relative abundance of fishes (e.g. secondary consumers) (Livore *et al.* 2013) and zooplankton abundance (Shiel and Aldridge 2011; Shiel and Tan 2013a; 2013b), that there was greater relative importance of pelagic production in the Murray Estuary and North Lagoon during years of high freshwater inflows (i.e.

phytoplankton → zooplankton → sandy sprat and juvenile bony herring → Australian salmon, mulloway, piscivorous birds and long-nosed fur seal). Enhanced pelagic productivity was a result of increased zooplankton abundances (dominated by freshwater species) during high inflows, presumably due to: 1) increased primary productivity stimulated from allochthonous nutrient input; and/or 2) direct transportation of zooplankton to the Coorong through inflows.

Conversely, benthic production appeared to play the dominant role in transferring energy to higher trophic levels during low inflows (e.g. detritus and benthic algae/macrophytes → benthic invertebrates → smallmouthed hardyhead and yellow-eye mullet → mulloway, Australian salmon and piscivorous birds), particularly in the North and South Lagoon where pelagic production seems almost absent. The importance of benthic production during low inflows is consistent with other freshwater deprived temperate estuaries (Marais 1984; Whitfield 1999). Recent findings from stable isotope-based studies in the Coorong provide support for a shift in the proportion of carbon source with inflows from benthic to pelagic production and/or a greater influence of river-derived organic carbon in the Coorong food-web transferred to higher trophic levels (Johnson 2014; Bice *et al.* 2016; Giatas and Ye 2015). Past hydrodynamic and biogeochemical modelling in the Coorong also suggests greater influence of riverine nutrients in the estuarine food-web during high inflows (Grigg *et al.* 2009).

### Responses of key biota

The clupeids sandy sprat and bony herring were the key secondary consumers involved in the pelagic loop of the food-web that were, in turn, important food sources for higher level carnivores (e.g. mulloway and piscivorous birds). These two clupeid species were more abundant and important in the Coorong food-web during high freshwater inflows (Livore *et al.* 2013). Being a zooplanktivorous marine species, sandy sprat is likely favoured by increased zooplankton abundances (dominated by freshwater species) during high inflows (Shiel and Aldridge 2011; Shiel and Tan 2013a). This species has demonstrated preferences for freshwater zooplankton species, e.g. the cladoceran *Bosmina meridionalis* (Bice *et al.* 2016). In St. Lucia estuary, South Africa, the increase in abundance of a similar zooplanktivorous clupeid *Gilchristella aestuaria* was linked to zooplankton blooms after freshwater flooding (Martin *et al.* 1992). In South African estuaries, *G. aestuaria* is important in the diet of mulloway (Whitfield and Blaber 1978; Marais 1984; Griffiths 1997) and is also likely to play a pivotal role in the food-web during years of high freshwater inflows, similar to sandy sprat. Bony herring is a freshwater species that shows a distinct ontogenetic shift in diet; zooplankton is replaced almost exclusively by detritus at

approximately 70 mm TL (Atkins 1984; Bunn *et al.* 2003; Medeiros and Arthington 2008b). It is unclear if the increase in the abundance/importance of bony herring in the food-web during high inflows is mostly due to: 1) increased zooplankton abundances, which would be beneficial to juveniles; 2) an increase in favourable habitat as a result of decreased salinities from marine to fresh/brackish; 3) passive transport of individuals through the barrages into the Coorong during high inflows; or 4) a combination of these factors.

A review of macroinvertebrate literature (e.g. Dittmann *et al.* 2013) identified that amphipods characterised the Coorong macroinvertebrate assemblage during years of high freshwater inflows and thus, are considered to be among the most important prey for benthic-feeding fishes during high inflows. Similarly, freshwater zooplankton (Shiel and Aldridge 2011; Shiel and Tan 2013a) and mysid shrimp (Dittmann *et al.* 2014) abundances were higher during high inflows. Zooplankton are widely recognised as a primary food source for most fish larvae and are critical for early stages of growth and recruitment (Werner and Gilliam 1984; Whitfield 1985; Cushing 1990). For many benthivorous feeding fishes in temperate estuaries, a transition from larval to juvenile stages is associated with a shift in diet from small to larger crustaceans, e.g. zooplankton → amphipods → mysid shrimp (Shaw and Jenkins 1992; Edgar and Shaw 1995; Griffiths 1997; Platell *et al.* 2006). The presence of a succession in suitable-sized prey allows for a smooth transition in diet with ontogeny from larval to juvenile stages. Diet studies conducted in the Coorong have considered these prey items to be important in the diet of many small-bodied fishes (Giatas and Ye 2015; L. Silvester unpublished data; A. Hossain unpublished data) and early juveniles of large-bodied species such as mulloway and greenback flounder (Hall 1986; Earl 2014; Giatas and Ye 2015). This could imply that fish recruitment, particularly of large-bodied fishes (e.g. mulloway and greenback flounder), may be enhanced during high freshwater inflows due to increased abundances of zooplankton, amphipods and mysid shrimp. Conversely, low delivery of nutrient and freshwater zooplankton into the Coorong during low inflows reduces food availability for zooplanktivorous, large-bodied larvae/juveniles and small-bodied fishes (Geddes *et al.* 2016). Consequently, preferential predation of large zooplankton may lead to low abundances of larger-sized prey species (e.g. calanoid copepods) and thus, limit fish recruitment (Geddes *et al.* 2016).

#### *Influence of shifts in distribution of biota on food-web structure*

During low inflows and high salinities, contraction of suitable habitat was reflected in food-web structure. Diversity and abundances of macroinvertebrates and fishes were highest in the Murray Estuary region where salinities were marine (~30–45 ppt). Typically uncommon marine fishes

(e.g. Australian herring) were relatively abundant during low inflows in this region, while freshwater species were only recorded in low abundances. Species diversity declined considerably and food chain lengths decreased when progressing into the North and South Lagoons, as previously identified by Deegan *et al.* (2010). Fish abundances in the North Lagoon were dominated by two halotolerant species: smallmouthed hardyhead and yellow-eye mullet. In the South Lagoon, macroinvertebrate diversity was low and smallmouthed hardyhead was the only species of fish present, which was recorded in low abundance and expected to be absent at the southern end of the South Lagoon. During high inflows, favourable habitat (i.e. <~55 ppt) was widespread and extended far into the North Lagoon where fish and macroinvertebrate diversities remained high and food-web complexity increased. Unlike the low inflow period, the South Lagoon macroinvertebrate and fish assemblages comprised multiple taxonomic groups/species (e.g. yellow-eye mullet and gobies), with highly abundant smallmouthed hardyhead (Livore *et al.* 2013).

Models identified that smallmouthed hardyhead and sandy sprat were the two most important small-bodied fishes in the food-web supporting larger predators. Sandy sprat is the most abundant small-bodied species until marine salinities are exceeded. Thereafter, the halotolerant smallmouthed hardyhead replaced sandy sprat as the dominant small-bodied species. During high inflow, the range of habitat with salinity <40 ppt extends from the Murray Mouth to the middle of the North Lagoon. In contrast, sandy sprat distribution is largely restricted to the Murray Estuary during low inflows and probably has little influence on the food-web in the North and South Lagoon. While fish and macroinvertebrate distributions may be primarily structured by salinity (Dittmann *et al.* 2013; Livore *et al.* 2013), distributions of large, mobile, air-breathing predators such as piscivorous birds and the long-nosed fur seal are likely to be highly dependent on the distribution of their prey. For example, piscivorous bird (e.g. fairy tern *Sterna nereis*) distribution of foraging should extend further into the South Lagoon during high inflows where smallmouthed hardyhead are present. Given that foraging of birds and seals is not limited to the Coorong, these biota may derive a significant proportion of their diet composition from other environments. During low inflows, when prey distributions are restricted, piscivorous bird and/or seal foraging may increase in nearby lacustrine habitats (i.e. Lower Lakes).

## 4.2 Model limitations

Generalised conceptual food-web models were created for two inflow periods using data pooled from multiple years that best represented a particular inflow scenario. It is important to note that species composition, abundance and distribution of biota varied inter-annually within inflow

periods, likely driven by freshwater–estuarine connectivity, salinity, the season of flow and antecedent hydrology. In addition, seasonal variations in salinity and water level, such as salinity reductions in the South Lagoon during winter, may result in intra-annual variations in food-web structure. Coorong food-web models were created for broad spatial scales (i.e. regions), which may encompass a broad range of salinities (e.g. brackish to hypermarine). Food-web structure can change considerably at finer spatial scales within a region as identified previously by Deegan *et al.* (2010), particularly where salinities increase from marine to moderately hypermarine. A finer spatial scale analysis may identify importance of particular species that were not identified as important in the regional models. For example, congolli was considered to play a negligible role in the Coorong food-web for all regions; however, this species can exhibit high localised abundances at slightly more saline sites (e.g. 50–80 ppt, Livore *et al.* 2013) and is an important prey item for larger predatory species such as mulloway in the more saline limits of the predator's distribution (Giatas and Ye 2015).

To keep the models useful and simple to interpret, there was a limit applied to the level of detail each included. These models were simplified through a series of stages of biotic groupings to create the final conceptual models, which did not divide benthic invertebrates into smaller groups. Consequently, benthic invertebrate abundances were not quantitatively incorporated into the models. Models also did not incorporate ontogenetic changes in diet for fishes due to the resulting increase in model complexity; therefore, it is acknowledged that, in reality, food-web models are more complex than what is shown.

When considering the quantitative importance of species or taxonomic groups regarding energy transfer in food-webs, biomass is a more appropriate metric to use. In addition, the level of productivity (i.e. the rate of biomass generated) is another key factor to consider. In the absence of biomass, numerical abundance of fish was used in the current study, which has the potential to overestimate the contribution of small-sized species and underestimate the contribution of large-sized species. Furthermore, gill net catches were used to estimate the relative percentage contribution of large-bodied fishes. For some species such as greenback flounder and black bream, gill nets may not be as efficient in catching these species compared to others (e.g. yellow-eye mullet, bony herring); therefore, abundances of these species may be underestimated. Nonetheless, given these limitations, we feel the models generated best represent, to date, simplified food-webs in the Coorong.

### 4.3 Further research and development of models

The development of these conceptual food-web models focused on interactions involving fishes (as a primary objective and the area of expertise of the authors); however, there is opportunity for these models to be modified and updated across other biotic groups where data and knowledge exists. For example, these models inadequately represent processes that occur at the base of the food-web such as the decomposition of matter (e.g. bacteria) and formation of detritus, and the introduction of freshwater-derived nutrients and organic matter. Further knowledge of these aspects and incorporation into models is required to improve our understanding of the whole Coorong food-web.

Dotted trophic links in food-web models are those that are based on studies outside of the Coorong or personal observations; these require quantitative validation in the Coorong. Whilst recent studies have resolved major knowledge gaps on the diet and trophic interactions of understudied fishes in the Coorong such as congolli (Johnson 2014; Giatas and Ye 2015), Australian salmon (Giatas and Ye 2015) and sandy sprat (Bice *et al.* 2016; A. Hossain unpublished data), the current food-web models suggest data remains lacking on the diet of some fishes (e.g. bony herring) that play an important role in the food-web. More importantly, quantitative investigation of bird species is required in the Coorong, given that all of our current knowledge is based on external literature (Marchant and Higgins 1990; Higgins and Davies 1996; Page *et al.* 2005) or personal observations. Bird diet can be quantitatively analysed using non-invasive methods such as regurgitation or scat analysis, which may be particularly useful for identifying important prey fishes through otolith identification techniques (Fea and Harcourt 1997; Barrett *et al.* 2007). Furthermore, despite not being reflected in current food-web models, our understanding of larval fish diets in the Coorong is poor.

The crab *Paragrapsus gaimardii* is important in the diet of mulloway (Geddes and Francis 2008; Deegan *et al.* 2010; Giatas and Ye 2015) and black bream (Weng 1970; Deegan *et al.* 2010) in the Coorong. No sampling has been conducted using suitable methods to quantify the abundance of this species in the Coorong; therefore, it is unknown if abundance is influenced by inflow, which has implications for the current food-web models. A better understanding of abundance, distribution and the effect of inflows on *P. gaimardii* is required. The tubeworm *Ficopomatus enigmaticus* is abundant and widely distributed throughout the Coorong (Dittmann *et al.* 2009; 2013); however, this species does not seem to have many fish predators, likely due to the morphology of the species' calcareous tubes. *F. enigmaticus* may be consumed by predatory invertebrates (e.g. crabs) or have other important functions such as providing habitat for various

invertebrate species (Davies *et al.* 1989) or maintaining phytoplankton and organic matter levels (Bruschetti *et al.* 2008). Further research into the direct and indirect roles of *F. enigmaticus* in the Coorong food-web is required.

Conceptual models are based on singular low (drought) and high inflow events, which occurred sequentially. During the high inflow event (2010–2013), it is possible that some biota were still in a period of recovery following the drought and that food-web models may differ when multiple high inflow periods are considered. For example, the distribution of *Ruppia tuberosa* pre-drought covered the entire South Lagoon (Geddes and Butler 1984), but by the end of the drought, abundance had declined and distribution contracted to only the northern end of the South Lagoon (Rogers and Paton 2009a). After inflows returned, the distribution of this macrophyte increased; however, it was not to the same extent as pre-drought (Frahn *et al.* 2012; Paton and Bailey 2014). Models will be further strengthened if other drought/flood events are incorporated. Similarly, these models are based on data from monitoring that was conducted during warmer months, namely October–March. Data are deficient for winter months and different species are likely to be important in the food-web given seasonal variation in abundance of species driven by their life-history characteristics.

Conceptual models have been developed for two extreme periods (low and high inflows). When sufficient data are available, conceptual models should also be developed for intermediate inflows (e.g. 2,000–5,000 GL/yr). Furthermore, there is capacity for these semi-quantitative food-web models, which specifically focused on predator–prey interactions, to progress into more quantitative ecosystem models (e.g. Ecopath with Ecosim software) and incorporate other major sources of mortality such as fishing (Pauly *et al.* 2000; Harvey *et al.* 2003; Christensen and Walters 2004).

## 5. CONCLUSION AND MANAGEMENT IMPLICATIONS

To appropriately manage and maintain the ecological character of the Coorong, a *Ramsar Wetland of International Importance*, it is important to understand food-web function, particularly in relation to hydrology. The conceptual models developed in the current study highlight the importance of key species and taxonomic groups involved in the function of the Coorong food-web and describe how different inflow scenarios can affect food-web structure in the Coorong. These models have the potential to aid management of the Coorong, particularly in the context of freshwater inflows.

Inflows are considered to be highly beneficial to the food-web structure of the Coorong. High inflows lead to a reduction in salinities along the longitudinal gradient and an expansion of suitable habitat southeastwards towards, and into, the South Lagoon. Food-web complexity across the Murray Estuary and North Lagoon during high inflows is high – due to the presence of most functional guilds far into the North Lagoon and a relatively greater influence of pelagic production from allochthonous sources, i.e. nutrients or freshwater zooplankton input. Increased food-web complexity implies greater resilience to environmental or biotic disturbances. Furthermore, freshwater inflows are associated with relative increases in small crustaceans such as zooplankton and amphipods, which may provide food resources for juveniles of large-bodied fishes and thus, enhance recruitment. Furthermore, the input of riverine and lacustrine nutrients during high inflow years may be stored in estuaries and can be re-mobilised from the sediment pool during low inflow years, which may help maintain ecological productivity in estuaries during low inflow years (Aldridge *et al.* 2009).

During years when flow in the lower River Murray is low and barrage releases into the Coorong are minimal or absent, managed delivery of environmental water could be beneficial to biota of the Coorong at a local-scale (Geddes 2005; Geddes *et al.* 2016). Environmental water delivery is likely to enhance food-web function and resilience given the anticipated reduction in salinities and subsequent expansion of suitable habitat, and the increase in zooplankton abundance that benefit zooplanktivorous fishes (Bice *et al.* 2016) and higher level predators (Giatas and Ye 2015). Nevertheless, ecological responses to low volumes (~280 GL) are likely to be localised and short-lived (Geddes 2005; Geddes *et al.* 2016), and longer durations and higher frequencies of inflow to the Coorong are likely required for long-term benefits.

The maintenance or ecological restoration of habitat (i.e. salinity, macrophytes and food resources) within the Coorong will contribute to the overall resilience of the ecosystem. Specific

management considerations relating to maintaining or promoting food-web stability and structure include:

- Maintaining regular inflows into the Coorong to expand favourable habitat (i.e. <~55 ppt) and enhance productivity is critical for maintaining/improving food-web complexity and maintaining ecosystem resilience.
- Maintaining freshwater–estuarine and estuarine–marine connectivity is essential for food-web function in the Coorong. Many diadromous and marine fishes, which are important prey or predators in the Coorong, have life history stages that depend on habitat connectivity. Estuarine–marine connectivity through the Murray Mouth may be achieved through adequate freshwater inflows or anthropogenic intervention (e.g. dredging), while freshwater–estuarine connectivity for diadromous species may be achieved through optimal barrage fishway operation.
- When water resources are scarce, low volume deliveries of water may provide localised temporary ecological benefits to the food-web and are recommended during adverse conditions (e.g. extended drought).
- Maintaining the presence and abundance of *Ruppia tuberosa* in the South Lagoon and re-establishing *Ruppia megacarpa* in the North Lagoon, where it was historically prolific, will provide a source of energy for primary consumers through the detrital/benthic pathway.
- Regular monitoring of biotic components (e.g. plankton, macroinvertebrates and fishes) provides an understanding of contemporary species composition and abundances, which allows predictions to be made on food-web structure based upon the models developed.

## 6. REFERENCES

- Alber, M. (2002). A conceptual model of estuarine freshwater inflow management. *Estuaries* **25**, 1246–1261.
- Aldridge, K.T., Payne, A.P. and Brookes, J.D. (2009). Literature review: Nutrient cycling and phytoplankton communities of the Lower River Murray, Lower Lakes and Coorong. The University of Adelaide, Adelaide.
- Allanson, B.R. and Read, G.H.L. (1995). Further comment on the response of Eastern Cape Province estuaries to variable freshwater inflows. *South African Journal of Aquatic Sciences* **21**, 56–70.
- Atkins, B. (1984). Feeding ecology of *Nematolosa erebi* in the lower River Murray. Honours Thesis, University of Adelaide, Adelaide.
- Balcombe, S.R., Bunn, S.E., Davies, P.M. and McKenzie-Smith, F.J. (2005). Variability of fish diets between dry and flood periods in an arid zone floodplain river. *Journal of Fish Biology* **67**, 1552–1567.
- Baring, R., Dittmann, S., Dutton, A., Gannon, R., Cummings, C., Humphries, J. and Hunt, T. (2009). Macrobenthic survey 2008: Murray Mouth, Coorong and Lower Lakes Ramsar site. Flinders University, Adelaide.
- Barrett, R.T., Camphuysen, C.J., Anker-Nilssen, T., Chardine, J.W., Furness, R.W., Garthe, S., Hüppop, O., Leopold, M.F., Montevecchi, W.A. and Veit, R.R. (2007). Diet studies of seabirds: a review and recommendations. *ICES Journal of Marine Science* **64**, 1675–1691.
- Becker, A. and Laurenson, L.J.B. (2007). Seasonal and diel comparisons of the diets of four dominant fish species within the main channel and flood-zone of a small intermittently open estuary in south-eastern Australia. *Marine and Freshwater Research* **58**, 1086–1095.
- Bennett, B.A., and Branch, G.M. (1990) Relationships between production and consumption of prey species by resident fish in the Bot, a cool temperate South African estuary. *Estuarine, Coastal and Shelf Science* **31**, 139–155.
- Bice, C.M., Furst, D., Lamontagne, S., Oliver, R.L., Zampatti, B.P. and Revill, A. (2016). The influence of freshwater discharge on productivity, microbiota community structure and trophic dynamics in the Murray estuary: evidence of freshwater derived trophic subsidy in the sandy sprat. Goyder Institute for Water Research Technical Report Series No. 15/40, Adelaide, South Australia.
- Bice, C.M., Zampatti, B.P., Jennings, P.R. and Wilson, P. (2012). Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2011/12. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000186-3. SARDI Research Report Series No. 680.
- Brookes, J., Aldridge, K., Ganf, G., Paton, D., Shiel, R. and Wedderburn, S. (2009). Environmental watering for food webs in The Living Murray icon sites - a literature review and identification of research priorities. University of Adelaide, Adelaide.

- Bruschetti, M., Luppi, T., Fanjul, E., Rosenthal, A. and Iribarne, O. (2008). Grazing effect of the invasive reef-forming polychaete *Ficopomatus enigmaticus* (Fauvel) on phytoplankton biomass in a SW Atlantic coastal lagoon. *Journal of Experimental Marine Biology and Ecology* **354**, 212–219.
- Bunn, S.E., Davies, P.M. and Winning, M. (2003). Sources of organic carbon supporting the food web of an arid zone floodplain river. *Freshwater Biology* **48**, 619–635.
- Cappo, M.C. (1987). The fate and fisheries biology of sub-adult Australian Salmon in South Australian waters. South Australian Department of Fisheries Research Branch, South Australia.
- Chapman, A. (2003). Biology of the spotted minnow *Galaxias maculatus* (Jenyns 1842) (Pisces: Galaxiidae) on the south coast of Western Australia. Murdoch University, Perth.
- Christensen, V. and Walters, C.J. (2004). Ecopath with Ecosim: methods, capabilities and limitations. *Ecological Modelling* **172**, 109–139.
- Chuwen, B.M., Platell, M.E. and Potter, I.C. (2007). Dietary compositions of the sparid *Acanthopagrus butcheri* in three normally closed and variably hypersaline estuaries differ markedly. *Environmental Biology of Fishes* **80**, 363–376.
- Crinall, S.M. and Hindell, J.S. (2004). Assessing the use of saltmarsh flats by fish in a temperate Australian embayment. *Estuaries* **27**, 728–739.
- Cushing, D.H. (1990). Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. *Advances in Marine Biology* **26**, 249–293.
- Davies, B.R., Stuart, V. and de Villiers, M. (1989). The filtration activity of a serpulid polychaete population (*Ficopomatus enigmaticus* (Fauvel)) and its effects on water quality in a coastal marina. *Estuarine, Coastal and Shelf Science* **29**, 613–612.
- de Sylva, D.P. (1975). Nektonic food webs in estuaries. In *Estuarine Research: Chemistry, Biology and the Estuarine System*. Vol. 1. (Ed. LE Cronin) pp. 420–447. (Academic Press: New York)
- Deegan, B.M., Lamontagne, S., Aldridge, K.T. and Brookes, J.D. (2010). Trophodynamics of the Coorong. Spatial variability in food web structure along a hypersaline coastal lagoon. CSIRO: Water for a Healthy Country National Research Flagship. CSIRO, Canberra.
- DeNiro, M.J. and Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* **42**, 495–506.
- Dittmann, S., Baggalley, S., Baring, R., Brown, E., Gannon, R. and Silvester, L. (2010). Macrobenthic survey 2009: Murray Mouth, Coorong and Lower Lakes Ramsar site. Flinders University, Adelaide.
- Dittmann, S., Baggalley, S., Brown, E. and Keuning, J. (2011). Macrobenthic survey 2010: Lower Lakes, Coorong and Murray Mouth icon site. Flinders University, Adelaide.
- Dittmann, S., Brown, E., Navong, N., Beyer, K., Silvester, L., Baggalley, S. and Keuning, J. (2012). Macrobenthic invertebrate survey 2011-12: Lower Lakes, Coorong and Murray Mouth icon site. Flinders University, Adelaide.

- Dittmann, S., Cantin, A., Imgraben, S. and Ramsdale, T. (2006a). Macrobenthic survey 2005 in the Murray Mouth, Coorong and Lower Lakes Ramsar site. Flinders University, Adelaide.
- Dittmann, S., Cantin, A., Noble, W. and Pocklington, J. (2006b). Macrobenthic survey 2004 in the Murray Mouth, Coorong and Lower Lakes Ramsar site, with an evaluation of food availability for shorebirds and possible indicator functions of benthic species. Department for Environment and Heritage, Adelaide.
- Dittmann, S., Dutton, A. and Earl, J. (2008). Macrobenthic survey 2007: Murray Mouth, Coorong and Lower Lakes Ramsar site. Flinders University, Adelaide.
- Dittmann, S., Ramsdale, T., Keuning, J., Navong, N. and Baggalley, S. (2013). Benthic macroinvertebrate response monitoring in the Coorong and Murray Mouth, 2012/13. Report for the Department of Environment, Water and Natural Resources. Flinders University, Adelaide.
- Dittmann, S., Ramsdale, T., Navong, N. and McGuire, A. (2014). Benthic Macroinvertebrate Response Monitoring in the Coorong and Murray Mouth, 2013/14. Report for the Department of Environment, Water and Natural Resources. Flinders University, Adelaide.
- Dittmann, S., Rolston, A., Bengler, S.N. and Kupriyanova, E.K. (2009). Habitat requirements, distribution and colonisation of the tubeworm *Ficopomatus enigmaticus* in the Lower Lakes and Coorong. Report for the South Australian Murray-Darling Basin Natural Resources Management Board, Adelaide.
- Drinkwater, K.F. and Frank, K.T. (1994). Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Marine and Freshwater Ecosystems* **4**, 135–151.
- Earl, J. (2014). Population biology and ecology of the greenback flounder (*Rhombosolea tapirina*) in the Coorong estuary, South Australia. PhD Thesis, Flinders University, Adelaide.
- Edgar, G.J. and Shaw, C. (1995). The production and trophic ecology of shallow-water fish assemblages in southern Australia II. Diets of fishes and trophic relationships between fishes and benthos at Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, 83–106.
- Elliott, M., Hemingway, K.L., Costello, M.J., Duhamel, S., Hostens, K., Labropoulou, M., Marshall, S. and Winkler, H. (2002). Links between fish and other trophic levels. In 'Fish in estuaries'. (Eds. M Elliott and K Hemingway) pp. 124–216. (Blackwell Publishing: Oxford, UK)
- Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G. and Harrison, T.D. (2007). The guild approach to categorizing estuarine fish assemblages: a global review. *Fish and Fisheries* **8**, 241–268.
- Fauchald, K. and Jumars, P.A. (1979). The diet of worms: a study of polychaete feeding guilds. *Oceanography and Marine Biology - An Annual Review* **17**, 193–284.
- Fea, N. and Harcourt, R. (1997). Assessing the use of faecal and regurgitate analysis as a means of determining the diet of New Zealand fur seals. In 'Marine mammal research in the Southern Hemisphere: status, ecology and medicine' (Eds. MA Hindell and C Kemper) pp. 143–150. (Surrey Beatty and Sons: NSW, Australia)

- Frahn, K., Nicol, J. and Strawbridge, A. (2012). Current distribution and abundance of *Ruppia tuberosa* in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2012/000074-1. SARDI Research Report Series No. 615.
- Fry, B. and Sherr, E.B. (1984).  $\delta^{13}\text{C}$  measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contributions in Marine Science* **27**, 13–47.
- Gaughan, D.J. and Potter, I.C. (1997). Analysis of diet and feeding strategies within an assemblage of estuarine larval fish and an objective assessment of dietary niche overlap. *Fishery Bulletin* **95**, 722–731.
- Geddes, M.C. (1987). Changes in salinity and in the distribution of macrophytes, macrobenthos and fish in the Coorong Lagoons, South Australia, following a period of River Murray flow. *Transactions of the Royal Society of South Australia* **111**, 173–181.
- Geddes, M.C. (2005). Ecological outcomes for the Murray Mouth and Coorong from the managed barrage release of September–October 2003. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. RD03/0199-2. SARDI Research Report Series No. 79.
- Geddes, M.C. and Butler, A.J. (1984). Physiochemical and biological studies on the Coorong Lagoons, South Australia, and the effect of salinity on the distribution of the macrobenthos. *Transactions of the Royal Society of South Australia* **108**, 51–62.
- Geddes, M.C. and Francis, J. (2008). Trophic ecology pilot study in the River Murray estuary at Pelican Point. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/001193-1. SARDI Research Report Series No. 274.
- Geddes, M.C. and Tanner, J.E. (2007). Ecology of the Murray Mouth and Coorong 2004/2005; and comparisons with 2003/2004. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.
- Geddes, M.C., Shiel, R.J. and Francis, J. (2016). Zooplankton in the Murray Estuary and Coorong during flow and no-flow periods. *Transactions of the Royal Society of South Australia* <http://dx.doi.org/10.1080/03721426.2016.1151497>
- Giatas, G. (2012). Diet of the yelloweye mullet (*Aldrichetta forsteri*) in the River Murray estuary and Coorong Lagoon, South Australia. Honours Thesis, Flinders University, Adelaide.
- Giatas, G.C. and Ye, Q. (2015). Diet and trophic characteristics of mulloway (*Argyrosomus japonicus*), congolli (*Pseudaphritis urvillii*) and Australian salmon (*Arripis truttaceus* and *A. trutta*) in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000479-1. SARDI Research Report Series No. 858.
- Gill, H.S. and Potter, I.C. (1993). Spatial segregation amongst goby species within an Australian estuary, with a comparison of the diets and salinity tolerance of the two most abundant species. *Marine Biology* **117**, 515–526.

- Griffiths, M.H. (1997). Influence of prey availability on the distribution of dusky kob *Argyrosomus japonicus* (Sciaenidae) in the Great Fish estuary, with notes on the diet of early juveniles from three other estuarine systems. *South African Journal of Marine Science* **18**, 137–145.
- Grigg, N.J., Robson, B.J., Webster, I.T. and Ford, P.W. (2009). Nutrient budgets and biogeochemical modelling of the Coorong. CSIRO: Water for a Healthy Country National Research Flagship.
- Hall, D. (1981). The feeding ecology of the European carp (*Cyprinus carpio* L.) in Lake Alexandrina and the lower River Murray, South Australia. University of Adelaide, Adelaide
- Hall, D.A. (1986). An assessment of the mulloway (*Argyrosomus hololepidotus*) fishery in South Australia with particular reference to the Coorong Lagoon. Department of Fisheries, South Australia.
- Harvey, C.J., Cox, S.P., Essington, T.E., Hansson, S. and Kitchell, J.F. (2003). An ecosystem model of food web and fisheries interactions in the Baltic Sea. *ICES Journal of Marine Science* **60**, 939–950.
- Higgins, P.J. and Davies, S.J.J.F. (1996). 'Handbook of Australian, New Zealand and Antarctic birds. Volume 3, Snipes to Pigeons.' (Oxford University Press: Melbourne)
- Hindell, J.S. (2006). Assessing the trophic link between seagrass habitats and piscivorous fishes. *Marine and Freshwater Research* **57**, 121–131.
- Hindell, J.S., Jenkins, G.P. and Keough, M.J. (2000). Variability in abundances of fishes associated with seagrass habitats in relation to diets of predatory fishes. *Marine Biology* **136**, 725–737.
- Hindell, J.S., Jenkins, G.P. and Keough, M.J. (2002). Variability in the numbers of post-settlement King George whiting (Sillaginidae: *Sillaginodes punctata*, Cuvier) in relation to predation, habitat complexity and artificial cage structure. *Journal of Experimental Marine Biology and Ecology* **268**, 13– 31.
- Hoedt, F.E. and Dimmlich, W.F. (1994). Diet of subadult Australian salmon, *Arripis truttaceus*, in Western Port, Victoria. *Australian Journal of Marine and Freshwater Research* **45**, 617–623.
- Hortle, M.E. and White, R.W.G. (1980). Diet of *Pseudaphritis urvillii* (Cuvier and Valenciennes) (Pisces: Bovichthyidae) from South-eastern Tasmania. *Australian Journal of Marine and Freshwater Research* **31**, 533–539.
- Humphries, P. and Potter, I.C. (1993). Relationship between the habitat and diet of three species of atherinids and three species of gobies in a temperate Australian estuary. *Marine Biology* **116**, 193–204.
- Jenkins, G.P. (1987). Comparing diets, prey selection, and predatory impact of co-occurring larvae of two flounder species. *Journal of Experimental Marine Biology and Ecology* **110**, 147–170.

- Jennings, P.R., Zampatti, B.P. and Bice, C.M. (2008). Fish Movement and Recruitment in the Coorong and Lower Lakes: 2007/08 Progress Report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000555-2. SARDI Research Report Series No. 302.
- Johnson, R. (2014). Trophic interactions of congolli (*Pseudaphritis urvillii*) in the Murray Estuary and Coorong Lagoon, South Australia. Honours Thesis, Flinders University, Adelaide.
- Kent, A.C. and Day, R.W. (1983). Population dynamics of an infaunal polychaete: the effect of predators and an adult-recruit interaction. *Journal of Experimental Marine Biology and Ecology* **73**, 185–203.
- Khan, T.A. (2003). Dietary studies on exotic carp (*Cyprinus carpio* L.) from two lakes of western Victoria, Australia. *Aquatic Sciences* **65**, 272–286.
- Kimmerer, W.J. (2002). Effects of freshwater flow on abundance of estuarine organisms: Physical effects or trophic linkages? *Marine Ecological Progress Series* **243**, 39–55.
- King, A.J. (2005). Ontogenetic dietary shifts of fishes in an Australian floodplain river. *Marine and Freshwater Research* **56**, 215–225.
- Lamontagne, S., Geddes, M.C., Fernandes, M. and Krull, E. (2007). Analysis of fish diet from the Murray Estuary using C, N & S stable isotopes: A preliminary assessment. CSIRO, Canberra.
- Lenanton, R.C.J., Robertson, A.I. and Hansen, J.A. (1982). Nearshore accumulations of detached macrophytes as nursery areas for fish. *Marine Ecological Progress Series* **9**, 51–57.
- Leterme, S.C., Allais, L., Hemraj, D.A., Newton, K., Mitchell, J. and Shanafield, M. (2015). Drought conditions and recovery in the Coorong wetland, South Australia in 1997–2013. *Estuarine, Coastal and Shelf Science* **163**, 175–184.
- Lieschke, J.A. and Gloss, G.P. (1999). Regulation of zooplankton composition and distribution by a zooplanktivorous fish in a shallow, eutrophic floodplain lake in south east Australia. *Archiv für Hydrobiologie* **146**, 397–412.
- Linke, T.E. (2011). Trophic interactions among abundant members of the fish fauna in a permanently-open and a seasonally-open estuary in south-western Australia. Murdoch University, Perth.
- Livore, J.P., Ye, Q., Bucater, L. and Short, D. (2013). Fish response to flow in the Coorong during 2012/13. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000486-1. SARDI Research Report Series No. 732.
- Lui, L.C. (1969). Salinity tolerance and osmoregulation of *Taeniomembras microstomus* (Gunther, 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. *Australian Journal of Marine and Freshwater Research* **20**, 157–162.
- Marais, J.F.K. (1984). Feeding ecology of major carnivorous fish from four Eastern Cape estuaries. *South African Journal of Zoology* **19**, 210–223.
- Marchant, S.M., and Higgins, P.J. (1990). 'Handbook of Australian, New Zealand and Antarctic birds. Volume 1, Ratites to Ducks.' (Oxford University Press: Melbourne)

- Martin, T.J., Cyrus, D.P. and Forbes, A.T. (1992). Episodic events: The effects of cyclonic flushing on the ichthyoplankton of St. Lucia estuary on the southeast coast of Africa. *Netherlands Journal of Sea Research* **30**, 273–278.
- Mazumbder, D., Saintilan, N. and Williams, R.J. (2006). Trophic relationships between initerant fish and crab larvae in a temperate Australian saltmarsh. *Marine and Freshwater Research* **57**, 193–199.
- McNeil, D.G., Westergaard, S.W., Cheshire, K.J.M., Noell, C.J. and Ye, Q. (2013). Effects of hyper-saline conditions upon six estuarine fish species from the Coorong and Murray Mouth. South Australian Research and Development Institute (SARDI) Aquatic Sciences, Adelaide. SARDI Publication No. F2009/000014-4. SARDI Research Report Series No. 700.
- Medeiros, E.S.F. and Arthington, A.H. (2008a). Diel variation in food intake and diet composition of three native fish species in floodplain lagoons of the Macintyre River, Australia. *Journal of Fish Biology* **73**, 1024–1032.
- Medeiros, E.S.F. and Arthington, A.H. (2008b). The importance of zooplankton in the diets of three native fish species in floodplain waterholes of a dryland river, the Macintyre River, Australia. *Hydrobiologia* **614**, 19–31.
- Medeiros, E.S.F. and Arthington, A.H. (2014). Fish diet composition in floodplain lagoons of an Australian dryland river in relation to an extended dry period following flooding. *Environmental Biology of Fishes* **97**, 797–812.
- Nedwell, D.B., Jickells, T.D., Trimmer, M. and Sanders, R. (1999). Nutrients in estuaries. In 'Advances in Ecological Research'. (Eds. DB Nedwell and DG Raffaelli) pp. 43–92. (Academic Press: New York, USA)
- 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. SARDI Publication No. F2009/000014-1. SARDI Research Report Series No. 339.
- Page, B., McKenzie, J. and Goldsworthy, S.D. (2005). Dietary resource partitioning among sympatric New Zealand and Australian fur seals. *Marine Ecological Progress Series* **293**, 283–302.
- Paton, D.C. and Bailey, C.P. (2011). Condition monitoring of the Lower Lakes, Coorong and Murray Mouth icon site: waterbirds using the Coorong and Murray Estuary 2011. University of Adelaide.
- Paton, D.C. and Bailey, C.P. (2012). Condition Monitoring of the Lower Lakes, Coorong and Murray Mouth Icon Site: Waterbirds using the Coorong and Murray Estuary 2012. The University of Adelaide, Adelaide.
- Paton, D.C. and Bailey, C.P. (2013a). Annual monitoring of *Ruppia tuberosa* in the Coorong region of South Australia, July 2012. The University of Adelaide, Adelaide.
- Paton, D.C. and Bailey, C.P. (2013b). Condition Monitoring of the Lower Lakes, Coorong and Murray Mouth Icon Site: Waterbirds 2013. The University of Adelaide, Adelaide.

- Paton, D.C. and Bailey, C.P. (2014). Annual monitoring of *Ruppia tuberosa* in the Coorong region of South Australia, July 2013. The University of Adelaide, Adelaide.
- Paton, D.C. and Rogers, D.J. (2008). 2007 winter monitoring of the southern Coorong. The University of Adelaide, Adelaide.
- Paton, D.C. and Rogers, D.J. (2009). Condition monitoring of indicator bird species in the Lower Lakes, Coorong and Murray Mouth icon site: Coorong and Murray Mouth Estuary 2009. University of Adelaide, Adelaide.
- Pauly, D., Christensen, V., and Walters, C. (2000). Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Sciences* **57**, 697–706.
- Peterson, B.J. and Fry, B. (1987). Stable isotopes in ecosystem studies. *Annual Review of Ecology and Systematics* **18**, 293–320.
- Phillips, W. and Muller, K. (2006). Ecological Character of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance. South Australian Department for Environment and Heritage.
- Platell, M.E. and Freewater, P. (2009). Importance of saltmarsh to fish species of a large south-eastern Australian estuary during a spring tide cycle. *Marine and Freshwater Research* **60**, 936–941.
- Platell, M.E., Orr, P.A. and Potter, I.C. (2006). Inter- and intraspecific partitioning of food resources by six large and abundant fish species in a seasonally open estuary. *Journal of Fish Biology* **69**, 243–262.
- Post, D.M. (2002). Using stable isotopes to estimate trophic position: models, methods and assumptions. *Ecology* **83**, 703–718.
- Pollard, D.A. (1973). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). V. Composition of the diet. *Australian Journal of Freshwater Research* **24**, 281–295.
- Puckridge, J.T., Sheldon, F. and Walker, K.F. (1998). Flow variability and the ecology of large rivers. *Marine and Freshwater Research* **49**, 55–72.
- Reinhold, S. (2015). Investigating the importance of commercially fished species and little penguins as prey items in the long-nosed fur seal diet. Honours Thesis, Flinders University, Adelaide.
- Robertson, A.I. (1982). Population dynamics and feeding ecology of juvenile Australian salmon (*Arripis trutta*) in Western Port, Victoria. *Australian Journal of Marine and Freshwater Research* **33**, 369–375.
- Robertson, A.I. and Howard, R.K. (1978). Diel trophic interactions between vertically-migrating zooplankton and their fish predators in an eelgrass community. *Marine Biology* **48**, 207–213.
- Rogers, D.J. and Paton, D.C. (2009a). Changes in the distribution and abundance of *Ruppia tuberosa* in the Coorong. CSIRO, Canberra.

- Rogers, D.J. and Paton, D.C. (2009b). Spatiotemporal variation in the waterbird communities of the Coorong. CSIRO, Canberra.
- Rolston, A. and Dittmann, S. (2009). The distribution and abundance of macrobenthic invertebrates in the Murray Mouth and Coorong lagoons 2006 to 2008. CSIRO, Canberra.
- Sarre, G.A., Platell, M.E. and Potter, I.C. (2000). Do the dietary compositions of *Acanthopagrus butcheri* in four estuaries and a coastal lake vary with body size and season and within and amongst these water bodies? *Journal of Fish Biology* **56**, 103–122.
- Shaw, W. and Jenkins, G.P. (1992). Spatial variation in feeding, prey distribution and food limitation of juvenile flounder *Rhombosolea tapirina*. *Journal of Experimental Marine Biology and Ecology* **165**, 1–21.
- Shiel, R.J. and Aldridge, K.T. (2011). The response of zooplankton communities in the North Lagoon of the Coorong and Murray Mouth to barrage releases from the Lower Lakes, November 2010 – April 2011. University of Adelaide, Adelaide.
- Shiel, R.J. and Tan, L. (2013a). Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth October 2011 – April 2012. University of Adelaide, Adelaide.
- Shiel, R.J. and Tan, L. (2013b). Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth September 2012 – March 2013. University of Adelaide, Adelaide.
- Sternberg, D., Balcombe, S., Marshall, J. and Lobegeiger, J. (2008). Food resource variability in an Australian dryland river: evidence from the diet of two generalist native fish species. *Marine and Freshwater Research* **59**, 137–144.
- Stewart, J., Hughes, J., McAllister, J., Lyle, J. and MacDonald, M. (2011). Australian salmon (*Arripis trutta*): population structure, reproduction, diet and composition of commercial and recreational catches. Department of Primary Industries, Cronulla, NSW.
- Taylor, M.D., Fielder, D.S. and Suthers, I.M. (2006). Spatial and ontogenetic variation in the diet of wild and stocked mulloway (*Argyrosomus japonicus*, Sciaenidae) in Australian estuaries. *Estuaries and Coasts* **29**, 785–793.
- Thomson, J.M. (1957). Biological studies of economic significance of the Yellow-eye mullet, *Aldrichetta forsteri* (Cuvier & Valenciennes) (Mugilidae). *Australian Journal of Marine and Freshwater Research* **8**, 1–13.
- Thomson, J.M. (1959). Some aspects of the ecology of Lake Macquarie, N.S.W, with regard to an alleged depletion of fish. IX. The fishes and their food. *Australian Journal of Marine and Freshwater Research* **10**, 365–374.
- Tibbets, I.R. and Carseldine, L. (2005). Trophic shifts in three subtropical Australian halfbeaks (Teleostei: Hemiramphidae). *Marine and Freshwater Research* **56**, 925–932.
- Vilizzi, L. (1998). Observations on ontogenetic shifts in diet of 0+ carp, *Cyprinus carpio*, from the River Murray, Australia. *Folia Zoologica* **47**, 225–229.
- Webb, B.F. (1973). Fish populations of the Avon–Heathcote estuary, 3. Gut-contents. *New Zealand Journal of Marine and Freshwater Research* **7**, 223–234.

- Weng, H.T.C. (1970). The black bream, *Acanthopagrus butcheri* (Munro); its life history and its fishery in South Australia. University of Adelaide, Adelaide.
- Werner, E.E. and Gilliam, J.F. (1984). The ontogenetic niche and species interactions in size-structured populations. *Annual Review of Ecology and Systematics* **15**, 393–425.
- Whitfield, A.K. (1985). The role of zooplankton in the feeding ecology of fish fry from some southern African estuaries. *South African Journal of Zoology* **20**, 166–171.
- Whitfield, A.K. (1999). Ichthyofaunal assemblages in estuaries: a South African case study. *Reviews in Fish Biology and Fisheries* **9**, 151–186.
- Whitfield, A.K. and Blaber, S.J.M. (1978). Food and feeding of piscivorous fishes at Lake St. Lucia, Zululand. *Journal of Fish Biology* **13**, 675–691.
- Williams, J., Jenkins, G.P., Hindell, J.S. and Swearer, S.E. (2013). Linking environmental flows with the distribution of black bream *Acanthopagrus butcheri* eggs, larvae and prey in a drought affected estuary. *Marine Ecological Progress Series* **483**, 273–287.
- Ye, Q., Bucater, L. and Short, D. (2011). Coorong fish intervention monitoring during barrage releases in 2010/11. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000309-1. SARDI Research Report Series No. 559.
- Ye, Q., Bucater, L. and Short, D. (2013). Coorong fish condition monitoring 2008-2013: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-3. SARDI Research Report Series No. 748.
- Ye, Q., Bucater, L. and Short, D. (2015). Fish response to flows in the Murray Estuary and Coorong during 2013/14. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000786-1. SARDI Research Report Series No. 884.
- Ye, Q., Bucater, L., Short, D. and Livore, J. (2012). Fish response to barrage releases in 2011/12, and recovery following the recent drought in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2012/000357-1. SARDI Research Report Series No. 665.
- Zampatti, B.P., Bice, C.M. and Jennings (2012). Fish assemblage response and fishway effectiveness at Goolwa, Tauwitcherie and Hunters Creek Barrages in 2010/11. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000186-2. SARDI Research Report Series No. 605.
- Zampatti, B.P., Bice, C.M. and Jennings, P.R. (2010). Temporal variability in fish assemblage structure and recruitment in a freshwater-deprived estuary: the Coorong, Australia. *Marine and Freshwater Research* **61**, 1298–1312.
- Zampatti, B.P., Bice, C.M. and Jennings, P.R. (2011). Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes from 2006-2010. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000186-1. SARDI Research Report Series No. 569.

## APPENDICES

**Appendix 1. Spring/summer salinities in the Murray Estuary (ME), North Lagoon (NL) and South Lagoon (SL) of the Coorong from 2003–2014. Inflow period classification is based on arbitrary values of <1,200 GL/yr and >5,000 GL/yr for low and high inflow years, respectively (refer to Section 1.2). Mean site salinities for regions are ME = BC19 to Pelican Point, NL = Mark Point to Hell’s Gate, SL = Villa De Yumpa to Salt Creek (Figure 1) unless otherwise specified. Methods for measuring salinity varied between projects – for more detail refer to the cited monitoring reports.**

Inflows	Year	Salinities (‰)			Source
		ME	NL	SL	
Low	2003-04	34–39 <sup>a</sup>	35–94 <sup>a</sup>		(Geddes 2005)
Low	2004-05	16–37 <sup>b</sup>	30–96 <sup>b</sup>		(Geddes and Tanner 2007)
Low	2005-06				N/A
Low	2006-07	31–40	43–113	137–138 <sup>c</sup>	(Noell <i>et al.</i> 2009)
Low	2007-08	39–42	44–113	123–128 <sup>c</sup>	(Ye <i>et al.</i> 2011)
Low	2008-09	38–41 <sup>d</sup>	49–133	130–134 <sup>c</sup>	(Ye <i>et al.</i> 2013)
Low	2009-10	37–44 <sup>d</sup>	55–132	82–120 <sup>c</sup>	(Ye <i>et al.</i> 2013)
High	2010-11	1–5	5–76	54–98	(Ye <i>et al.</i> 2011)
High	2011-12	0–14	11–71	86–94	(Ye <i>et al.</i> 2012)
High	2012-13	7–21	20–76	76–79	(Livore <i>et al.</i> 2013)
Low–High	2013-14	9–30	31–69	61–77	(Ye <i>et al.</i> 2015)

<sup>a</sup> Minimum and maximum recorded salinities; ME = Ewe Island–Pelican Point and NL = Mark Point–North of Needle Island.

<sup>b</sup> Minimum and maximum recorded salinities; ME = Barkers Knoll–Pelican Point and NL = Mark Point–North of Needles Islands.

<sup>c</sup> Mean site salinities; SL = Jack Point–Salt Creek.

<sup>d</sup> Mean site salinities; ME = Goolwa Barrage–Godfrey’s Landing.

**Appendix 2. Key species or taxonomic groups that were abundant during LOW inflows (i.e. 2003–2010) in the Murray Estuary (ME), North Lagoon (NL) and the South Lagoon (SL) of the Coorong.**

Biological group	Region		
	ME	NL	SL
Phytoplankton	Diatoms and dinoflagellates dominant (Leterme <i>et al.</i> 2015).		
<i>Ruppia tuberosa</i>	Likely absent	Present at the southern part of the North Lagoon (Rogers and Paton 2009a).	Present at the most northern part of the South Lagoon during low inflows (Rogers and Paton 2009a).
Zooplankton	Calanoid copepodites, nauplii and adults ( <i>Gladioferens</i> spp. and <i>Boeckella</i> ), halotolerant rotifer <i>Synchaeta</i> and meroplankton (crustacean, bivalve and gastropod larvae) abundant (Geddes 2005; Geddes and Tanner 2007; Geddes <i>et al.</i> 2016).	Halotolerant rotifer <i>Synchaeta</i> , meroplankton (mainly bivalve larvae) and halotolerant harpacticoid copepods, copepodites and nauplii abundant (Geddes 2005; Geddes and Tanner 2007).	Brine shrimp ( <i>Parartemia</i> sp.) and ostracods abundant (Paton and Rogers 2008). <i>Parartemia</i> sp. abundant in extremely hypermarine salinities (Paton and Rogers 2008; Paton and Rogers 2009).
Macro-invertebrates	Characterised by the polychaete <i>Capitella capitata</i> , the small bivalve <i>Arthritica helmsi</i> , amphipods and the nereid <i>Simplisetia aequisetis</i> (Dittmann <i>et al.</i> 2013).	Characterised by the polychaete <i>Capitella capitata</i> and chironomids (Dittmann <i>et al.</i> 2013).	Characterised by chironomids (Dittmann <i>et al.</i> 2013).
Fish (refer to Appendices 5 and 6).	Large-bodied: Australian salmon, yellow-eye mullet and mulloway abundant.  Small-bodied: sandy sprat and smallmouthed hardyhead abundant.	Large-bodied: yellow-eye mullet and mulloway abundant.  Small-bodied: smallmouthed hardyhead abundant.	Small-bodied: smallmouthed hardyhead only species present.

**Appendix 3. Key species or taxonomic groups that were abundant during HIGH inflows (i.e. 2010–2013) in the Murray Estuary (ME), North Lagoon (NL) and the South Lagoon (SL) of the Coorong.**

Biological group	Region		
	ME	NL	SL
Phytoplankton	Chlorophytes dominant (Leterme <i>et al.</i> 2015).	Chlorophytes dominant in northern end of North Lagoon (<20 ppt). Diatoms abundant in southern end of North Lagoon (>20 ppt) (Leterme <i>et al.</i> 2015).	Diatoms dominant (Leterme <i>et al.</i> 2015).
<i>Ruppia tuberosa</i>	Likely absent	Present at the most southern part of the North Lagoon (Frahn <i>et al.</i> 2012; Paton and Bailey 2014).	Present throughout most of the South Lagoon (Frahn <i>et al.</i> 2012; Paton and Bailey 2014).
Zooplankton	Comprised of protists (e.g. the tintinnid <i>Stenosemella</i> ), rotifers ( <i>Keratella</i> and <i>Synchaeta</i> ), cladocerans, ( <i>Daphnia</i> and <i>Moina</i> ) and the calanoid copepod <i>Boeckella</i> (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b).	Comprised of protists (e.g. the tintinnid <i>Stenosemella</i> ), rotifers ( <i>Keratella</i> and <i>Synchaeta</i> ), cladocerans ( <i>Daphnia</i> and <i>Moina</i> ) and the calanoid copepod <i>Boeckella</i> . Halophilic/halotolerant zooplankton such as tintinnids, rotifers, copepods (e.g. <i>Acartia</i> , Calanoida) and meroplankton (bivalve and crab larvae) increasing in abundance with increasing salinity (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b).	Halophilic/halotolerant zooplankton such as tintinnids, rotifers, copepods (e.g. <i>Acartia</i> , Calanoida) and meroplankton (bivalve and crab larvae) (Shiel and Aldridge 2011; Shiel and Tan 2013a; Shiel and Tan 2013b).
Macro-invertebrates	Characterised by amphipods and chironomid larvae (Dittmann <i>et al.</i> 2013).	Characterised by chironomids, <i>Capitella capitata</i> and amphipods (Dittmann <i>et al.</i> 2013).	Characterised by chironomids and amphipods (Dittmann <i>et al.</i> 2013).
Fish (refer to Appendices 5 and 6).	Large-bodied: bony herring, Australian salmon and yellow-eye mullet abundant.  Small-bodied: sandy sprat abundant.	Large-bodied: bony herring and yellow-eye mullet abundant.  Small-bodied: smallmouthed hardyhead and sandy sprat abundant.	Large-bodied: yellow-eye mullet, bony herring and black bream present.  Small-bodied: smallmouthed hardyhead abundant. Other species also present.

#### Appendix 4. Feeding modes and diets of invertebrates and vertebrates of the Coorong

Invertebrates of the Coorong that have been collected during zooplankton and macrobenthic monitoring programs are presented in Table A1, along with their habitat and feeding modes, adapted from Fauchald and Jumars (1979):

- Suspension feeding (also known as ‘filter feeding’) – feeding on food particles suspended in the water column. May actively feed on particles in the water column, use cilium to produce feeding currents, or feed with mucous webs;
- Deposit feeding – feeding on food particles at the sediment surface (‘surface deposit-feeders’) or suspended in soil (‘sub-surface deposit-feeders’/‘burrowers’);
- Herbivorous grazing/browsing – feeding on plant and/or algal material;
- Predators – active carnivorous feeding on live animals;
- Scavengers – feeding on dead/decaying animal and/or plant material.

Many zooplankton (e.g. microcrustaceans, rotifers and protists) are generally considered to be suspension feeders; however, copepods may have a variety of feeding modes (Table A1). Amphipods (deposit feeders and herbivorous grazers) and mysid shrimp (predators/suspension feeders) are both omnivorous. Stable isotope results from the Coorong suggest that levels of carnivory are low for amphipods compared to mysid shrimp (Deegan *et al.* 2010; Giatas 2012). Bivalves found within the Coorong are suspension and/or deposit feeders, while gastropods are herbivorous grazers.

While the majority of benthic annelids (e.g. *Capitella capitata*) are deposit feeders that feed on algal or detrital matter, *Phyllodoce novaehollandiae* and *Aglaophamus australiensis* are strictly predatory polychaetes, which occupy higher trophic levels in the Coorong (Lamontagne *et al.* 2007; Deegan *et al.* 2010; Giatas 2012; Johnson 2014). The nereid *Simplisetia aequisetis* is an omnivorous feeder and the sessile tubeworm *Ficopomatus enigmaticus*, is a suspension feeder (Table A1).

All decapods show similar feeding; they are mostly omnivorous scavengers and predators (Table A1). Diet and trophic position of these invertebrates are likely to vary in response to changes in food type and availability. Insect larvae in the Coorong have a variety of feeding modes, from being carnivorous predators to herbivorous grazers. *Tanytarsus* (Chironomidae), which is the most common genus of insect larvae in the South Lagoon of the Coorong (Geddes 2005; Dittmann

*et al.* 2006b; Geddes and Tanner 2007; Paton and Rogers 2008; 2009; Paton and Bailey 2013b), feeds on algae, diatoms and detritus.

A comprehensive summary of the diet of abundant fishes and the potential diet of abundant bird species within the Coorong are presented in Table A2 and Table A3, respectively. Using all available dietary literature, fish and bird species were assigned to feeding mode functional groups that were adapted from Elliott *et al.* (2007):

- Zooplanktivore (ZP) – feeding predominantly on zooplankton;
- Detritivore (DV) – feeding predominantly on detritus and/or microphytobenthos;
- Obligate herbivore (HV-o) – grazing on macroalgae, macrophytes or phytoplankton;
- Facultative herbivore (HV-f) – feeding predominantly on macroalgae, macrophytes or phytoplankton, but may include animal items;
- Omnivore (OV) – feeding on macroalgae, macrophytes and animal items;
- Piscivore (PV) – feeding predominantly on fish, but may include large nektonic or benthic invertebrates;
- Obligate invertivore (IV-o) – feeding on macroinvertebrates;
- Facultative invertivore (IV-f) – feeding predominantly on macroinvertebrates, but may include fish.

Many fishes in the Coorong show broad diets (e.g. yellow-eye mullet) and may feed on a variety of food sources (Table A2), which is an adaptation to variable environmental conditions such as fluctuations in food availability in estuaries. In other estuaries, fishes with broad diets tend to be the most successful and abundant species as they are resistant to changes in food availability (Bennett and Branch 1990; Elliott *et al.* 2002).

Birds within the Coorong fall into three feeding mode categories: piscivore (e.g. Australian pelican and terns); obligate herbivore (e.g. black swan); and facultative invertivore (e.g. most shorebird species) (Table A3). Shorebird species are facultative invertivores that mainly feed on invertebrates (e.g. insect larvae, polychaetes, amphipods etc.), but may also feed on plant material such as seeds (Higgins and Davies 1996). Piscivorous birds are capable of feeding on a variety of pelagic and benthic fishes (Table A3), which might suggest that diet of piscivorous birds (e.g. cormorants) would be highly dependent on the presence and availability of prey. In the South Lagoon of the Coorong, smallmouthed hardyhead has been considered to be the most important prey item for piscivorous birds (e.g. terns) as this species is often the only fish species present (Rogers and Paton 2009b).

**Table A1. Invertebrate taxa that are found in the Coorong (Dittmann *et al.* 2006a; 2006b; 2008; Baring *et al.* 2009; Dittmann *et al.* 2009; Rolston and Dittmann 2009; Dittmann *et al.* 2010; 2011; Shiel and Aldridge 2011; Dittmann *et al.* 2012; 2013; Shiel and Tan 2013a; 2013b) with feeding mode information adapted from Fauchald and Jumars (1979). Habitat categories include benthic infauna, epibenthic and pelagic modes. Feeding modes include suspension feeder (or filter-feeder), deposit feeder, herbivorous grazer, predator and scavenger.**

Taxa	Description	Habitat mode	Feeding mode	Additional feeding information
<b>Bivalvia</b>				
<i>Arthritica helmsi</i>	small bivalve	benthic infauna	suspension feeder <sup>1,2</sup>	
<i>Soletellina alba</i>	bivalve	benthic infauna	suspension/deposit feeder <sup>2</sup>	primarily a suspension feeder <sup>2</sup>
<i>Spisula (Notospisula) trigonella</i>	bivalve	benthic infauna	suspension feeder <sup>3</sup>	
<b>Gastropoda</b>				
Hydrobiidae	freshwater/brackish gastropod	epibenthic	herbivorous grazer <sup>1</sup>	feed on algae, diatoms, bacteria and detritus <sup>1</sup>
<i>Salinator fragilis</i>	air-breathing gastropod	epibenthic	herbivorous grazer <sup>4</sup>	
<i>Coxiella striata</i>	halophilic gastropod	epibenthic	herbivorous grazer <sup>1</sup>	grazes on diatoms/bacteria under mud surface
<b>Oligochaeta</b>	motile annelid	benthic infauna	deposit feeder <sup>5</sup>	
<b>Polychaeta</b>				
<i>Ficopomatus enigmaticus</i>	sessile, calcareous-tubed polychaete	epibenthic	suspension feeder <sup>6</sup>	
<i>Capitella capitata</i>	motile polychaete	benthic infauna	deposit feeder <sup>5</sup>	non-selective surface deposit feeder <sup>5</sup> . Primarily feeds on algal fragments and faecal pellets <sup>5</sup>
<i>Boccardiella limnicola</i>	discretely motile polychaete	benthic infauna	deposit/suspension feeder <sup>7</sup>	
<i>Australonereis ehlersi</i>	large, motile tube-building polychaete	benthic infauna	deposit /suspension feeder <sup>7</sup>	primarily a deposit feeder, but may also construct a suspension-feeding net <sup>7</sup>
<i>Phyllodoce novaehollandiae</i>	large motile polychaete	benthic infauna/epibenthic	predator <sup>5</sup>	hunting predator that feeds on small invertebrates <sup>5</sup>
<i>Simplisetia aequisetis</i>	motile polychaete	benthic infauna	deposit feeder/omnivorous scavenger <sup>7,8</sup>	selectively deposit-feeds on surface sediments and feeds on dead/decaying animals (i.e. macroinvertebrates) on or in sediments <sup>7,8</sup>

<sup>1</sup> Beesley, P.L., Ross, G.J.B. and Wells, A. (1998). 'Mollusca: the southern synthesis. Fauna of Australia. Vol. 5 (Parts A and B).' (CSIRO Publishing: Melbourne)

<sup>2</sup> Lautenschlager, A.D. (2011). Feeding ecology of benthic invertebrates in an intermittently open estuary. Deakin University, Victoria.

<sup>3</sup> Rueda, J.L. and Smaal, A.C. (2004). Variation of the physiological energetics of the bivalve *Spisula subtruncata* (da Costa, 1778) with an annual cycle. *Journal of Experimental Marine Biology and Ecology* **301**, 141–157.

<sup>4</sup> Deegan, B.M., Lamontagne, S., Aldridge, K.T. and Brookes, J.D. (2010). Trophodynamics of the Coorong. Spatial variability in food web structure along a hypersaline coastal lagoon. CSIRO: Water for a Healthy Country National Research Flagship. CSIRO, Canberra.

<sup>5</sup> Fauchald, K. and Jumars, P.A. (1979). The diet of worms: a study of polychaete feeding guilds. *Oceanography and Marine Biology - An Annual Review* **17**, 193–284.

<sup>6</sup> MDFRC (2013). The Murray–Darling Freshwater Research Centre Bug Guide: Identification and ecology of Australian freshwater invertebrates. <http://www.mdfrc.org.au/bugguide/>

<sup>7</sup> Beesley, P.L., Ross, G.J.B., and Glasby, C.J. (2000) 'Polychaetes and allies: the southern synthesis. Fauna of Australia. Volume 4 (Parts A and B).' (CSIRO Publishing: Melbourne)

<sup>8</sup> Kent, A.C. and Day, R.W. (1983). Population dynamics of an infaunal polychaete: the effect of predators and an adult-recruit interaction. *Journal of Experimental Marine Biology and Ecology* **73**, 185–203.

Taxa	Description	Habitat mode	Feeding mode	Additional feeding information
<i>Aglaophamus australiensis</i> (formerly <i>Nephtys australiensis</i> )	motile polychaete	benthic infauna	Predator <sup>6,7</sup>	feeds on small molluscs, small crustaceans, juvenile bivalves, other polychaetes and oligochaetes <sup>7</sup>
<i>Euchone variabilis</i>	Sessile, polychaete	tubed epibenthic	suspension feeder <sup>5</sup>	
<b>Sipuncula</b>	motile peanut worm	benthic infauna	deposit feeder <sup>7</sup>	eats detritus <sup>7</sup>
<b>Malacostraca</b>				
Gammaridea, Corophiidae, <i>Melita</i>	amphipods	epibenthic	various <sup>4,9</sup>	feeding modes include deposit feeder <sup>4</sup> , herbivorous grazer, omnivorous scavenger and suspension feeder <sup>9</sup> . Generally feed omnivorously on detritus, algae and small animals <sup>5,9</sup>
Isopoda	isopods	benthic/epibenthic/parasitic	various	isopods may be parasitic or may feed on algae and small invertebrates
Mysidacea	small shrimp	epibenthic	predator/suspension feeder <sup>10</sup>	feed on phytoplankton, microcrustaceans (e.g. cladocerans and copepods), worms, mussels and plant material <sup>10</sup>
<i>Macrobrachium</i>	freshwater shrimp	epibenthic	omnivorous scavenger/browser <sup>13</sup>	feeds on animal material <sup>11</sup> , biofilms and algae <sup>12,13</sup>
<i>Paragrapsus gaimardii</i>	large crab	epibenthic	omnivorous scavenger/predator <sup>14,15,16</sup>	Grapsidae diet includes animal material, algal material, plant material and inorganic sediments <sup>14,15</sup>
<i>Helograpsus haswellianus</i>	intertidal burrowing crab	epibenthic	omnivorous scavenger/predator <sup>14,15,16</sup>	Grapsidae diet includes animal material, algal material, plant material and inorganic sediments <sup>14,15</sup>
<i>Amarinus laevis</i>	small freshwater crab	epibenthic	omnivorous scavenger/predator <sup>17</sup>	feeds on amphipods, plant and algal material <sup>17</sup>
<b>Maxillopoda</b>				
Copepoda	microcrustaceans	pelagic/epibenthic	various <sup>6,10,18,19</sup>	feeding modes include omnivorous, herbivorous and detritivorous suspension feeding and browsing or predation. Benthic copepods (harpacticoids and cyclopoids) are primarily detritivores and herbivores <sup>19</sup> . Main diet includes phytoplankton, nauplii, rotifers and small cladocerans <sup>6</sup>

<sup>9</sup> Maurer, D., Watling, L., Leathem, W. and Kinner, P. (1979). Seasonal changes in feeding types of estuarine benthic invertebrates from Delaware Bay. *Journal of Experimental Marine Biology and Ecology* **36**, 125–155.

<sup>10</sup> Felgenhauer, B.E., Watling, L. and Thistle, A.A. (1989). 'Functional morphology of feeding and grooming in Crustacea. Crustacean Issues, Vol. 6.' (A. A. Balkema: Rotterdam, The Netherlands)

<sup>11</sup> Kelleway, J., Mazumder, D., Wilson, G.G., Saintilan, N., Knowles, L., Iles, J. and Kobayashi, T. (2010). Trophic structure of benthic resources and consumers varies across a regulated floodplain wetland. *Marine and Freshwater Research* **61**, 430–440.

<sup>12</sup> Burns, A. and Walker, K. (2000). Biofilms as food for decapods (Atyidae, Palaemonidae) in the River Murray, South Australia. *Hydrobiologia* **437**, 83–90.

<sup>13</sup> Lee, C.L. and Fielder, D.R. (1982). Maintenance and reproductive behaviour in the freshwater prawn *Macrobrachium australiense* Holthuis (Crustacea: Decapoda: Palaemonidae). *Australian Journal of Marine and Freshwater Research* **33**, 629–646.

<sup>14</sup> Poon, D.Y.N., Chan, B.K.K. and Williams, G.A. (2010). Spatial and temporal variation in diets of the crabs *Metopograpsus frontalis* (Grapsidae) and *Perisesarma bidens* (Sesarmidae): implications for mangrove food webs. *Hydrobiologia* **638**, 29–40.

<sup>15</sup> Ledesma, M.E. and O'Connor, N.J. (2001). Habitat and diet of the non-native crab *Hemigrapsus sanguineus* in southeastern New England. *Northeastern Naturalist* **8**, 63–78.

<sup>16</sup> Buck, T.L., Breed, G.A., Pennings, S.C., Chase, M.E., Zimmer, M. and Carefoot, T.H. (2003). Diet choice in an omnivorous salt-marsh crab: different food types, body size and habitat complexity. *Journal of Experimental Marine Biology and Ecology* **292**, 103–116.

<sup>17</sup> Lucas, J.S. (1981). Spider crabs of the family *Hymenosomatidae* (Crustacea; Brachyura) with particular reference to Australian species: systematics and biology. *Records of the Australian Museum* **33**, 148–247.

<sup>18</sup> Mauchline, J. (1998). The biology of calanoid copepods. In 'Advances in Marine Biology, Volume 33'. (Eds. HS Blaxter, AJ Southward and PA Tyler). (Academic Press: San Diego, USA)

<sup>19</sup> Gooderham, J. and Tsyrlin, E. (2002). 'The waterbug book: a guide to the freshwater macroinvertebrates of temperate Australia.' (CSIRO Publishing: Victoria)

Taxa	Description	Habitat mode	Feeding mode	Additional feeding information
<b>Ostracoda</b>	microcrustaceans	pelagic/epibenthic	suspension feeder <sup>6,19</sup>	detritus and algae <sup>6</sup>
<b>Branchiopoda</b>				
Cladocera	microcrustaceans	pelagic	suspension feeder <sup>19,20</sup>	microorganisms – bacteria and unicellular algae <sup>19,20</sup>
<i>Parartemia</i>	microcrustaceans	pelagic	suspension feeder <sup>6,19</sup>	
<b>Rotifera</b>	rotifers	pelagic	suspension feeder <sup>6,21</sup>	feed on organic material, algae bacteria, ciliates, flagellates and other protozoans <sup>21</sup>
<b>Protista</b> (e.g. tintinnids)	protists	epibenthic/pelagic	suspension feeder <sup>22</sup>	photosynthetic algae, nanoflagellates and cyanobacteria <sup>22</sup>
<b>Meroplankton</b> (e.g. mollusc veligers and decapod larvae)	macroinvertebrate larval and small juveniles	epibenthic/pelagic	various <sup>23</sup>	microalgae (phytoplankton), diatoms, bacteria, protists <sup>23</sup>
<b>Diptera</b>				
Chironomidae	insect larvae/pupae	benthic infauna	various <sup>6,19,24</sup>	feeding modes include detritivore/herbivorous grazer/deposit feeder/suspension feeder/predator. Most chironomid larvae are detritivores or herbivorous grazers, which feed on plant, algal and detrital material. Although there are a few genera that are strictly carnivorous (feeding on other chironomids, oligochaetes, nematodes and small invertebrates) <sup>6,19,24</sup> . <i>Tanytarsus</i> (the genus most common in the Coorong) feeds primarily on algae <sup>25</sup> , diatoms and detritus <sup>26</sup>
Ceratopogonidae	insect larvae/pupae	benthic infauna	deposit feeder/predator <sup>6,27</sup>	feed on algae, diatoms <sup>27</sup> , detritus, and small invertebrates <sup>6</sup>
Ephydriidae	insect larvae/pupae	benthic infauna	deposit feeder <sup>6</sup> /herbivorous grazer <sup>19</sup> .	feed on algae and bacteria <sup>6</sup>
Dolichopodidae	insect larvae/pupae	benthic infauna	herbivorous grazer/predator <sup>6</sup>	feed on small arthropods and oligochaetes, or macrophytes <sup>6</sup>
<b>Hemiptera</b>				
Notonectidae, Corixidae etc.	freshwater insects	aquatic pelagic	omnivorous scavenger <sup>28,19</sup> /predator <sup>19</sup>	feed primarily on small invertebrates (e.g. insect larvae) and vegetation <sup>19</sup>
<b>Coleoptera</b>				
Hydrophilidae	insect larvae/pupae	benthic infauna	predator <sup>6,19</sup>	feed on snails, worms, small crustaceans and insect larvae <sup>6</sup>

<sup>20</sup> Cannon, H.G. (1932). On the feeding mechanism of the Branchiopoda. *Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character* **222**, 267–339.

<sup>21</sup> Arndt, H. (1993). Rotifers as predators on components of the microbial web (bacteria, heterotrophic flagellates, ciliates) – a review. *Hydrobiologia* **255/256**, 231–246.

<sup>22</sup> Bernard, C. and Rassoulzadegan, F. (1993). The role of picoplankton (cyanobacteria and plastidic picoflagellates) in the diet of tintinnids. *Journal of Plankton Research* **15**, 361–373.

<sup>23</sup> Strathmann, R.R. (1985). Feeding and nonfeeding larval development and life-history evolution in marine invertebrates. *Annual Reviews of Ecology and Systematics* **16**, 339–361.

<sup>24</sup> Oliver, D.R. (1971) Life history of the Chironomidae. *Annual Review of Entomology* **16**, 211–230.

<sup>25</sup> Cavanaugh, W.J. and Tilden, J.E. (1930). Algal food, feeding and case-building habits of the larva of the midge fly, *Tanytarsus dissimilis*. *Ecology* **11**, 281–287.

<sup>26</sup> Ingvason, H.R., Olafsson, J.S. and Gardarsson, A. (2004). Food selection of *Tanytarsus gracilentus* larvae (Diptera: Chironomidae): an analysis of instars and cohorts. *Aquatic Ecology* **38**, 231–237.

<sup>27</sup> Aussel, J.P. and Linley, J.R. (1994). Natural food and feeding-behaviour of *Culicoides furens* larvae (Diptera, Ceratopogonidae). *Journal of Medicinal Entomology* **31**, 99–104.

<sup>28</sup> Klecka, J. (2014). The role of a water bug, *Sigara striata*, in freshwater food webs. *PeerJ*. doi: 10.7717/peerj.389.

**Table A2. Diet summary table for abundant fishes of the Coorong, and the long-nosed fur seal. Food categories (i.e. Algae/plants, Annelids, Crustaceans, Detritus, Insects, Molluscs, Teleosts and Other) are presented in order of importance. ‘Main food items’ may not have been incorporated into the models if they contributed <~10% towards total index. Where applicable, total length (TL) ranges and sample sizes (*n*) have been provided. Species have been allocated into marine, estuarine, freshwater and diadromous (catadromous) categories based on definitions in Potter *et al.* (2015), and into feeding mode functional groups (FM) based on all available literature: ZP = zooplanktivore, DV = detritivore, HV-o = obligate herbivore, HV-f = facultative herbivore, OV = omnivore, PV = piscivore, IV-o = obligate invertivore, IV-f = facultative invertivore (adapted from Elliott *et al.* 2007). Note that ‘larvae’ is used as a loose term and may include early juvenile stages.**

Species	FM	Main food items in Coorong	TL (mm)	<i>n</i>	Source	Other literature
<u>Marine</u>						
Mulloway ( <i>Argyrosomus japonicus</i> )	Early juv = IV-f; Juv/adult = PV	Teleosts – Atherinids, bony herring; Crustaceans – shrimp ( <i>Macrobrachium</i> sp.), amphipods ( <i>Paracorophium</i> spp.).	150–460		Hall 1986	
		Teleosts – mugilids, atherinids, congolli; Crustaceans – crabs.	480–660	20	Geddes and Francis 2008	
		Crustaceans – crabs, shrimp ( <i>Macrobrachium</i> sp.), amphipods; Teleosts – mugilids, atherinids and gobies; Annelids – <i>Arenicola</i> sp.	135–548	46	*Deegan <i>et al.</i> 2010	Whitfield and Blaber 1978; Marais 1984; Griffiths 1997; Taylor <i>et al.</i> 2006
		Teleosts – sandy sprat ( <i>Hyperlophus vittatus</i> ), yellow-eye mullet ( <i>Aldrichetta forsteri</i> ), congolli ( <i>Pseudaphritis urvillii</i> ), bony herring ( <i>Nematalosa erebi</i> ), smallmouthed hardyhead ( <i>Atherinosoma microstoma</i> ), gobies (e.g. <i>Afurcagobius tamarensis</i> ); Crustaceans – crabs (e.g. <i>Paragrapsus gaimardii</i> ), mysid shrimp, amphipods.	174–949	265	Giatas and Ye 2015	
Yellow-eye mullet ( <i>Aldrichetta forsteri</i> )	Early juv = IV-f; Juv/adult = OV	Annelids – capitellid ( <i>Capitella</i> sp.), nereid, arenicolid and spionid polychaetes; Crustaceans – amphipods, crabs and ostracods; Molluscs – <i>Arthritica</i> sp.	30–300	40	Geddes and Francis 2008	
		Algae/plants – diatoms; Annelids – capitellid ( <i>Capitella</i> sp.), nereid (e.g. <i>Simplisetia aequisetis</i> ) and nephtyid ( <i>Aglaophamus australiensis</i> ) polychaetes; Crustaceans – amphipods, ostracods and harpacticoid copepods; Molluscs – <i>Arthritica</i> sp.; Other – foraminiferans.	41–375	135	*Deegan <i>et al.</i> 2010	Thomson 1957; Webb 1973; Robertson and Howard 1978; Edgar and Shaw 1995; Crinall and Hindell 2004; Platell <i>et al.</i> 2006
		Detritus; Algae/plants – filamentous algae (e.g. <i>Cladophora</i> ); Annelids – capitellid (e.g. <i>Capitella</i> sp.), nereid, spionid and nephtyid polychaetes; Crustaceans – amphipods, copepods, mysid shrimp; Teleosts – unknown.	37–270	99	Giatas 2012	

Species	FM	Main food items in Coorong	TL (mm)	n	Source	Other literature
Greenback flounder ( <i>Rhombosolea tapirina</i> )	Larvae = ZP; Juv/adult = IV-f	Annelids – nereid ( <i>Simplisetia aequisetis</i> ) and nephtyid ( <i>Aglaophamus australiensis</i> ) polychaetes; Crustaceans – amphipods and crabs; Molluscs - <i>Arthritica</i> sp.	35–365	28	*Deegan <i>et al.</i> 2010	Robertson and Howard 1978; Kent and Day 1983; Jenkins 1987; Shaw and Jenkins 1992; Edgar and Shaw 1995
		Crustaceans – amphipods, crab (e.g. <i>Paragrapsus gaimardii</i> ), copepods, mysid shrimp, cumaceans; Annelids – <i>Aglaophamus australiensis</i> (formerly <i>Nephtys</i> ); Molluscs – <i>Tellina</i> spp.; Insects – chironomid larvae.	23–357	398	Earl 2014	
Australian salmon ( <i>Arripis trutta</i> and <i>A. truttaceus</i> )	PV	Teleosts – sandy sprat, smallmouthed hardyhead, gobies (e.g. <i>Afurcagobius tamarensis</i> ); Crustaceans – copepods, amphipods, mysid shrimp.	56–205	78	Giatas and Ye 2015	Robertson and Howard 1978; Robertson 1982; Cappo 1987; Hoedt and Dimmlich 1994; Edgar and Shaw 1995; Hindell <i>et al.</i> 2000; 2002; Hindell 2006; Stewart <i>et al.</i> 2011
Australian herring ( <i>Arripis georgianus</i> )	IV-f	No investigation				Lenanton <i>et al.</i> 1982; Platell <i>et al.</i> 2006
Sandy sprat ( <i>Hyperlophus vittatus</i> )	ZP	Crustaceans – harpacticoid, cyclopoid and calanoid copepods and nauplii, cladocerans (e.g. <i>Bosmina meridionalis</i> ), amphipods, crab zoea, ostracods; Other – rotifers (e.g. <i>Keratella australis</i> ).	23–57	60	Bice <i>et al.</i> 2016	Thomson 1959; Edgar and Shaw 1995
		Crustaceans – harpacticoid and calanoid copepods and nauplii, amphipods, ostracods, mysid shrimp, cladocerans (e.g. <i>Bosmina</i> sp.).	18–70	9	A. Hossain unpublished data	
Long-nosed fur seal ( <i>Arctocephalus forsteri</i> )	PV	Teleosts – common carp ( <i>Cyprinus carpio</i> ), bony herring, gobies (e.g. <i>Afurcagobius tamarensis</i> ), **mulloway ( <i>Argyrosomus japonicus</i> ), **golden perch ( <i>Macquaria ambigua</i> ).		32,**2	SARDI unpublished data (FRDC Project No. 2013-011)	Page <i>et al.</i> 2005; Reinhold 2015

Species	FM	Main food items in Coorong	TL (mm)	n	Source	Other literature
<u>Estuarine</u>						
Black bream ( <i>Acanthopagrus butcheri</i> )	Larvae = ZP;	Crustaceans – crabs ( <i>Paragrapsus gaimardii</i> ); Algae/plants – filamentous algae ( <i>Ulva</i> , formerly <i>Enteromorpha</i> ); Molluscs – pipi ( <i>Donax deltooides</i> ); Teleosts – gobies.			***Weng 1970	Thomson 1959; Weng 1970; Sarre <i>et al.</i> 2000; Chuwen <i>et al.</i> 2007; Linke 2011; Williams <i>et al.</i> 2013
	Juv/adult = OV	Crustaceans – crabs; Annelids – nereid, nephtyid ( <i>Aglaophamus australiensis</i> ) and capitellid ( <i>Capitella</i> sp.) polychaetes; Teleosts – gobies; Molluscs – <i>Arthritica</i> sp.	182–410	14	*Deegan <i>et al.</i> 2010	
River garfish ( <i>Hyporthamphus regularis</i> )	<100 mm = ZP; >100 mm = HV-f	No investigation				Tibbets and Carseldine 2005
Smallmouthed hardyhead ( <i>Atherinosoma microstoma</i> )	IV-o	Crustaceans – amphipods, harpacticoid copepods, mysid shimp and ostracods; Annelids – capitellid ( <i>Capitella</i> sp.) and spionid polychaetes.	20–50	20	Geddes and Francis 2008	Crinall and Hindell 2004; Becker and Laurenson 2007; Platell and Freewater 2009
		Crustaceans – amphipods and harpacticoid copepods; Annelids – polychaetes; Insects – terrestrial insects.	36–74	41	*Deegan <i>et al.</i> 2010	
		Crustaceans – amphipods, copepods; Insects – chironomids, corixids, dolichopodids.		546	L. Silvester unpublished data	
		Crustaceans – harpacticoid copepods, ostracods, amphipods, mysid shrimp; Insects – dipterans (e.g. chironomids); Annelids – nereid polychaetes.	16–85	11	A. Hossain unpublished data	
Tamar goby ( <i>Afurcagobius tamarensis</i> )	IV-f	Crustaceans – amphipods; Annelids – capitellid ( <i>Capitella</i> sp.) and spionid polychaetes.	20–50	20	Geddes and Francis 2008	Edgar and Shaw 1995
		Crustaceans – amphipods, copepods; Insects – chironomids; Annelids - nereid polychaetes; Teleosts – unknown.		305	L. Silvester unpublished data	
		Crustaceans – amphipods, harpacticoid copepods, ostracods, mysid shrimp; Annelids – nereid polychaetes.	15–89	12	A. Hossain unpublished data	
Lagoon goby ( <i>Tasmanogobius lasti</i> )	?	No investigation				No available literature

Species	FM	Main food items in Coorong	TL (mm)	n	Source	Other literature
Bridled goby ( <i>Arenigobius bifrenatus</i> )	OV	No investigation				Robertson and Howard 1978; Robertson 1980; Edgar and Shaw 1995
Bluespot goby ( <i>Pseudogobius olorum</i> )	Larvae = ZP; Juv/adults = OV	No investigation				Gill and Potter 1993; Humphries and Potter 1993; Edgar and Shaw 1995; Gaughan and Potter 1997; Mazumbder <i>et al.</i> 2006; Becker and Laurenson 2007; Platell and Freewater 2009
<u>Catadromous</u>						
Congolli ( <i>Pseudaphritis urvillii</i> )	IV-f	Crustaceans – crabs, mysid shrimp and <i>Macrobrachium</i> sp.; Teleosts – gobies; Annelids – unknown.  Crustaceans – amphipods, mysid shrimp; Annelids – nereid ( <i>Simplisetia aequisetis</i> and <i>Australonereis ehlersi</i> ) and capitellid polychaetes.	155–205	17	*Deegan <i>et al.</i> 2010	Hortle and White 1980
			37–230	255	Johnson 2014/Giatas and Ye 2015	
<u>Freshwater</u>						
Bony herring ( <i>Nematolosa erebi</i> )	Small juv = ZP; Large juv/adults = HV-f/DV	No investigation				Atkins 1984; Balcombe <i>et al.</i> 2005; Medeiros and Arthington 2008a; 2008b; Sternberg <i>et al.</i> 2008; Medeiros and Arthington 2014
Common carp ( <i>Cyprinus carpio</i> )	Larvae = ZP; Juv/adults = DV/OV	No investigation				Hall 1981; Vilizzi 1998; Khan 2003; King 2005
Australian smelt ( <i>Retropinna semoni</i> )	ZP	No investigation				Pollard 1973; Chapman 2003; Becker and Laurenson 2007

Species	FM	Main food items in Coorong	TL (mm)	n	Source	Other literature
Flathead gudgeon ( <i>Philypnodon grandiceps</i> )	IV-f	No investigation				Becker and Laurenson 2007

Species that contributed to <1% of the total seine or gill net catches (Livore *et al.* 2013) for small and large-bodied fishes, respectively, were excluded from the table above (refer to Section 2.1), with the exception of black bream as it is a commercially important species that was previously abundant. Four abundant species of gobies that collectively contributed to >1% of total seine net catch are presented. Other species that occur in the Coorong include common galaxias (*Galaxias maculatus*), longsnout flounder (*Ammotretis rostratus*), goldspot mullet (*Liza argentea*), sea mullet (*Mugil cephalus*), smooth toadfish (*Tetractenos glaber*), common toadfish (*Tetractenos hamiltoni*), soldier fish (*Gymnapistes marmoratus*), redfin perch (*Perca fluviatilis*), golden perch (*Macquaria ambigua*), southern long-fin goby (*Favonigobius lateralis*), Australian anchovy (*Engraulis australis*), blue sprat (*Spratelloides* spp.), pouched lamprey (*Geotria australis*), short-headed lamprey (*Mordacia mordax*), dwarf flathead gudgeon (*Philypnodon macrostomus*), goldfish (*Carassius auratus*), eastern gambusia (*Gambusia holbrooki*), king george whiting (*Sillaginodes punctatus*), sea sweep (*Scorpiis aequipinnis*), Australian sardine (*Sardinops sagax*), pipefish (Family Sygnathidae), western striped grunter (*Pelates octolineatus*), Yellowfin whiting (*Sillago schomburgkii*). Sharks (e.g. bronze whaler *Carcharhinus brachyurus*) and rays (e.g. eagle ray *Myliobatis australis*) were observed in low abundance during monitoring programs.

\*Stomach-content data from Deegan *et al.* (2010) was re-evaluated to include all prey items originally identified, with the most frequently occurring prey items presented above.

Important prey species are presented for 32 long-nosed seal scats (SARDI unpublished data). \*\*Mulloway and golden perch did not contribute to total prey biomass in scat samples, but were important in stomach samples ( $n=2$ ).

\*\*\*Black bream stomach samples from Weng (1970) also include those from other South Australian estuaries, i.e. Patawalonga and Onkaparinga Rivers.

**Table A3. Diet of Coorong birds by feeding mode grouping, represented by a few abundant species. Information is from Marchant and Higgins (1990), Higgins and Davies (1996) and references within. Most information is taken from studies using stomach content analyses outside of the Coorong. Prey items listed are restricted to those that occur within the Coorong. Feeding mode functional groups (FM) are: HV-o = obligate herbivore, PV = piscivore, and IV-f = facultative invertivore.**

Common name	Species	Prey items
<u>Piscivorous waterbirds (PV)</u>		
Australian pelican*	<i>Pelecanus conspicillatus</i>	<u>Main prey:</u> Freshwater habitats – common carp ( <i>Cyprinus carpio</i> ), redfin perch ( <i>Perca fluviatilis</i> ), goldfish ( <i>Carassius auratus</i> ). <u>Other:</u> Shrimp ( <i>Macrobrachium</i> sp.).
Cormorants	<i>Phalacrocorax carbo</i>	<u>Main prey:</u> Estuarine habitats – gobies (e.g. <i>Arenigobius bifrenatus</i> ), yellow-eye mullet ( <i>Aldrichetta forsteri</i> ), Australian salmon ( <i>Arripis trutta</i> ), black bream ( <i>Acanthopagrus butcheri</i> ), smallmouthed hardyhead ( <i>Atherinosoma microstoma</i> ), Australian anchovy ( <i>Engraulis australis</i> ), sandy sprat ( <i>Hyperlophus vittatus</i> ), eel ( <i>Anguilla australis</i> ), striped perch ( <i>Pelates</i> sp.), soldier ( <i>Gymnapistes marmoratus</i> ), lamprey ( <i>Mordacia mordax</i> ), galaxias ( <i>Galaxias maculatus</i> ), river garfish ( <i>Hyporhamphus regularis</i> ), flathead gudgeon ( <i>Philypnodon</i> spp.), greenback flounder ( <i>Rhombosolea tapirina</i> ), Australian herring ( <i>Arripis georgianus</i> ), congolli ( <i>Pseudaphritis urvillii</i> ). Freshwater habitats – goldfish ( <i>Carassius auratus</i> ), redfin perch ( <i>Perca fluviatilis</i> ), bony herring ( <i>Nematalosa erebi</i> ), golden perch ( <i>Macquaria ambigua</i> ). <u>Other:</u> shrimp (e.g. <i>Macrobrachium</i> sp.), crabs (e.g. <i>Paragrapsus gaimardii</i> ), insects.
	<i>Phalacrocorax varius</i>	<u>Main prey:</u> Estuarine habitats – soldier, sandy sprat, yellow-eye mullet, sea mullet ( <i>Mugil cephalus</i> ), gobies (e.g. <i>Arenigobius bifrenatus</i> ), Australian salmon, toadfish, flounder ( <i>Rhombosolea</i> ), striped perch ( <i>Pelates</i> sp.). Freshwater habitats – bony herring, Australian smelt ( <i>Retropinna semoni</i> ), goldfish, redfin perch, flathead gudgeon, galaxiids, common carp, golden perch. <u>Other:</u> shrimp, gastropods, bivalves.
	<i>Phalacrocorax sulcirostris</i>	<u>Main prey:</u> Estuarine habitats – sandy sprat, atherinids, soldier, striped perch ( <i>Pelates</i> sp.), gobies (including bluespot goby, <i>Pseudogobius olorum</i> and bridled goby), black bream, blue sprat ( <i>Spratelloides</i> sp.), yellow-eye mullet, sea mullet. Freshwater habitat – Australian smelt, goldfish, redfin, flathead gudgeon, galaxiids <u>Other:</u> shrimp, insects (Hydrophilidae, Dytiscidae), molluscs.
Fairy tern	<i>Sterna nereis</i>	<u>Main prey:</u> garfish (Hemiramphidae), mullet (Mugilidae), flounder ( <i>Rhombosolea</i> sp.), Australian smelt, Australian anchovy, gobies, atherinids.
<u>Carnivorous shorebirds (IV-f)</u>		
Red-neck stint	<i>Calidris ruficollis</i>	<u>Main prey:</u> polychaetes, oligochaetes, bivalves, gastropods, amphipods, prawns, insects, plant seeds <u>Other:</u> flounder.

Common name	Species	Prey items
Banded stilt	<i>Cladorhynchus leucocephalus</i>	<u>Main prey:</u> brine shrimp, ostracods, gastropods (e.g. <i>Salinator fragilis</i> ), bivalves, insect larvae, plant seeds and turions (e.g. <i>Ruppia</i> ) <u>Other:</u> atherinids (e.g. <i>Atherinosoma microstoma</i> )
Sharp-tailed sandpiper	<i>Calidris acuminata</i>	<u>Main prey:</u> polychaetes, bivalves, gastropods, ostracods, amphipods, insects, plant seeds (e.g. <i>Ruppia</i> spp.)
Black-winged stilt	<i>Himantopus himantopus</i>	<u>Main prey:</u> oligochaetes, gastropods, shrimps, mysid shrimp, amphipods, brine shrimp, insect larvae <u>Other:</u> plant seeds (e.g. <i>Ruppia</i> spp.), galaxiids
Red-capped plover	<i>Charadrius ruficapillus</i>	<u>Main prey:</u> annelids, gastropods, ostracods, isopods, amphipods, crabs, insect larvae <u>Other:</u> plant seeds (e.g. <i>Ruppia</i> spp.),
Red-necked avocet	<i>Recurvirostra novahollandiae</i>	<u>Main prey:</u> insects, crustaceans (e.g. brine shrimp), fish (atherinids). <u>Other:</u> plant seeds
<hr/>		
<u>Herbivorous waterbirds (HV-o)</u>		
Black swan	<i>Cygnus atratus</i>	<u>Main prey:</u> leaves and shoots of aquatic plants (e.g. <i>Ruppia</i> spp.).

\*No detailed diet studies for Australian pelican.

**Appendix 5. Percentage contribution of medium- and large-bodied fishes to total gill net catches in the Coorong. Regions are ME = Murray Estuary, NL = North Lagoon, SL = South Lagoon. 2006-07 data represents the ‘low inflow period’ and the mean of the 2010-11, 2011-12 and 2012-13 data represents the ‘high inflow’ period.**

Common Name	Scientific Name	Low inflow				High inflow			
		ME	NL	SL	Total	ME	NL	SL	Total
Bony herring	<i>Nematolosa erebi</i>	4.07	0.46		2.96	66.10	71.37	*	69.58
Yellow-eye mullet	<i>Aldrichetta forsteri</i>	21.18	69.86		36.20	10.30	21.42	*	17.64
Western Australian salmon	<i>Arripis truttaceus</i>	42.57	2.28		30.14	14.46	3.25		7.06
Mulloway	<i>Argyrosomus japonicus</i>	27.49	24.66		26.62	4.30	3.37		3.68
Australian herring	<i>Arripis georgianus</i>	2.24			1.55		0.03		0.02
Carp	<i>Cyprinus carpio</i>					3.24	0.19		1.23
Greenback flounder	<i>Rhombosolea tapirina</i>	1.22	0.91		1.13		0.11		0.07
Other mugilids		0.20	0.91		0.42	0.59	0.05		0.23
Sea mullet	<i>Mugil cephalus</i>	0.20	0.91		0.42	0.06			0.02
Goldspot mullet	<i>Liza argentea</i>					0.53	0.05		0.21
Western striped grunter	<i>Pelates octolineatus</i>	0.81			0.56				
Redfin perch	<i>Perca fluviatilis</i>					0.73	0.17		0.36
Golden perch	<i>Macquaria ambigua</i>					0.09	0.02		0.04
Toadfishes	Family Tetraodontidae		0.91		0.28				
Black bream	<i>Acanthopagrus butcheri</i>	0.20			0.14	0.09	0.02	*	0.05
Goldfish	<i>Carassius auratus</i>					0.08			0.03
Soldier	<i>Gymnapistes marmoratus</i>						0.01		0.01
Yellowfin whiting	<i>Sillago schomburgkii</i>					0.02			0.01

\*No gill netting was performed in the SL for the low inflow period; therefore, all gill net data in SL was omitted. Yellow-eye mullet, bony herring and black bream were collected in the SL during high inflow period in low quantities during seine netting for small-bodied species.

**Appendix 6. Percentage contribution of small-bodied fishes to total seine net catches in the Coorong. Regions are ME = Murray Estuary, NL = North Lagoon, SL = South Lagoon. 2006-07 data represents the 'low inflow period' and the mean of the 2010-11, 2011-12 and 2012-13 data represents the 'high inflow' period.**

Common Name	Scientific Name	Low inflow				High inflow			
		ME	NL	SL	Total	ME	NL	SL	Total
Smallmouthed hardyhead	<i>Atherinosoma microstoma</i>	21.70	96.91	100.00	74.35	3.72	66.30	99.98	59.73
Sandy sprat	<i>Hyperlophus vittatus</i>	70.88	2.22		22.82	88.38	30.79		36.90
Gobies		0.84	0.31		0.47	2.54	1.72	0.01	1.45
Tamar goby	<i>Afurcagobius tamarensis</i>	0.63	0.30		0.40	1.61	0.25		0.53
Scary's Tasman goby	<i>Tasmanogobius lasti</i>	0.14	0.01		0.05	0.29	1.09	0.01	0.58
Bridled goby	<i>Arenigobius bifrenatus</i>	0.02			0.01	0.50	0.20		0.22
Bluespot goby	<i>Pseudogobius olorum</i>	0.05			0.02	0.02	0.18	0.00	0.09
Southern Longfin goby	<i>Favonigobius lateralis</i>					0.13	0.00		0.03
River garfish*	<i>Hyporhamphus regularis</i>	5.21	0.12		1.65	0.25	0.14		0.13
Australian smelt	<i>Retropinna semoni</i>	0.02			0.01	2.53	0.41		0.84
Longsnout flounder*	<i>Ammotretis rostratus</i>	0.93	0.42		0.57	0.16	0.04		0.06
Common galaxias	<i>Galaxias maculatus</i>	0.18			0.05	0.24	0.00		0.06
Congolli*	<i>Pseudaphritis urvillii</i>	0.02	0.02		0.02	0.95	0.58	0.01	0.52
Flat-headed gudgeon	<i>Philypnodon grandiceps</i>					1.24	0.01		0.32
Australian anchovy	<i>Engraulis australis</i>	0.22			0.06				

\*While congolli, river garfish and longsnout flounder are not considered to be small-bodied species, they have been included in the 'small-bodied' fish assemblage as gill nets are not considered efficient in targeting them due to the size of fish present.