Ecosystem models to inform the development of strategies to restore a functioning South Lagoon food web in the Coorong

Simon D. Goldsworthy, Ryan Baring, George Giatas,
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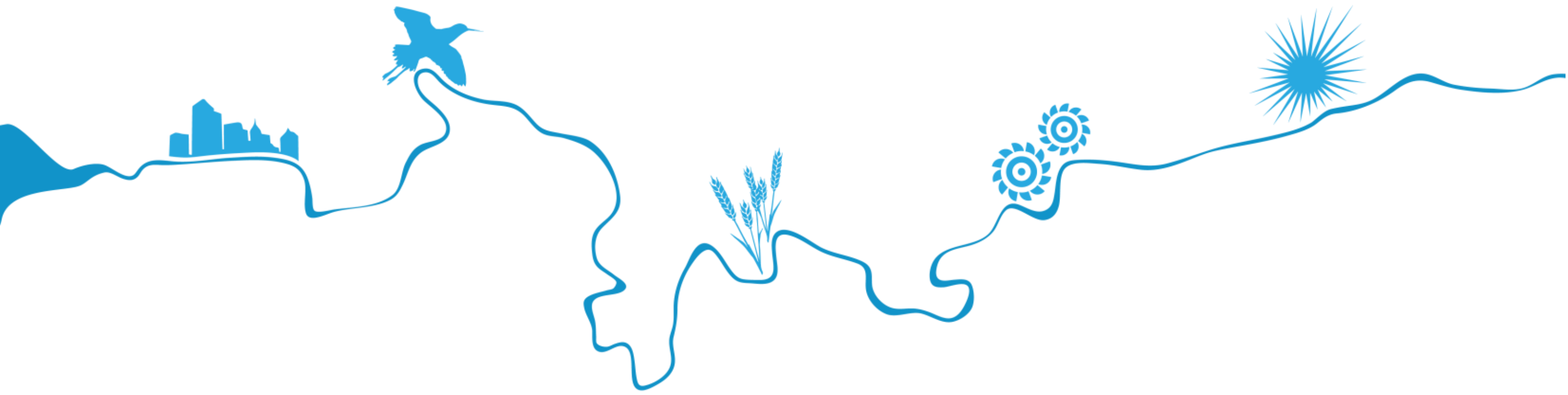

Goyder Institute for Water Research
Technical Report Series No. 22/11

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

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Associate Parties of the Institute involved:

This program is part of the South Australian Government's Healthy Coorong, Healthy Basin Program, which is jointly funded by the Australian and South Australian governments.

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Citation

Goldsworthy S, Baring R, Giatas G, Nitschke J, Bucater L, Ye Q (2022). *Ecosystem models to inform the development of strategies to restore a functioning South Lagoon food web in the Coorong*. Goyder Institute for Water Research Technical Report Series No. 22/11.

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Respect and reconciliation

Aboriginal people are the First Peoples and Nations of South Australia. The Coorong, connected waters and surrounding lands have sustained unique First Nations cultures since time immemorial.

The Goyder Institute for Water Research acknowledges the range of First Nations' rights, interests and obligations for the Coorong and connected waterways and the cultural connections that exist between Ngarrindjeri Nations and First Nations of the South East peoples across the region and seeks to support their equitable engagement.

Aboriginal peoples' spiritual, social, cultural and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages and laws which are of ongoing importance.

Executive summary

The Coorong ecosystem is an important ecological component of the Murray-Darling Basin that provides significant cultural, environmental, and economic values at local, national and international scales. Along with the Murray Mouth and Estuary, and Lower Lakes it forms a wetland of International Importance under the Ramsar Convention. The combined impacts of reduced flows from the River Murray and other anthropogenic impacts, exacerbated during the Millennium Drought (particularly during the period 2001-2010), have resulted in long-term declines in the ecological condition of the Coorong. This is most notable in the South Lagoon, where increased eutrophication, hypersalinity and other impacts have resulted in a significant loss of ecosystem function.

The Healthy Coorong, Healthy Basin Program (HCHB) represents a government commitment to improve the health of the Coorong. Part of the commitment is to conduct Scientific Trials and Investigations (T&I) to provide knowledge that informs the future management of the Coorong and facilitate restoration and maintenance of ecological condition, particularly for the South Lagoon. Investigations for '*Restoring a functioning Coorong food web*' forms *Component 3* of the HCHB T&I Project. The primary objectives were to improve understanding of food web dynamics by investigating the diet, prey availability and energy supply for key biota (waterbirds and fish) in the Coorong and develop a quantitative food web model. This report details the outputs of Activity 3.4 *'Ecosystem models to inform the development of strategies to restore a functioning South Lagoon food web in the Coorong'*, which specifically aimed to develop quantitative food web models for the North Coorong (Murray Estuary and North Lagoon) and South Lagoon and use these models to inform the development of strategies to restore a functioning South Lagoon food web. This report presents the results of work completed during the period from April 2021 to May 2022.

Trophic mass balance models of the North Coorong (i.e. Goolwa Barrages to Parnka Point North) and South Lagoon (i.e. Parnka Point South to Salt Creek) sections of the Coorong ecosystem were developed using the *Ecopath* with *Ecosim* (EwE) software. The North Coorong and South Lagoon ecosystem models were composed of 56 and 48 trophic groups respectively, including mammals, birds, chondrichthyans, teleosts, invertebrates, autotrophs, and detritus. The base *Ecopath* models used available data to estimate four key parameters: biomass (B), production per biomass (P/B), consumption per unit of biomass (Q/B) and ecotrophic efficiency (EE). A significant portion of this report details how these parameters were estimated for each trophic group and will form important assumptions for future ecological studies. Each model required a detailed dietary matrix and information on the landings and discard estimates for the commercial fishing fleet (target species by fishing gear type). Models were balanced using three of the four key parameters, with the final parameter value estimated by the model. *Ecopath* models were constructed to represent the status of each ecosystem in 1984-85, to coincide with the initial year of commercial fishery logbook data for the Lakes and Coorong fishery.

Ecopath models were used to develop time dynamic models in *Ecosim*, using a combination of best available data from the commercial fishery, fish research sampling and bird abundance data obtained across a 37-year time period (1984-85 to 2020-21). These provided a total of 67 and 44 individual reference time-series data sets for the North Coorong and South Lagoon ecosystem models, respectively, including estimates of annual catch, fishing effort, and relative biomass (CPUE) of key commercially targeted species (e.g. yelloweye mullet, mulloway, black bream, flounder); annual fish catch sampling data for other fish taxa, and annual data from the Coorong waterbird monitoring program. Environmental forcing time-series for flow (barrage flow/Salt Creek flow), water level and salinity were fitted to the reference biological time-series using the nutrient loading forcing function application of *Ecosim*. For both the North Coorong and South Lagoon models, the addition of environmental time-series data (e.g. flow, water level, salinity) with the nutrient loading forcing function and a primary production anomaly, provided the best models. Fits to annual mean salinity produced better model fits than mean annual water level, and water level produced better model fits than total annual barrage (North Coorong) or Salt Creek flows (South Lagoon).

To provide information to assist assessments of potential infrastructure developments on ecosystem recovery, scenarios were developed that examined the response relationships between key bird and fish groups to changes in observed flow, water level and salinity. For the North Coorong ecosystem, there was a strong response relationship between barrage flow and the relative biomass of bird groups with most group biomasses reaching a peak when flow rates were between 6,000 and 10,000 GL/y. All bird groups demonstrated a strong positive response to increases in water level up to +0.6m AHD. The response relationships between bird groups and salinity were more complex, with some group biomasses peaking at lower salinity levels and others peaking at higher salinity levels. For the South Lagoon ecosystem, the response relationships between water level and the biomass of bird groups were positive, with the optimal water level ranges for most groups being between +0.2 and +0.5 m AHD. There was a strong negative response relationship among all bird groups to salinity in the South Lagoon, with biomasses generally increasing markedly as salinity reduced below 100 g/l. The response relationships between bird biomass and Salt Creek flow in the South Lagoon ecosystem were more complex, peaking at average flow levels (~10 GL/y) and then declining as flow increased to 35 GL/y, increasing again as flow exceeded 40 GL/yr. This unexpected response relationship may indicate that the observed range of Salt Creek flows have been insufficient to raise water level or decrease salinity to a point that would elicit a positive response by bird groups. The environmental response relationships identified for fish groups were less clear than for bird groups, and this may not be unexpected given that the fits to times series for fish was generally poorer than for birds.

This work presents the first quantitative ecosystem models developed for the Coorong. Both the model development process, and the simulations to examine ecological response to environmental change (flow, water level and salinity), have improved our understanding of the key drivers of ecosystem health, and provide a basis to evaluate the likely improvements in key bird and fish taxa that could be achieved under the projected salinity and water level endpoints for different management options. However, given the early stages of model development, outputs need to be interpreted with caution, and further model development is needed to improve ecosystem models and their utility as a decision support tool for the management of the Coorong. This could include identification of new knowledge, data, and modelling products from other HCHB T&I components not yet integrated into ecosystem models; an analysis to identify data gaps and improve data provenance; identifying if environmental response relationships for key species can be improved by fitting monthly instead of annual time-series; and developing spatial and temporal models for the Coorong using the *Ecospace* module, to improve our understanding of how habitat availability and suitability may change under different environmental conditions. Such developments will increase confidence in the application of ecosystem models to support complex management decisions to improve the ecological health of the Coorong.

Acknowledgments

This project is part of the South Australian Government's Healthy Coorong, Healthy Basin Program, which is jointly funded by the Australian and South Australian governments.

We would like to acknowledge the following researchers who provided useful data and information during the food web model building phase of the project: Sabine Dittmann, Micha Jackson, Ryan Lewis, Rowan Mott, Jody O'Connor, Steve Klose (BirdLife Australia) Gareth Oerman, Thomas Prowse, Dan Rogers, Claire Sims and Michelle Waycott. We thank Angelo Tsolos (SARDI) for assistance with accessing fisheries time-series data. Advice on *Ecopath*/*Ecosim* food web models came from the expertise of Cathy Bulman at CSIRO, Tasmania.

Historical data used in this report was funded by The Living Murray, a joint initiative funded by the New South Wales, Victorian, South Australian and Commonwealth governments, coordinated by the Murray–Darling Basin Authority.

Photographs for separate taxonomic groups used in the appendix of this report were obtained from: authors personal collections; Atlas of Living Australia, https://bie.ala.org.au; Fishes of Australia, https://www.fishesofaustralia.net.au; The Australian Museum, https://australian.museum; BirdLife Australia, https://birdlife.org.au; The Victorian Museum, https://museumsvictoria.com.au; publications by Dittmann et al. (2018), Leterme et al. (2018), and Shiel and Tan 2013.

1 Introduction

1.1 Overview

The Coorong ecosystem is an important ecological component of the Murray-Darling Basin and along with the Murray Mouth and Estuary, and Lower Lakes it forms a wetland of International Importance under the Ramsar Convention (Phillips and Muller 2006). Long-term decline in the ecological condition of the Coorong due to reduced freshwater flows, particularly during the Millennium Drought, has resulted in ecological decline in the South Lagoon (Kingsford et al. 2010). More specifically, the River Murray, Lower Lakes and Coorong has experienced oscillations of drought and flood through time, but since the 1890s there have been three significant drought events (Federation Drought, 1895-1903; WWII Drought, 1937-1945; and Millennium Drought, 1996-2010). Most notable was the Millennium Drought, particularly during the late 2000s when flows through the Murray-Darling Basin were the lowest ever recorded and for the longest period, nine years (Figure 1a; James et al. 2015, Ryan 2018).

The Coorong receives freshwater inflows, predominately from the River Murray through the series of five barrages from Goolwa to Tauwitchere and smaller inflows through Salt Creek from the Morella Basin (Gibbs et al. 2018). Since the 1860s, changes to south-east flows via Salt Creek commenced as water was diverted for agricultural requirements; and in the 1930s flows from the River Murray into the Coorong were beginning to be managed with the construction of barrages (Hemming 2018). Seasonal and annual oscillations in water levels in the Coorong have been observed through time coinciding with flows through barrages and Salt Creek (Figure 2a). The South Lagoon has experienced lower water levels since the Millennium Drought ended in 2010, particularly when compared with the North Coorong, and water levels have only increased with some consistency since early 2020 (Figure 2a). Salinities in the Coorong increased during the Millennium Drought and declined with the onset of flows from 2010 onwards and have been more consistent across the last decade due to improved regulation of flows through the barrages and South East flow improvement program (Figure 2b). Salinity levels in the South Lagoon, however, remain high, indicative of a hypersaline ecosystem (Figure 2b).

In recent years, due to changes in flow and nutrient dynamics, filamentous algae has increased and dominated the ecosystem in South Lagoon (Asanopolous and Waycott 2020). Overall, environmental conditions have continued to decline, impacting habitat suitability for waterbirds, fish and macroinvertebrates and food web function (Mosley et al. 2020, Prowse 2020, Ye et al. 2020). The complexities of ecosystem dynamics and contributing environmental factors have limited capability to forecast responses to management interventions that aim to improve the ecological condition of the Coorong.

Several past studies have investigated trophic ecology of the Coorong ecosystem. Notably in 2016, Giatas and Ye developed conceptual models of the Coorong food web that were used to characterise likely variation in trophic structure and pathways across different hydrological regimes (Giatas and Ye 2016). This conceptual understanding was informed by data on species' abundances and distributions, and preceding empirical investigations of trophic ecology that used gut content and stable isotope analyses, to identify variation in the food web in association with barrage flows and salinity gradients (Giatas and Ye 2016).

Additionally in 2018, a static baseline conceptual food web model of the Coorong ecosystem was developed to inform the pelagic and benthic production pathways from primary producers through to higher order consumers (Figure 3, Giatas et al. 2018). Conceptual understanding of food web scenarios under conditions of low and high flows through the barrages was also explored for each of the Murray Mouth, North Lagoon and South Lagoon regions. Food web scenarios for low and high flow rates were distinct for each of the three regions, but particularly between the hypersaline South Lagoon versus the Murray Mouth and North Lagoon (Giatas and Ye 2016). Specifically, in the Murray Mouth and North Lagoon, the switch between pelagic to benthic dominated food web functioning was proposed in high and low flow scenarios (Giatas and Ye 2016). In comparison, food web functioning was severely limited in the South Lagoon and dominated by benthic production. The conceptual understanding of the Coorong food web under low and high flows provided the baseline for advancing into quantitative ecosystem-based food web models such as *Ecopath* with *Ecosim*. Thus, the progression of food web models investigated in the report herein.

(a)

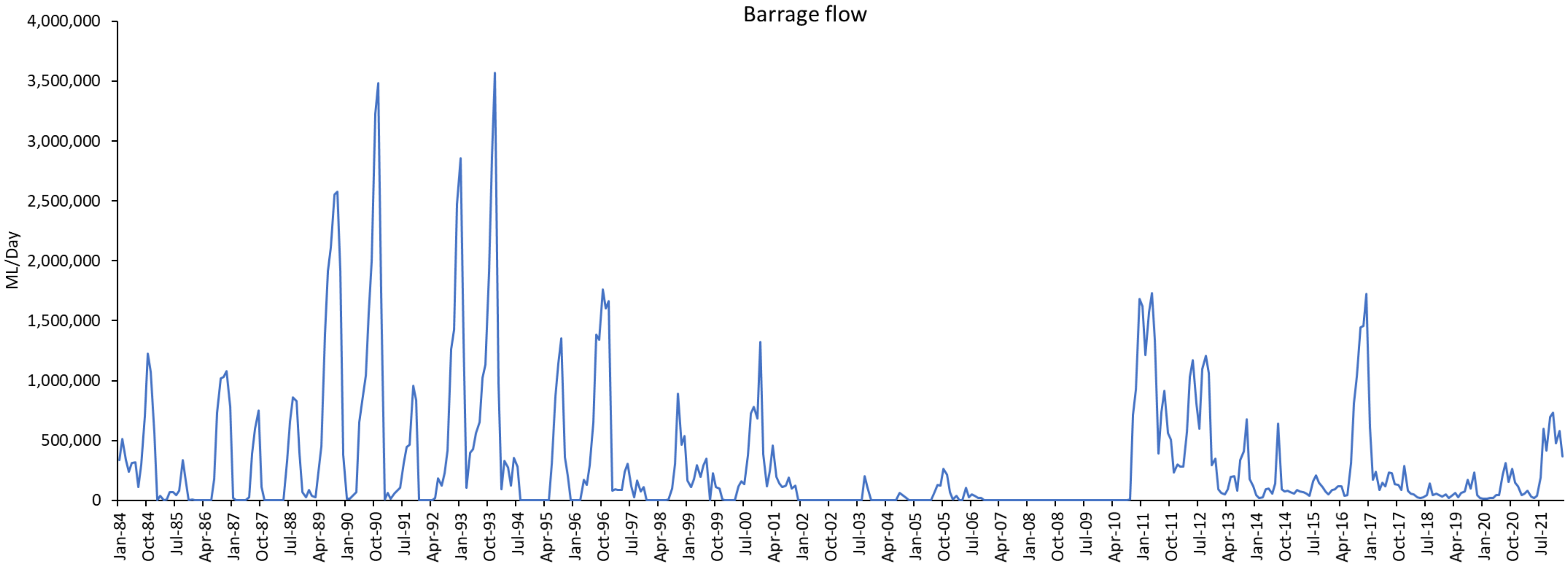
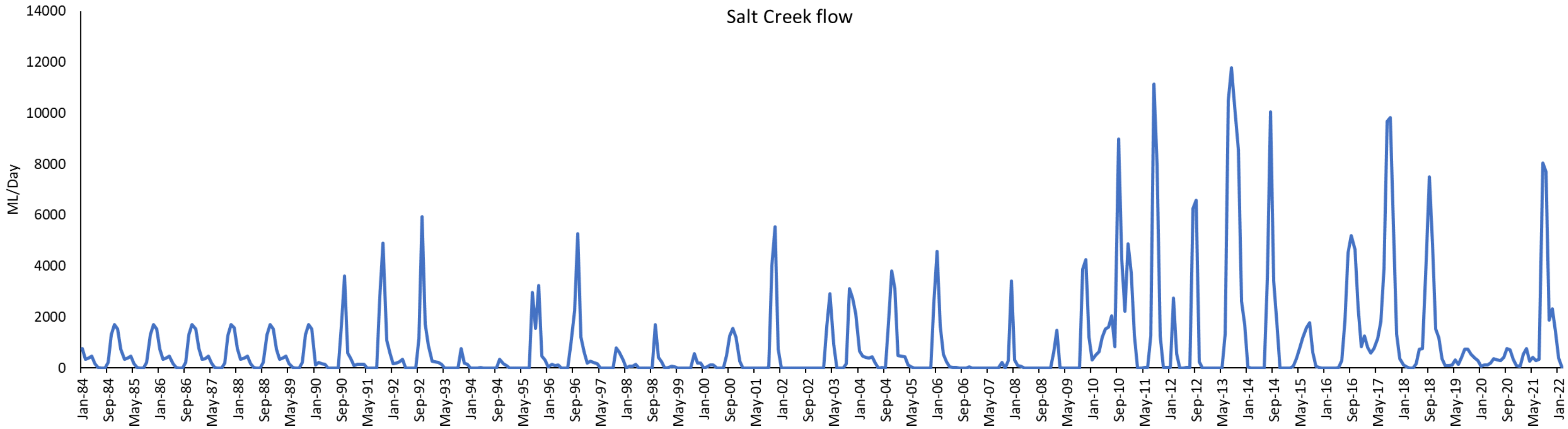


Figure 1. Monthly sum of freshwater flows (ML/Day) through (a) Lower Lakes barrages from 1984 to mid-2021 and (b) Salt Creek from 1984 to January 2022. Modelled data were obtained from DEW.

(b)



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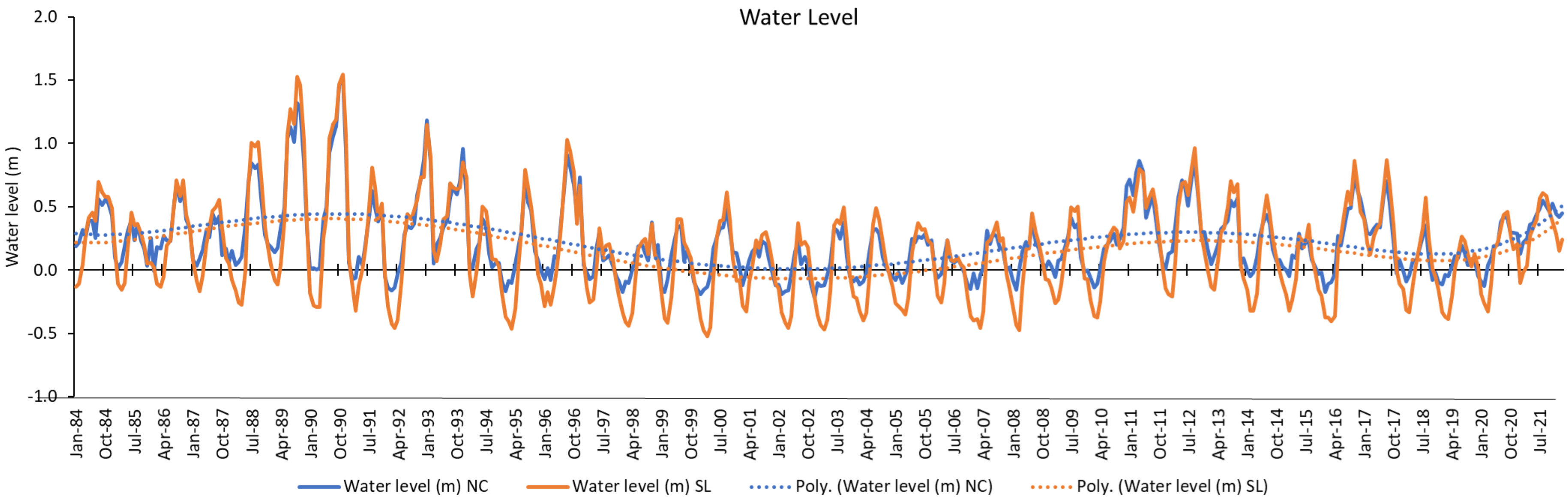


Figure 2. Monthly (a) water levels (m AHD) and (b) salinity from 1984 to mid-2021 for the North Coorong (NC) and South Lagoon (SC) with polynomial line fits (dashed line). Modelled data were obtained from DEW.

(b)

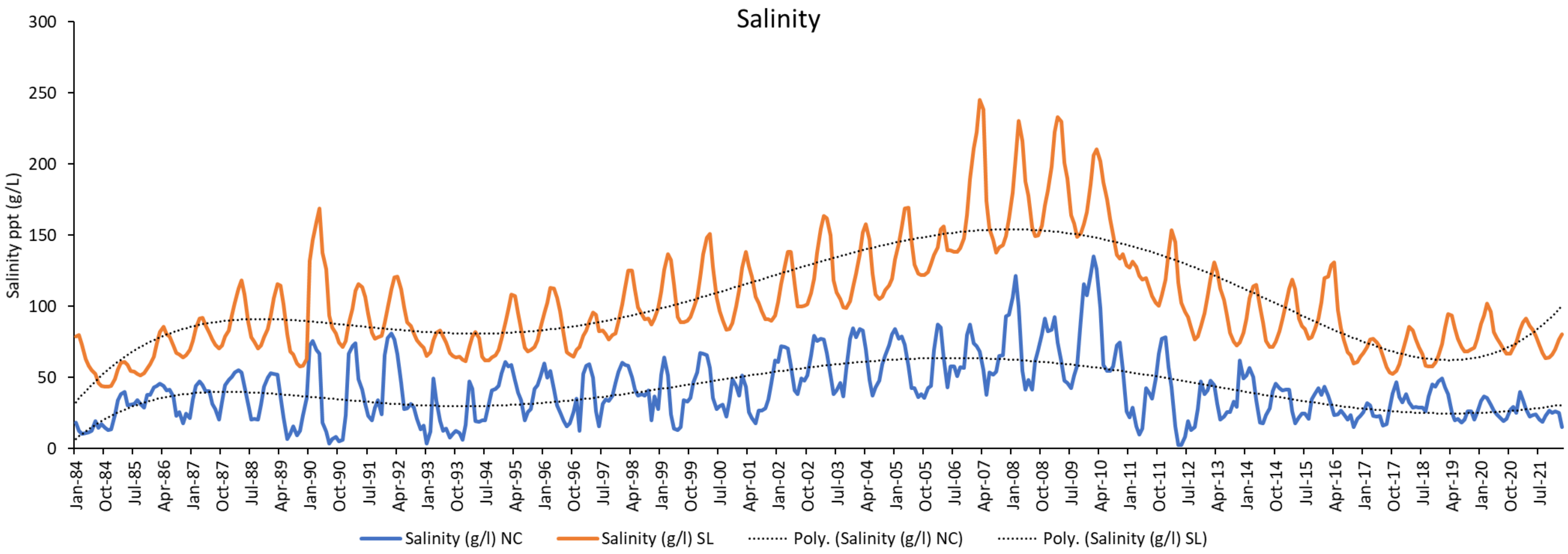


Figure 2. Cont.

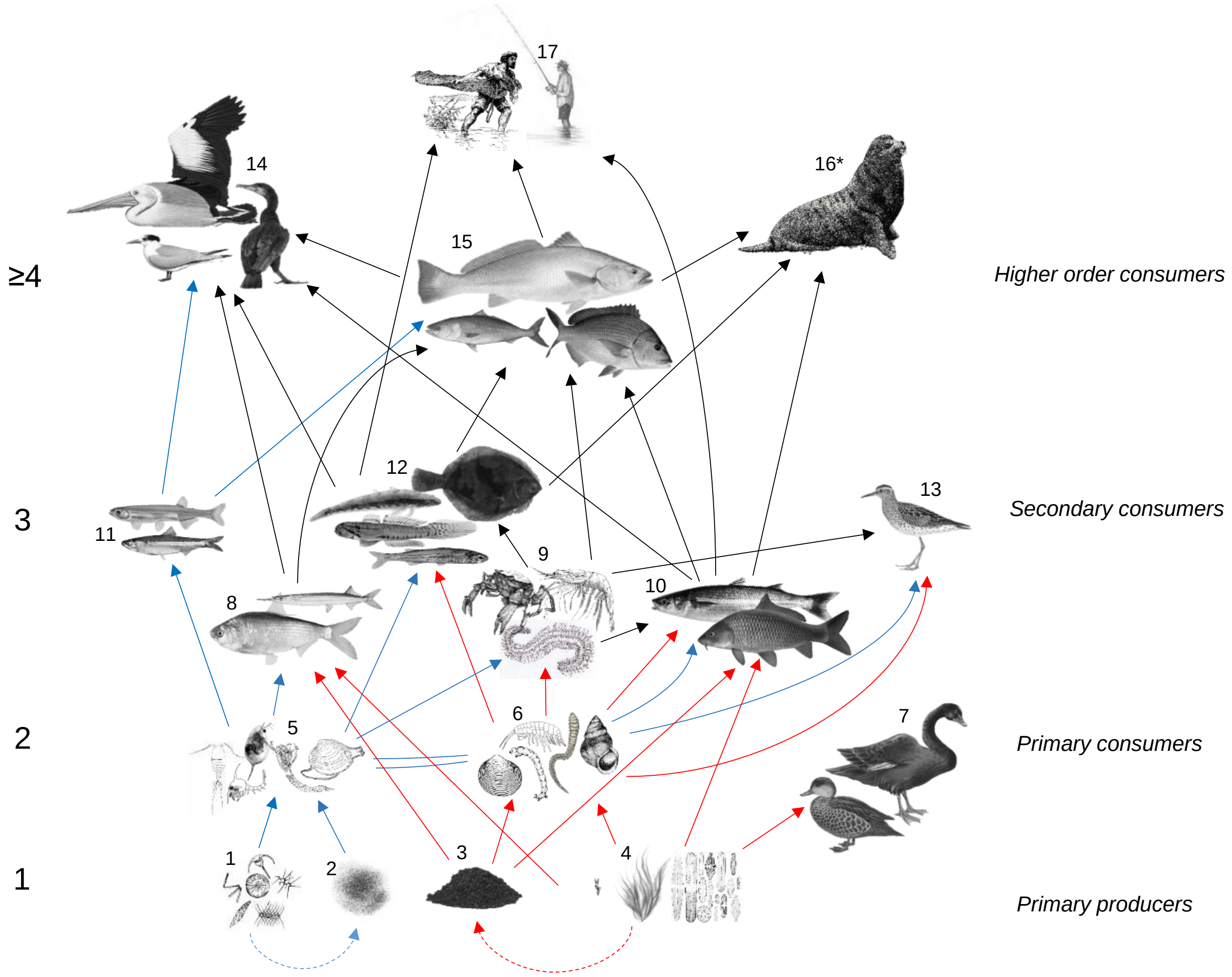


Figure 3. Conceptual food web of the Coorong using feeding functional guilds. Red trophic links represent those supported by benthic production (benthic algae/plants), blue trophic links represent those supported by pelagic production (phytoplankton), while black trophic links may represent either or a combination. Primary producers and organic matter material are (1) phytoplankton, (2) suspended particulate organic matter, (3) benthic detritus and (4) benthic macrophytes, micro- and macro- algae. Feeding guilds are (5) suspension-feeding micro- and macro-invertebrates, (6) deposit-feeding and herbivorous macro- invertebrates, (7) herbivorous waterfowl, (8) omnivorous fishes Part 1, (9) carnivorous invertebrates, (10) omnivorous fishes Part 2, (11) zooplanktivorous fishes, (12) zoobenthivorous fishes, (13) zoobenthivorous shorebirds, (14) piscivorous birds, (15) piscivorous fishes, (16) piscivorous mammals*, and (17) humans. Refer to Giatas et al. 2018 for members within feeding guilds. Organic matter and benthic detritus are not primary producers and represent the microbial loop (dotted trophic links). *Long-nosed fur seals were largely undocumented in the Coorong prior to 2007. Source: Giatas et al. (2018). Also see Ye et al. (2020). Numbers on left hand side of figure indicate trophic level (1, 2, 3, ≥4).

Trophic mass balance models of the North Coorong and South Lagoon sections of the Coorong ecosystem were produced using the *Ecopath* with *Ecosim* (EwE) software (www.*Ecopath*.org, Version 6.5). Polovina (1984) first developed *Ecopath* based on a simple, steady-state trophic box model, which was further developed by Christensen and Pauly (1992a) and Walters et al. (1997). From the 1990s to mid-2000s, EwE software was applicable to a niche of trophic food web research (e.g. Pauly et al. 2000) but in the 2010s use of the software increased considerably to become a mainstay in ecological trophic modelling (e.g. Albouy et al. 2010, Bueno-Pardo et al. 2018). The advantage of *Ecopath* is its functionality in describing the static-state energy flow of an ecosystem at a particular point in time pertinent to the ecosystem being studied (Pauly et al. 2000). The *Ecosim* component of EwE software enables dynamic simulations based on *Ecopath* parameters that allow the forecasting of ecosystem response to environmental perturbations. The EwE software has now been used to describe a diverse range of aquatic ecosystems world-wide, and details of the ecological theory and mathematical equations that underpin its key functions have been extensively detailed elsewhere (e.g. Christensen and Walters 2004, Griffiths et al. 2010, Piroddi et al. 2010, Shannon et al. 2008). For this study, the use of EwE enabled us to build trophic mass-balance models of the North Coorong and South Lagoon, which can be fit to time-series of environmental parameters, such as freshwater flow, water level and salinity, to establish an understanding of how the biological trophic group data best aligns with environmental anomalies. The environmental anomaly ranges will then be used to simulate trophic group response to environmental change using the *Ecopath* component of EwE, similar to projections made in other estuaries globally (Bueno-Pardo et al. 2018, Sinnickson et al. 2021).

Ecological changes in the Coorong ecosystem since European human occupation have been linked to changes in freshwater flow, but until the 1990's many of those ecological characters were recorded as narratives or qualitative data (see Hemming 2018 for a Ngarrindjeri narrative, Geddes and Butler 1984, Geddes 1987). Waterbird data records and fish data for some key commercially fished species (e.g. yelloweye mullet and mulloway) are available for the early 1980s and were collated for inclusion in the food web model of this study. More detailed and consistent ecological data have been recorded from the early 2000s onwards with improved understanding of environmental conditions, plankton, macrophytes, macroinvertebrates, fish, and waterbirds (Mosley et al. 2020, Prowse 2020, Ye et al. 2020). For reliable biological and environmental fit to time-series data in EwE modelling, multiple decades of data are required for the model to identify anomalies. Thus, the limited data for most ecological groups across the 37-year timespan of this study, from 1984-85 to 2020-21 meant that only waterbirds and some fish groups were explored in 'fit to time-series' and 'ecological response' scenarios.

The Phase One Trials and Investigations (T&I) project of the Healthy Coorong, Healthy Basin (HCHB) Program consists of a series of integrated components that will collectively provide knowledge to inform the future management of the Coorong. '*Component 3 – Restoring a functioning Coorong food web'* forms part of the T&I projects. It aims to understand food web dynamics in the Coorong, using empirical investigations on food resources and conditions required to increase food resource availability and energy supply for key biota (waterbirds and fish) to develop an integrated quantitative food web model that can assess food web responses to various environmental conditions (e.g. through management actions and interventions).

- A functioning and resilient food web is critical to the ecological character of the Coorong through the production and supply of energy to key biota, including waterbirds and fish. In particular, the South Lagoon food web has not recovered from decades of declining ecological conditions. The work reported herein provides a detailed investigation of the Coorong food web based on the North Coorong and South Lagoon regions. This report presents the results of work completed during the period from April 2021 to May 2022.

1.2 Objectives

The key management questions relating to food webs in the Coorong which informed the body of work for HCHB T&I Component 3 Food Webs were:

- How should barrage inflows, South East flows and the Murray Mouth dredging regime be managed in order to restore a functioning South Lagoon food web that supports diverse and abundant waterbirds and fish, including those species historically abundant or present?
- What are the implications of proposed future management interventions on the food web and reliant waterbirds and fish?

To address these questions, the food web modelling investigations aimed to:

- Establish balanced quantitative food web models of the North Coorong (Murray Mouth and North Lagoon) and South Lagoon;
- Identify the fit to time-series of food webs in the North Coorong and South Lagoon from the 1980s to 2021; and
- Investigate decadal food web projection responses to environmental drivers for future understanding of change in the North Coorong and South Lagoon.

1.3 Approach

To simplify the presentation of the model development steps and scenario outputs, the methods and results sections of this report have been combined and divided into four parts detailing a) model development, b) model balancing, c) time-series fitting and d) scenario development.

2 Model development

2.1 Model domain

The model domains for the North Coorong and South Lagoon *Ecopath* models were partitioned at Parnka Point based upon the shoreline narrowing into the channel at Hells Gate at this point, and restricting flows between the two water bodies. Areas for the two model domains were calculated based on 0 m AHD within the bounds of landward and peninsula shorelines, with the North Coorong domain encompassing 95.9 km^2 and the South Lagoon domain encompassing 105 km^2 (Figure 3). *Ecopath* models were constructed for the initial year of 1984-85, to coincide with the initial year of commercial fishery logbook data for the Lakes and Coorong fishery.

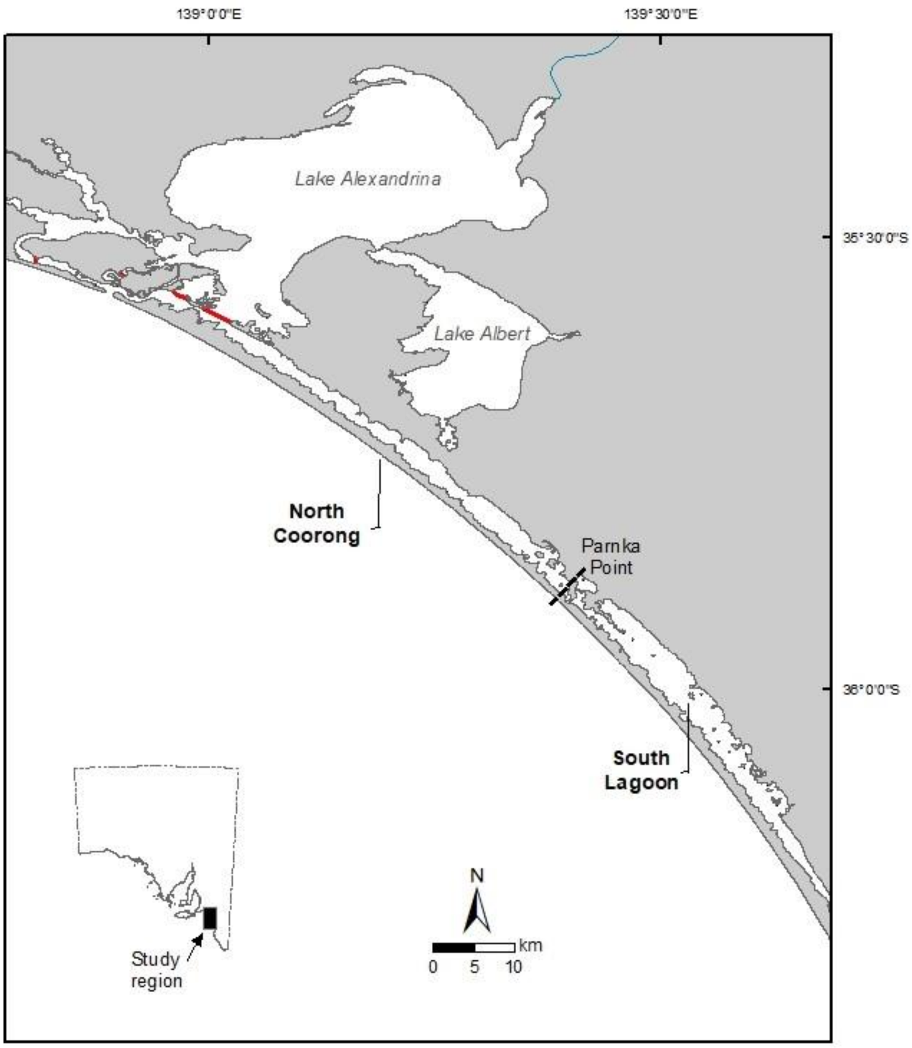


Figure 4. A map of the Coorong region showing the North Coorong and South Lagoon, barrages (red lines) and boundary for the two model domains with division at Parnka Point indicated by the dashed line.

2.2 Trophic groups, data sources, and parameter estimation

A number of trophic, or functional groups were used in the construction of the North Coorong and South Lagoon ecosystem models, whereby species were grouped based on similarities in diet, habitat use, foraging behaviour, body size, consumption and rates of production. Key iconic (e.g. Australian pelican) and commercial taxa (i.e. four commercially targeted species; mulloway (*Argyrosomus japonicus*), black bream, greenback flounder and yelloweye mullet) were modelled as single taxa groups to aid model scenario testing and facilitate the assessment of environmental drivers (e.g. water flow and level, salinity). The trophic grouping of bird groups incorporated advice from DEW managers and ecologists.

The North Coorong ecosystem model was built around 56 trophic groups: mammals (1), birds (18), chondrichthyans (2), teleosts (22), invertebrates (9), autotrophs (3) and detritus (1). For the South Lagoon, the ecosystem model was built around 48 trophic groups: birds (18), chondrichthyans (2), teleosts (16), invertebrates (8), autotrophs (3) and detritus (1) (Table 1).

Intrinsic to *Ecopath* model development, each trophic group operates as a single biomass, despite groups often being composed of multiple species. The aggregation of species into trophic groups will therefore affect model dynamics in some instances; however, by matching species for diet, consumption, and production rates we attempted to constrain the errors and uncertainty of aggregating. There are four key parameters that are required for each group to balance an *Ecopath* model:

- Biomass (B).
- Production per unit of biomass (P/B), equivalent to the instantaneous rate of total mortality (Z) used by fisheries biologists, under the steady-state assumption of the model.
- Consumption per unit of biomass (Q/B).
- Ecotrophic efficiency (EE), the fraction of the production that is used in the system (i.e. either passed up the food web, used for biomass accumulation, migration or export, which varies between 0 and 1 and can be expected to approach 1 for groups with considerable predation pressure).

Values for three of these four parameters need to be determined, with the final parameter value estimated by the model. Where possible, the biomasses (t km^2) of trophic groups were estimated either from field surveys and stock assessments, local published data for the Coorong region, or global studies in other estuarine ecosystems. The habitat area fraction (proportion of domain areas with suitable habitat for a given trophic group) and biomass in habitat areas were also estimated. A detailed description of the trophic groups and the methods and assumptions used to estimate parameters, is provided in Appendix A.

Central to *Ecopath* is the diet matrix. Diet matrices for the North Coorong and South Lagoon were largely based on available dietary information for each trophic group (Appendix B and C, respectively). Giatas et al. (2022) provide a review of the available dietary data for trophic groups within the Coorong, using data with provenance to the Coorong in preference to data collected elsewhere. The sources of these dietary data are detailed for each trophic group in Appendix A. Importantly, we were not able to distinguish dietary differences of trophic groups feeding within the North Coorong or South Lagoon, as most available dietary data was not resolvable to this scale. As such, the dietary matrices used for each model domain were the same, except where some groups were absent in the South Lagoon ecosystem. In these instances, the diet matrix was modified by allocating the prey from absent groups to similar taxa represented within the model.

Dietary import is an important consideration for many trophic groups and is the proportion of the diet consumed outside of the model domains. It includes both the exclusion of species in the diet that are not present in the modelled ecosystems (e.g. some exclusive freshwater species) and the proportion of time allocated over a year to feeding outside our model domains (e.g migratory or nomadic bird species). As such many freshwater fish species that were present in the diet of some trophic groups (Giatas et al. 2022) were treated as import (e.g. golden perch, redfin perch, estuary perch, Murray cod, trout, carp, gambusia and some gudgeon and galaxia species). Some of these species appear in the diet of birds and fish feeding in association with barrage outflows in North Coorong but would not survive for long in the estuarine environment. However, other freshwater estuarine opportunists and diadromous species were treated as part of the estuarine fish assemblage, as they are part of a healthy estuarine community, and they are commonly present with varying distributions in the Coorong (e.g. bony herring). Details on the estimation of dietary import for each trophic group is detailed in Appendix A.

Fishery data on landings and discards were obtained for the North Coorong and South Lagoon ecosystem model domains and allocated into 13 and six fishing fleets, respectively. A fishing fleet is defined by gear-type and target species. They need to be separated to because the different gear-types would have different selectivity's for different target species that effect estimates of catch-per unit effort (CPUE) which *Ecosim* using as a measure of relative biomass. There are two main fishing gear types used in the Coorong, large-mesh (LMG) and small-mesh gillnets (SMG). The 13 fleets in the North Coorong ecosystem were: mulloway LMG, mulloway SMG, Australian salmon LMG, Australian salmon SMG, black bream LMG, black bream SMG, greenback flounder LMG, greenback flounder SMG, yelloweye mullet LMG, yelloweye mullet SMG, yellow-eye mullet Other, bony herring LMG and bony herring SMG. The six South Lagoon fishing fleets were: mulloway LMG, black bream LMG, flounder LMG, yelloweye mullet SMG, yelloweye mullet other and bony herring LMG.

The annual fishery landings of each trophic group from each fleet in 1984-85 (the initial year of modelling) was calculated using the daily catch data from the Lakes and Coorong commercial fishery. The landings were standardised to tonnes per km^2 for the respective domain areas. The discards in 1984-85 were estimated based on the discard rates estimated by Ferguson (2010) (Table 2), the only bycatch study to date for these fisheries. The discard rates (kg/net-day) were multiplied by the fishing effort (net-days) of the main gear type (i.e. LMG or SMG) in 1984-85 to estimate the annual fishy discards in this initial year. For the 'Other' gear type, Ferguson (2010) provide no discard estimates, so we adopted the discard rates of small-mesh gear nets). For bony herring, the discards were estimated based on the percentage discard of total catch (86.5%) (Ferguson 2010), and we assumed other freshwater imported species (e.g. carp) had the same discard rate. Discards were also standardised to tonnes per km^2 using the areas of the two model domains.

Table 1. Summary of trophic groups and their key taxa in the North Coorong and South Lagoon ecosystem models. Key taxa that were used to estimate biomass, P/B and Q/B, and diet information for building diet matrices are highlighted in blue text. N/A refers to groups not included in the South Lagoon model.

NO.	NORTH COORONG GROUP NAME	NO.	SOUTH LAGOON GROUP NAME	KEY TAXA
1	Long-nosed fur seal		N/A	long-nosed fur seal
2	Raptors	1	Raptors	white-bellied sea eagle, whistling kite, swamp harrier
3	Australian pelican	2	Australian pelican	Australian pelican
4	Cormorants & grebes	3	Cormorants & grebes	cormorants (great, little black, pied, little pied, black-faced); grebes (great crested, hoary-headed, Australasian)
5	Terns	4	Terns	terns (crested, whiskered, Caspian, fairy)
6	Gulls	5	Gulls	silver and pacific gulls
7	Egrets & herons	6	Egrets & herons	egrets (great, little, cattle), white-faced heron
8	Ibis	7	Ibis	Australian white ibis, straw-neck Ibis
9	Spoonbills	8	Spoonbills	royal spoonbill, yellow-billed spoonbill
10	Migratory shorebirds (medium to long bill)	9	Migratory shorebirds (medium to long bill)	sandpipers (curlew, terek, common, marsh), godwits (black-tailed, bar-tailed), eastern curlew, common greenshank, whimbrel, little curlew and great knot
11	Migratory shorebirds (short bill)	10	Migratory shorebirds (short bill)	sandpipers (sharp-tailed sandpiper, wood), red-necked stints, sanderling, red knot, ruff, ruddy turnstone, red-necked phalarope, plovers (Pacific golden plover, grey, oriental, lesser sand plover)
12	Large non-migratory waders	11	Large non-migratory waders	stilts (banded, black-winged), red-necked avocet
13	Small non-migratory shorebirds	12	Small non-migratory shorebirds	plovers (red-capped plover, hooded), dotterels (black-fronted, red-kneed)
14	Oystercatchers	13	Oystercatchers	pied oystercatcher, sooty oystercatcher
15	Diving ducks	14	Diving ducks	Hardhead, musk duck, blue-billed duck
16	Dabbling ducks	15	Dabbling ducks	teal (chestnut, grey), Pacific black duck, mallard, Australian shelduck, Australian wood duck
17	Filter feeding ducks	16	Filter feeding ducks	Australasian shoveler, pink-eared duck
18	Coots	17	Coots	Eurasian coot
19	Swans	18	Swans	black swan
20	Sharks	19	Sharks	bronze whaler shark, gummy shark
21	Rays & skates	20	Rays & skates	southern eagle ray
22	Medium zoobenthivore/piscivore	21	Medium zoobenthivore/piscivore	Australian herring, silver trevally, southern crested weedfish,
23	Mulloway	22	Mulloway	Mulloway
24	Medium marine demersal piscivore	23	Medium marine demersal piscivore	blackspotted gurnard perch, common gurnard perch, reef ocean perch, red gurnard, southern sand flathead, blue-spotted flathead
25	Small demersal zoobenthivore/piscivore	24	Small demersal zoobenthivore/piscivore	flat-headed gudgeon, dwarf flat-headed gudgeon, sand fish, flathead sandfish
26	Large zoobenthivore/piscivore	25	Large zoobenthivore/piscivore	snapper

Table 1. cont.

NO.	NORTH COORONG GROUP NAME	NO.	SOUTH LAGOON GROUP NAME	KEY TAXA
27	Australian salmon	26	Australian salmon	Western Australian salmon
28	Black bream	27	Black bream	black bream
29	Syngnathids		N/A	rhino pipefish, common seadragon, spotted pipefish, potbelly seahorse, Verco's pipefish, big belly seahorse, Tucker's pipefish, pug-nosed pipefish
30	Flounder	28	Flounder	greenback flounder, longsnout flounder
31	Yelloweye mullet	29	Yelloweye mullet	yelloweye mullet
32	Smallmouth hardyhead	30	Smallmouth hardyhead	smallmouth hardyhead
33	Medium zoobenthivore		N/A	soldier, estuary cobbler, yellowfin whiting, King George whiting, southern school whiting, eastern school whiting, little weed whiting, longray weed whiting, magpie perch, old wife, silver spot, ornate cowfish, blue weed whiting
34	Toadfishes & leatherjackets		N/A	smooth toadfish, prickly toadfish, Richardson's toadfish, barred toadfish, bridled leatherjacket, Southern pygmy leatherjacket, Gunn's leatherjacket, sixspine leatherjacket, rough leatherjacket, toothbrush Leatherjacket, brownstriped leatherjacket, Velvet leatherjacket
35	Small demersal omnivore/zoobenthivore	31	Small demersal omnivore/zoobenthivore	bluespot goby, bridled goby, Southern longfin goby, Tasmanian blenny
36	Small demersal zoobenthivore	32	Small demersal zoobenthivore	congolli, Tamar goby, lagoon goby
37	Sandy sprat	33	Sandy sprat	sandy sprat
38	Small medium marine pelagic zooplanktivore		N/A	Australian anchovy, Australian pilchard, blue sprat, yellowtail scad
39	Small freshwater pelagic zooplanktivore/insectivore		N/A	Australian smelt, common galaxias, mountain galaxias, climbing galaxias, Murray hardyhead, un-specked hardyhead, eastern gambusia, carp gudgeon spp.
40	Garfish	34	Garfish	river garfish, southern garfish
41	Other mugilids	35	Other mugilids	sea mullet, goldspot mullet
42	Bony herring	36	Bony herring	bony herring
43	Medium omnivore/herbivore		N/A	western striped grunter, zebrafish, luderick, sea sweep, spangled perch, silver perch
44	Benthic decapods		N/A	crabs (incl. Paragrapsus gaimardii), Penaeid shrimp, ghost shrimp, Carid shrimp, freshwater yabby
45	Benthic annelids	37	Benthic annelids	nereids, phyllodocids, nephtyiids, Arenicolidae
46	Benthic deposit-feeding annelids	38	Benthic deposit-feeding annelids	capitellids, oligochaetes
47	Ficopomatus	39	Ficopomatus	*Ficopomatus enigmaticus*
48	Bentho-pelagic crustaceans	40	Bentho-pelagic crustaceans	amphipods, mysids, stracods
49	Insect larvae/pupae	41	Insect larvae/pupae	Chironomidae, Other dipterans, hemipterans, Other insects
50	Benthic micro-molluscs	42	Benthic micro-molluscs	Arthritica, *Salinator fragilis*, hydrobiids

Table 1. cont.

NO.	NORTH COORONG GROUP NAME	NO.	SOUTH LAGOON GROUP NAME	KEY TAXA
51	**Subtidal benthic molluscs**	**43**	**Subtidal benthic molluscs**	Tellina, Spisula, Hiatula
52	**Zooplankton**	**44**	**Zooplankton**	Calanoid, Harpacticoid, Cyclopid, Daphniids (Daphnia & Ceriodaphnia), Bosminids (Bosmina), Macroinvertebrate pelagic larvae (e.g. crab zoea and megalopa), Rotifers
53	**Filamentous algae**	**45**	**Filamentous algae**	Filamentous (e.g. Cladophora, Ulva)
54	**Phytoplankton**	**46**	**Phytoplankton**	Diatoms
55	**Macrophytes**	**47**	**Macrophytes**	*Ruppia tuberosa*
56	**Detritus**	**48**	**Detritus**	

Table 2. Fishery discard rates by large-mesh (LMG) and small-mesh gillnets (SMG) for key species in the Lakes and Coorong commercial fishery (adapted from Ferguson 2010).

GEAR TYPE	SPECIES	NO. DISCARDS/NET.DAY	KG/NET.DAY
LMGN	yelloweye mullet	0.0589	0.0078
LMGN	mulloway	1.0536	0.3566
LMGN	greenback flounder	0.2505	0.0512
LMGN	black bream	0.0214	0.0044
LMGN	Australian salmon	0.0196	0.0024
LMGN	other species	0.0411	0.0083
SMGN	yelloweye mullet	0.1477	0.0197
SMGN	mulloway	0.2809	0.0951
SMGN	greenback flounder	0.0460	0.0094
SMGN	black bream	0.0073	0.0015
SMGN	Australian salmon	0.6755	0.0836
SMGN	other species	0.0460	0.0093

3 Model balancing

The basic parameters used to inform the trophic groups within the North Coorong and South Lagoon *Ecopath* models are presented in Tables 3 and 4, respectively. The food webs of the North Coorong and South Lagoon ecosystem models, showing trophic flows between the trophic groups and the trophic levels as estimated by *Ecopath*, are depicted in Figures 5 and 6, respectively. Given the dietary matrices for both the North Coorong and South Lagoon ecosystems were based on the same Coorong-wide data (Giatas et al 2022), with the exception of the absence of some trophic groups in South Lagoon, the trophic flow and structure of the North Coorong and South Lagoon are very similar (Figures 5 and 6).

3.1 North Coorong

Model balancing for the North Coorong model required adjustments to some parameters or diets of groups where ecotrophic efficiencies (EE) initially exceeded 1. EE is the proportion of production that is used in the ecosystem (i.e. either passed up the food web via predation, used for biomass accumulation, migration or exported; Christensen and Walters 2004). It will approach 1 for groups with high predation pressure and 0 for groups with no predation, fishing pressure or migration. If EE exceeds 1 for one or more groups, the model is unbalanced because more production is leaving the system than is being produced.

To balance the North Coorong model, some iterative adjustments were made and included:

- Negative respiration with Group 49 (insect larvae/pupae) due to low initial Q/B (6.8). The issue was resolved by increasing the Q/B estimate (to 20.0).
- The diets of two fish groups, 24 (medium marine demersal piscivores) and 25 (small demersal zoobenthivore /piscivore), which had initial high levels of cannibalism (0.38 and 0.11, respectively) were both reduced to 0.05, with the diet spread to other fish diet groups weighted to their dietary importance.
- Group 25 (small demersal zoobenthivore/piscivore) had an initial high EE (5.27), principally due to the biomass estimate being too low (0.037595 t km^2). The biomass term was removed, and EE set to 0.95 to allow the model to estimate biomass, resulting in an estimate of an order of magnitude higher (0.3427465 t km^2).
- Group 32 (smallmouth hardyhead) had very high EE not related to excessive predation mortality rates, suggesting that initial biomass estimates was too low (5.94624 t km^2). The biomass term was removed, and EE set to 0.95 to allow the model to estimate biomass. An EE of 0.95 for groups that are heavily predated is appropriate (Christensen et al. 2008). The resulting biomass estimate was about 3.7 times that of the original estimate (22.26344 t km^2).
- Applying the initial biomass estimates for most invertebrate groups (based on 2020-21 estimates of biomass, see Dittmann et al. 2022) resulted in all groups being unbalanced with excessive EE. For many of the invertebrate groups (groups 45 benthic annelids, 46 benthic-deposit feeding annelids, 48 bentho-pelagic crustaceans, and 49 insect larvae/pupae), these were largely due to high predation mortality rates, especially from groups 31 (yelloweye mullet) and 32 (smallmouth hardyhead). These were typically reduced by transferring varying proportions of diet to zooplankton. Reducing cannibalism by group 45 (benthic annelids) and predation from group 36 (small demersal zoobenthivores) facilitated reducing the EEs of groups 45 and 46 to <1 (Table 3).
- For groups 48 (bentho-pelagic crustaceans) and 49 (insect larvae/pupae), initial high EEs were markedly reduced, but could not be balanced by further reductions in predation mortality, suggesting for these groups that initial biomasses were underestimated. The initial biomass estimates (15.31086 and 1.42545 t km^2, respectively) were removed and EE's set to 0.95 to allow the model to estimate biomass. The balanced model estimates of biomass were 3.3 to 3.6 times higher

(51.13025, 5.07314 t km^2, respectively) (Table 3). As groups 48 and 49 are mobile and not constrained to the sediments from where they were sampled, it is possible that the sediment core sampling approach used to estimate the biomass of these groups will result in underestimates.

Table 3. Final balanced North Coorong ecosystem model parameters. Where parameters were changed, initial values are in parentheses. Model–estimated values are in blue. TL = Trophic level, P/B = production/biomass, Q/B = consumption/biomass, EE = ecotrophic efficiency, P/Q = production/consumption. The estimated habitat area and biomass in habitat area is also provided.

NO	GROUP NAME	TL	HABITAT AREA (FRACTION)	BIOMASS IN HABITAT AREA TKM^{-2}	BIOMASS TKM^{-2}	P/B Y^{-1}	Q/B	EE	P/Q
1	Long-nosed fur seal	3.51	1.00	0.00104	0.00104	1.184	47.525	0.00	0.0249
2	Raptors	4.14	1.00	0.00019	0.00019	0.020	20.027	0.00	0.0010
3	Australian pelican	3.96	0.86	0.24474	0.21048	0.200	22.042	0.00	0.0091
4	Cormorants & grebes	3.65	0.86	0.29526	0.25392	0.037	43.799	0.01	0.0008
5	Terns	3.91	1.00	0.02187	0.02187	0.185	49.705	0.12	0.0037
6	Gulls	3.94	1.00	0.01735	0.01735	0.301	64.084	0.00	0.0047
7	Egrets & herons	3.46	0.15	0.00009	0.00001	0.104	73.182	0.00	0.0014
8	Ibis	3.37	0.18	0.10006	0.01801	0.034	65.361	0.00	0.0005
9	Spoonbills	3.36	0.22	0.00415	0.00091	0.035	60.153	0.00	0.0006
10	Mig. shorebirds (M-L bill)	2.96	0.14	0.12514	0.01752	1.480	188.456	0.00	0.0079
11	Mig. shorebirds (S bill)	2.87	0.22	0.15385	0.03385	2.169	242.056	0.00	0.0090
12	L non-migratory waders	2.80	0.13	0.60047	0.07806	0.387	106.747	0.00	0.0036
13	S non-migratory shorebirds	3.10	0.03	0.03835	0.00115	2.753	137.241	0.00	0.0201
14	Oystercatchers	3.15	0.05	0.02587	0.00129	0.106	92.084	0.00	0.0012
15	Ducks (diving)	2.34	0.86	0.00856	0.00736	0.046	101.235	0.16	0.0005
16	Ducks (dabbling)	2.08	0.15	2.20492	0.33074	0.113	98.731	0.01	0.0011
17	Ducks (filter feeding)	2.54	0.86	0.00069	0.00059	0.119	121.125	0.00	0.0010
18	Coots	2.14	1.00	0.01201	0.01201	0.140	133.966	0.03	0.0010
19	Swans	2.00	0.33	0.67491	0.22272	0.008	50.722	0.00	0.0002
20	Sharks	3.96	1.00	0.05150	0.05150	0.320	2.560	0.95	0.1250
21	Rays & skates	3.10	1.00	0.11172	0.11172	0.180	2.300	0.95	0.0783
22	Medium	3.47	1.00	0.01408	0.01408	1.640	6.320	0.95	0.2595
23	Mulloway	3.58	1.00	16.71200	16.71200	0.220	2.500	0.95	0.0880
24	M marine demersal	3.75	1.00	0.18196	0.18196	0.460	5.100	0.95	0.0902
25	S demersal	3.27	1.00	(0.0376)	0.34355	1.320	11.000	0.95	0.1200
26	L zoobenth/piscivore	3.28	1.00	0.13392	0.13392	0.490	3.800	0.95	0.1289
27	Aust salmon	3.89	1.00	0.90995	0.90995	0.400	3.600	0.95	0.1111
28	Black bream	3.20	1.00	0.67244	0.67244	0.440	4.500	0.95	0.0978
29	Syngnathids	3.03	1.00	0.00890	0.00890	1.450	5.300	0.95	0.2736
30	Flounder	3.08	1.00	0.30317	0.30317	1.440	12.800	0.95	0.1125
31	Yelloweye mullet	2.52	1.00	29.01219	29.01219	1.300	14.200	0.95	0.0915
32	Smallmouth hardyhead	3.00	1.00	(5.9462)	22.34251	1.500	26.100	0.95	0.0575
33	Medium zoobenthivore	3.13	1.00	3.37688	3.37688	0.500	6.600	0.95	0.0758
34	Toadfishes &	3.04	1.00	0.13414	0.13414	1.060	18.500	0.95	0.0573
35	S demersal	2.45	1.00	0.60076	0.60076	2.190	43.800	0.74	0.0500
36	S demersal zoobenthivore	3.12	1.00	(1.2858)	22.33767	1.530	22.500	0.95	0.0680
37	Sandy sprat	3.00	1.00	7.50428	7.50428	1.890	12.600	0.07	0.1500
38	S-M marine pelagic	2.88	1.00	3.96477	4.05616	1.050	14.530	0.95	0.0723
39	S freshwater pelagic	2.98	1.00	(0.1457)	1.37916	1.370	30.000	0.95	0.0457
40	Garfish	2.12	1.00	0.04439	0.04439	0.890	18.300	0.95	0.0486
41	Other mugilids	2.43	1.00	0.33694	0.33694	0.600	16.700	0.95	0.0359
42	Bony herring	2.24	1.00	3.19383	3.19383	0.800	4.900	0.95	0.1633
43	Medium	2.22	1.00	0.02788	0.02788	1.060	17.200	0.95	0.0616
44	Benthic decapods	2.30	1.00	(0.0000)	10.53382	3.280	13.000	0.95	0.2523
45	Benthic annelids	2.18	1.00	17.7229	17.72290	6.110	20.900	0.80	0.2923
46	Benthic deposit-feeding	2.00	1.00	6.53513	6.53513	7.980	13.000	0.93	0.6138
47	Ficopomatus	2.00	1.00	0.17822	0.17822	6.110	20.900	0.01	0.2923
48	Bentho-pelagic crustaceans	2.01	1.00	(15.312)	51.39891	8.610	20.500	0.95	0.4200
49	Insect larvae/pupae	2.22	1.00	(1.4255)	5.08700	8.520	20.000	0.95	0.4260
50	Benthic micro-molluscs	2.00	1.00	50.02911	50.02911	6.160	10.260	0.12	0.6004
51	Subtidal benthic molluscs	2.00	1.00	7.0673	7.06730	6.000	10.600	0.24	0.5660
52	Zooplankton	2.00	1.00	49.6609	49.6609	20.00	160.000	0.95	0.1250
53	Filamentous algae	1.00	1.00	100.00000	100.00000	3.072	-	0.88	-
54	Phytoplankton	1.00	1.00	15.00000	15.00000	887.9	-	0.55	-
55	Macrophytes	1.00	1.00	36.40050	36.40050	9.247	-	0.66	-
56	Detritis	1.00	1.00	300.00000	300.00000	-	-	0.29	-

Table 4. Final balanced South Lagoon ecosystem model parameters. Where parameters were changed, initial values are in parentheses. Model–estimated values are in blue. TL = Trophic level, P/B = production/biomass, Q/B = consumption/biomass, EE = ecotrophic efficiency, P/Q = production/consumption. The estimated habitat area and biomass in habitat area is also provided.

NO	GROUP NAME	TL	HABITAT AREA (FRACTION)	BIOMASS IN HABITAT AREA TKM^{-2}	BIOMASS TKM^{-2}	P/B Y^{-1}	Q/B	EE	P/Q
1	Raptors	4.17	1.00	0.00010	0.00010	0.02	16.550	0.00	0.0013
2	Australian pelican	3.91	0.87	0.40477	0.35215	0.20	22.040	0.00	0.0091
3	Cormorants & grebes	3.36	0.87	0.06535	0.05686	0.15	43.700	0.00	0.0035
4	Terns	3.86	1.00	0.02688	0.02688	0.26	49.700	0.03	0.0054
5	Gulls	4.03	1.00	0.01169	0.01169	0.30	64.080	0.00	0.0047
6	Egrets & herons	3.22	0.14	0.00006	0.00001	0.12	73.180	0.00	0.0017
7	Ibis	3.14	0.19	0.01129	0.00214	0.04	65.360	0.00	0.0007
8	Spoonbills	3.15	0.22	0.00016	0.00003	0.03	60.150	0.00	0.0005
9	Mig. shorebirds (M-L bill)	3.00	0.13	0.04656	0.00605	1.63	188.460	0.00	0.0087
10	Mig. shorebirds (S bill)	2.85	0.22	0.05188	0.01141	2.93	242.060	0.00	0.0121
11	L non-migratory waders	2.99	0.12	0.27155	0.03259	0.32	106.750	0.00	0.0030
12	S non-migratory shorebirds	3.21	0.03	0.02833	0.00085	2.78	137.240	0.00	0.0203
13	Oystercatchers	3.15	0.05	0.01840	0.00092	0.10	92.080	0.00	0.0011
14	Diving ducks	2.43	0.87	0.00053	0.00046	0.03	101.230	0.00	0.0003
15	Dabbling ducks	2.11	0.14	2.55008	0.35701	0.11	98.730	0.00	0.0011
16	Filter feeding ducks	2.57	0.87	0.00005	0.00004	0.11	121.120	0.00	0.0010
17	Coots	2.10	1.00	0.00018	0.00018	0.14	133.970	0.86	0.0010
18	Swans	2.00	0.34	0.10616	0.03610	0.00	50.720	0.00	0.0002
19	Sharks	4.11	1.00	0.00573	0.00573	0.32	2.560	0.95	0.1250
20	Rays & skates	3.06	1.00	0.00616	0.00616	0.18	2.300	0.95	0.0783
21	Medium	3.42	1.00	0.22891	0.22891	1.64	6.320	0.95	0.2595
22	Mulloway	3.53	1.00	22.18147	22.18147	0.22	2.500	0.95	0.0880
23	M marine demersal	3.75	1.00	0.04312	0.04312	0.46	5.100	0.95	0.0902
24	S demersal	3.20	1.00	6.71640	6.71640	1.32	11.000	0.95	0.1200
25	L zoobenth/piscivore	3.11	1.00	1.03273	1.03273	0.49	3.800	0.95	0.1289
26	Aust salmon	3.79	1.00	1.00025	1.00025	0.40	3.600	0.95	0.1111
27	Black bream	2.99	1.00	1.53662	1.53662	0.44	4.500	0.95	0.0978
28	Flounder	3.15	1.00	0.08426	0.08426	1.44	12.800	0.95	0.1125
29	Yelloweye mullet	2.55	1.00	35.77641	35.77641	1.30	14.200	0.95	0.0915
30	Smallmouth hardyhead	3.05	1.00	(13.7275)	15.75197	1.50	26.100	0.95	0.0575
31	S demersal omnivore	2.49	1.00	0.17392	0.17392	2.19	43.800	0.94	0.0500
32	S demersal zoobenthivore	3.30	1.00	(0.2554)	0.57607	1.53	22.500	0.95	0.0680
33	Sandy sprat	3.00	1.00	(0.4417)	1.03286	1.89	12.600	0.95	0.1500
34	Garfish	2.12	1.00	1.00609	1.00609	0.89	18.300	0.95	0.0486
35	Other mugilids	2.43	1.00	1.10074	1.10074	0.60	16.700	0.95	0.0359
36	Bony herring	2.24	1.00	4.22421	4.22421	0.80	4.900	0.95	0.1633
37	Benthic annelids	2.37	1.00	(0.00000)	19.25092	6.11	20.900	0.95	0.2923
38	Benthic deposit-feeding	2.00	1.00	(0.00069)	17.84050	7.98	13.000	0.95	0.6138
39	Ficopomatus	2.00	1.00	(0.00000)	0.00077	6.11	20.900	0.95	0.2923
40	Bentho-pelagic crustaceans	2.01	1.00	(0.00595)	55.65259	8.55	(10.26) 12.0	0.95	0.7125
41	Insect larvae/pupae	2.22	1.00	(1.32959)	13.17915	8.38	(6.80) 20.0	0.95	0.4190
42	Benthic micro-molluscs	2.00	1.00	(0.00050)	6.51232	5.95	10.260	0.95	0.5799
43	Subtidal benthic molluscs	2.00	1.00	(0.00000)	0.49312	2.85	10.600	0.95	0.2689
44	Zooplankton	2.00	1.00	6.68580	6.68580	20.0	160.000	0.95	0.1250
45	Filamentous algae	1.00	1.00	5.00000	5.00000	52.2	-	0.88	-
46	Phytoplankton	1.00	1.00	15.00000	15.00000	172.	-	0.55	-
47	Macrophytes	1.00	1.00	5.00000	5.00000	44.3	-	0.66	-
48	Detritus	1.00	1.00	200.00000	200.00000	-	-	0.50	

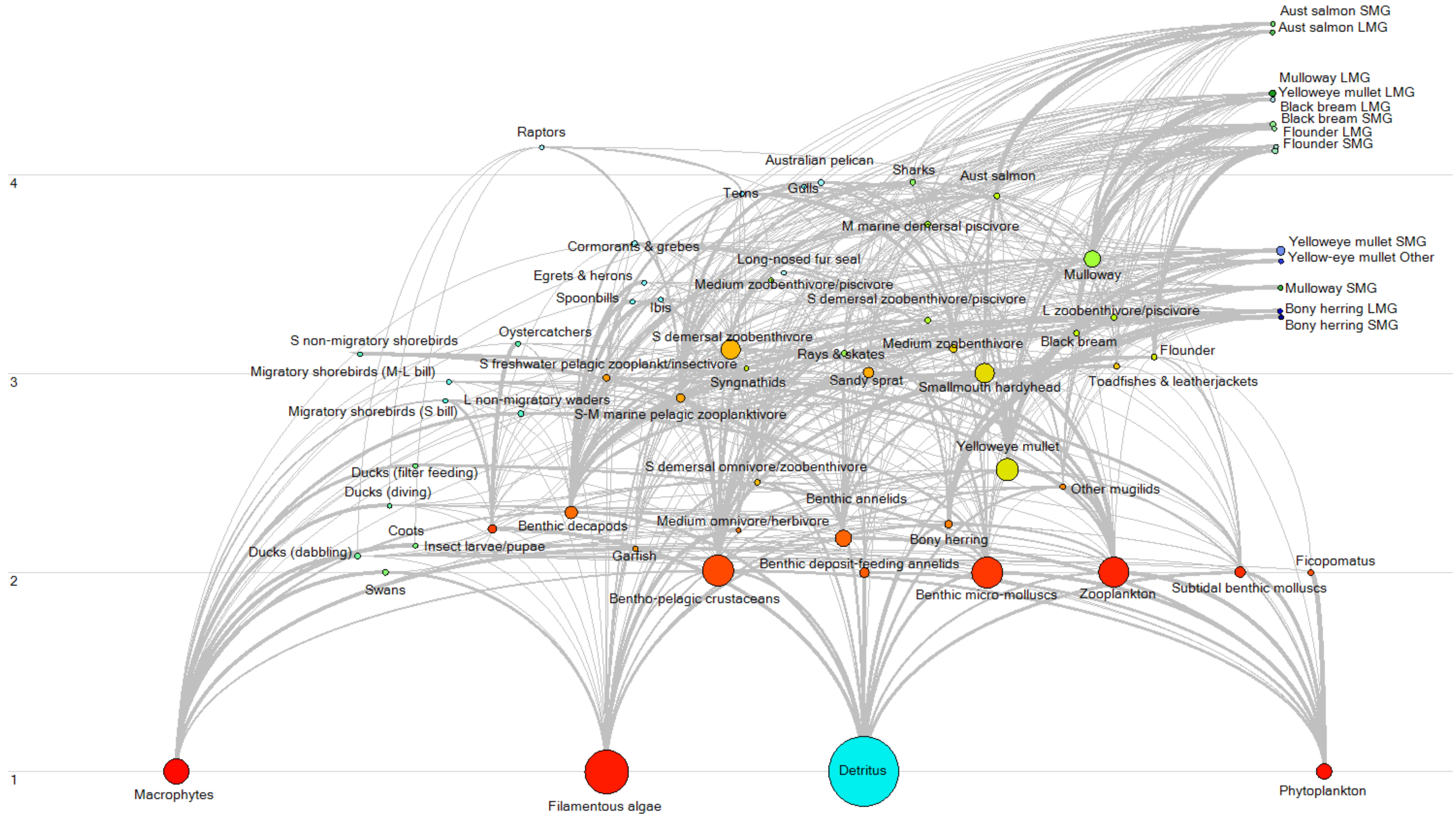


Figure 5. Flow diagram expression of the trophic flows between trophic groups in the North Coorong ecosystem as estimated by *Ecopath*. Trophic levels are on the y axis, the x-axis groups are arranged to allow the best visual representation of the food web. Trophic groups are represented by a circle; the size of the circle is proportional to its biomass and the colour of circles is unrelated to any parameter. Fishing fleets (target species by gear type) are also included (LMG = large-mesh gillnet; SMG small-mesh gillnet).

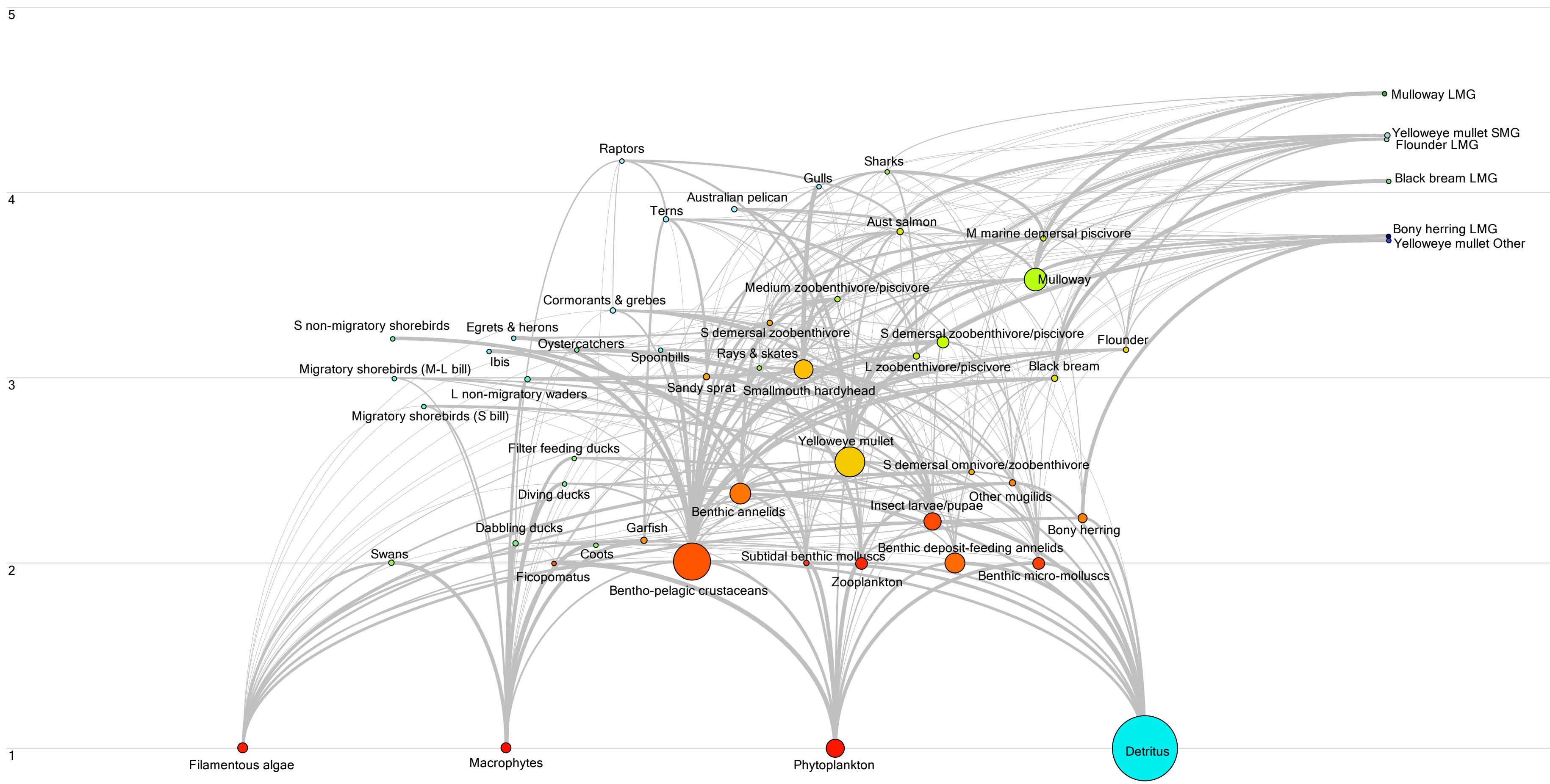


Figure 6. Flow diagram expression of the trophic flows between trophic groups in the South Lagoon ecosystem as estimated by *Ecopath*. Trophic levels are on the y axis, the x-axis groups are arranged to allow the best visual representation of the food web. Trophic groups are represented by a circle; the size of the circle is proportional to its biomass and the colour of circles is unrelated to any parameter. Fishing fleets (target species by gear type) are also included (LMG = large-mesh gillnet; SMG small-mesh gillnet).

3.2 South Lagoon

Model balancing for the South Lagoon required adjustments to some parameters or diets of groups where ecotrophic efficiencies (EE) were initially >1.

To balance the South Lagoon model, some iterative adjustments were made. Key changes included:

- Groups 31 (small demersal omnivore/zoobenthivore), 32 (small demersal zoobenthivore) and 33 (sandy sprat) all had high initial EEs, principally due to excessive predation mortality (high predation mortality coefficients). These were adjusted by reducing the diet contribution from impacted groups to a level that reduced EEs to near 1. This also caused the EEs of group 30 (smallmouth hardyhead) to exceed 1. The original biomass estimates for all groups (30: 13.72748, 31: 0.17392, 32: 0.25542, and 33: 0.44166 t km^2) were then removed and EE's set to 0.95 to allow the model to estimate biomass. For most groups these final estimated biomasses were close to the original estimates (Table 4).
- Negative respiration with Group 40 (bentho-pelagic crustaceans) and 41 (insect larvae/pupae) was identified due to low initial Q/B (10.26 and 6.8). These issues were resolved by increasing Q/B estimates to 12.00 and 20.00, respectively.
- For most invertebrate groups, we applied biomass estimates from 2020-21 samples obtained by Dittmann et al. (2022), as possible starting point proxies of 1984-85 estimates (Table 4). However, using these values resulted in all groups being unbalanced with excessive EEs. None of these could be resolved by adjusting predation mortality rates/diet. The only way to balance these groups was to remove 2020/21 data as proxies for the 1984/85 biomass estimates, set EEs to 0.95 and allow the model to estimate biomass. For these groups the final estimated (1984/85) biomasses were mostly many orders of magnitude greater than the empirical estimates derived from 2020-21 (Table 4). It is also noted that several invertebrate trophic groups (37 benthic annelids, 39 Ficopomatus and 43 subtidal benthic molluscs) were not recorded as present in the South Lagoon in 2020-21 (Dittmann et al. 2022).

4 Time-series fitting

Dynamic simulations were run in *Ecosim* using a combination of available commercial fishery, fishery independent sampling and bird abundance data, providing a total of 67 and 44 individual time-series data sets for the North Coorong and South Lagoon ecosystem models, respectively (the list of time-series is presented in Appendix D). Commercial fishery logbook data were available from 1984-85 to 2020-21 and included estimates of annual catch, fishing effort, and relative biomass (CPUE) of key commercially targeted species (e.g. yelloweye mullet, mulloway, black bream, flounder) by gear types (principally small and large mesh gillnets). In addition, data from annual research sampling using seine nets, funded by CLLAMMecology Program (Noell et al 2009) and The Living Murray Program (Ye et al. 2020), provided a shorter time-series (2006-07 to 2020-21) for some other fish taxa, including ecologically important species such as smallmouth hardyhead and sandy sprat (Ye et al. 2019). Waterbird surveys conducted in 1985 (South Lagoon only, Paton et al. 2009), 1987 and 1993 (AWSG – Birdlife Australia), were combined with the annual, spatially stratified, waterbird monitoring that has been conducted in the Coorong every year since 2000 (Gosbell and Grear 2005, Paton 2010, Paton et al. 2020, Prowse et al. 2021) (see Appendix A for details on how bird counts were used to estimate biomasses). Time-series of biomasses, fishing catches and effort, were loaded into each *Ecosim* model for the North Coorong and South Lagoon.

Several environmental time-series, including the sum of annual freshwater flow (barrage and Salt Creek discharge), mean annual water level and mean annual salinity (1984/85 to 2020/21), were used in each ecosystem model to explain ecological processes and variable rates of primary production. Long-term environmental data including modelled salinity and water level for North Coorong and South Lagoon were provided by Claire Sims DEW. Fitting each model to individual environmental time-series data was undertaken using the nutrient loading forcing function application of *Ecosim*. A two-stage optimisation (stepwise fitting procedure) was then run to modify the number of *Ecosim* predator vulnerability parameters that achieved the best model fit possible, i.e. that would minimise the model sum of squares (SS) and Akaike Information Criteria (AIC). *Ecosim* vulnerability parameters change the extent to which a predator (in the model) can impact its prey by adjusting the exchange rate between vulnerable and invulnerable proportions of the prey population. This concept is based on the foraging arena theory of Walters et al. (1997) and represents the "trophic control" of the predator-prey dynamics. For example, if an increase in the biomass of a predator has a large impact on the predation mortality of its prey, then it is considered to be "top-down" controlling and the vulnerability parameter would be high. Conversely, if predator biomass increase has very little influence on the predation mortality of its prey, and where prey abundance has more influence on the predator, then control is considered to be "bottom –up" controlling and the vulnerability parameter on the prey would be low (<1). The stepwise fitting tool initially explored the most sensitive and optimal number of vulnerability parameters (predator interactions), that produced the best fit to the time-series data. Through the second stage of the stepwise fitting procedure, we applied a primary production anomaly to each of the three primary production groups (i.e. phytoplankton, filamentous algae and macrophytes). Given the variable nature of estuarine environments under different flows, water levels and salinities, primary production anomalies were utilised to better predict bottom-up processes that may drive changes in invertebrate, fish, and bird biomasses (Sinnickson et al. 2021). The stepwise fitting procedure then examined each combination of vulnerability parameters and spline point numbers fitted to the anomaly (Table 5). Forcing functions can only be examined individually within *Ecosim* (i.e. not combined).

For both the North Coorong and South Lagoon models, the addition of environmental time-series through the nutrient loading forcing function, along with the application of a primary production anomaly, provided the best fits based on minimised model SS and AIC (Table 5). We consistently observed that fits to salinity produced better model fits than water level, and that water level produced better model fits than barrage (North Coorong) or Salt Creek flows (South Lagoon) (Table 5). Model fits to environmental times series were generally better in the South Lagoon than North Coorong model (50-60% lower model error), and the difference in model fit to salinity, water level and flows was less for South Lagoon (AIC range: 645 – 669) than for North Coorong (AIC range: 1280 – 1737) (Table 5). Plots of the relative change in annual flow, mean annual water level and salinity for the North Coorong and South Lagoon ecosystem models, with the fitted primary production anomalies, are presented in Figure 7. The number of spline points used to fit each anomaly in each model is indicated in Table 5.

Table 5. Model fitting series applied in Ecosim for the North Coorong and South Lagoon ecosystem models. The primary production (PP) forcing function (flow, water level, salinity) applied to each model is indicated, with the starting and final model sum of squares (SS) and Akaike Information Criteria (AIC). The number of vulnerability parameters (V's) and spline points (Splines) used to fit the anomaly are indicated.

MODEL	FORCING FUNCTION	START SS	PP ANOMALY	FINAL SS	AIC	V'S	SPLINES
North Coorong	**Barrage flow**	36082	No	12132	2524	38	
			Yes	5303	1737	38	6
	Water Level	19763	No	5426	1708	20	
			Yes	3971	1464	25	22
	Salinity	4299	No	3372	1298	43	
			Yes	3302	1280	44	5
South Lagoon	**Salt Creek Flow**	3236	No	2164	786	13	
			Yes	1709	669	10	11
	Water Level	3649	No	1868	715	19	
			Yes	1584	662	17	20
	Salinity	2052	No	1865	695	10	
			Yes	1655	645	8	10

Examples of trophic group model fits utilising the environmental forcing function in *Ecosim* for the North Coorong and South Lagoon ecosystem models are presented in Figures 8 and 9. These figures present the model predictions of biomass change utilising either flow, water level or salinity environmental forcing, relative to changes in the observed biomass of various trophic groups. The degree to which the model predictions contribute to the overall model error (SS) for each trophic group fitted to either a flow, water level or salinity forcing function, is detailed in Table 6. Viewed together, these outputs provide a measure of the degree that changes in flow, water level and salinity, explain the variability in observed changes in the biomass of different trophic groups over time.

In general terms, there was marked variability in the degree that models incorporating environmental forcing functions fitted to the observed biomass changes in trophic groups. For the North Coorong ecosystem, based on SS contribution, the abundance of many waterbird groups fitted moderately well to changes in forcing functions, with water level accounting for most of the variation in tern (SS=5), oystercatcher (SS=10) and ibis (SS=19) abundance; and salinity accounting for most of the variation in pelican (SS=9), gull (SS=7), egret and heron (SS=16) and spoonbill (SS=40) abundance (Figure 8, Table 6). For migratory and non-migratory waders and shorebirds, fits to barrage flow were generally poor (mean SS = 242), but better for water level (mean SS = 96) and salinity (mean SS = 67) (Figure 8, Table 6). For medium-large and small-billed migratory shorebirds, water level (SS=42) and salinity (ss=45) provided the best fits to changes in abundance, respectively. In general, none of the major reductions in abundance in shorebirds and waders observed between the 1980s and 2000s, fitted well to changes in flow, water level or salinity (Figure 8). For cormorants and grebes, diving and dabbling ducks and black swans, variability in barrage flow (mean SS=35), water level (mean SS = 36) and salinity (mean SS= 35) explained similar variability in the changes in their abundance, with salinity (SS=70) and barrage flow (SS=125) providing the best fits to changes in filter feeding duck and coot abundances, respectively (Figure 8, Table 6).

For fish species in the North Coorong ecosystem model, changes in commercial fish (mulloway, black bream, flounder and yelloweye mullet) abundance fitted best to changes in salinity (mean SS=99), relative to barrage flow (mean SS=115) and water level (mean SS=129), with the best fits to salinity for yelloweye mullet (SS=4) and mulloway (SS=21) (Figure 8, Table 6). For the remaining key fish species (smallmouth hardyhead, sandy sprat), fits to barrage flow were poor (mean SS=403), while salinity (SS=54) and water level (SS=64) provided the best fits to smallmouth hardyhead and sandy sprat, respectively (Figure 8, Table 6).

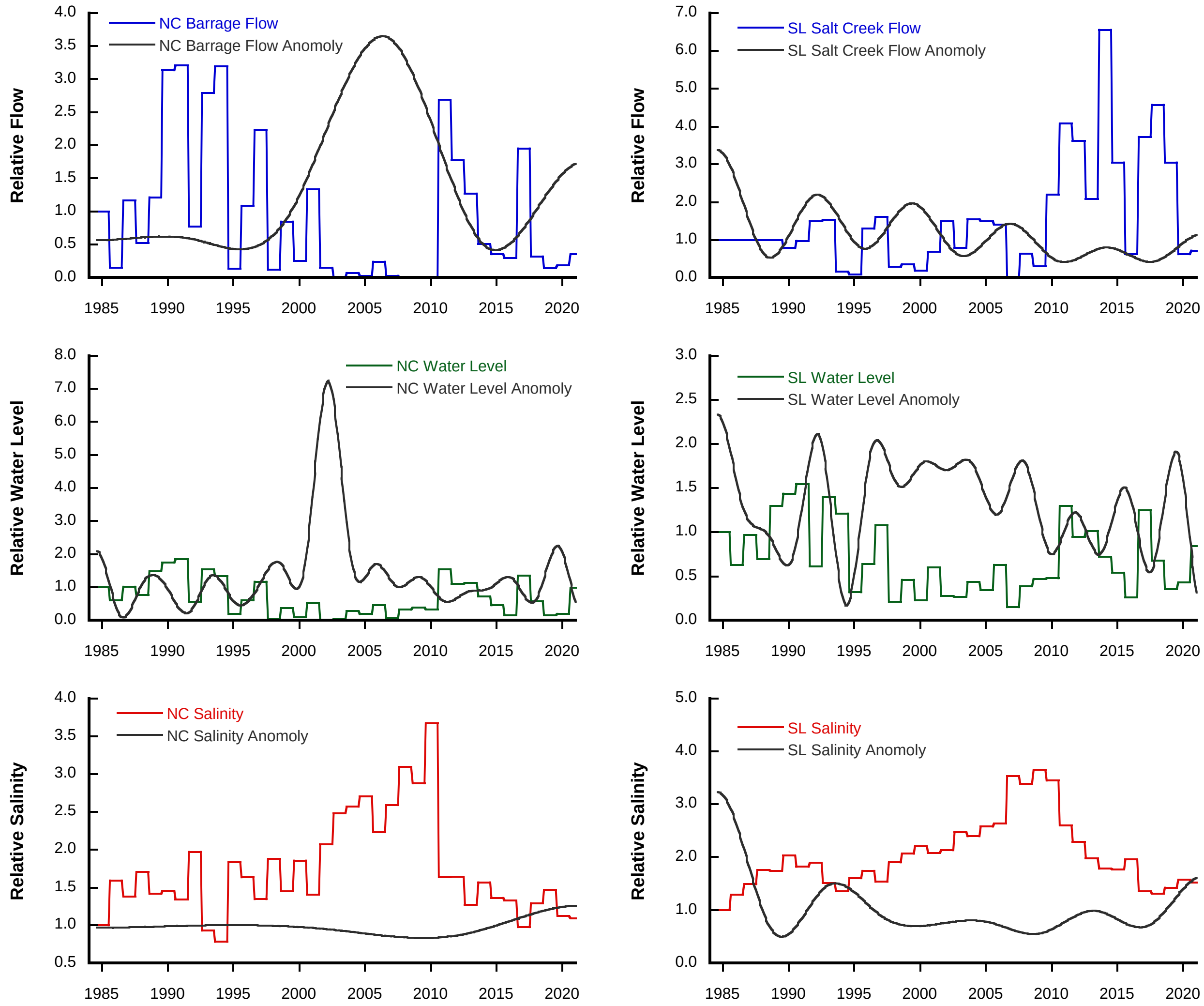


Figure 7. Plots of the environmental times series data (annual flow, annual mean water level and salinity), relative to 1984-85 levels, and primary production anomaly curves fitted to the North Coorong (NC) and South Lagoon (SL) ecosystem models.

For the South Lagoon ecosystem model, based on SS contribution, the abundance of many waterbird groups had similar fits in models incorporating Salt Creek flow, water level and salinity forcing functions (e.g. pelican, cormorants and grebes, terns, gulls, egrets and herons, and oystercatchers mean SS = 35, 34, 32, respectively; shorebirds and waders mean SS = 64, 52, 66; and ducks, coots and black swan mean SS = 78, 77, 76, respectively) (Figure 9, Table 6). Bird groups that fitted best to salinity were terns (SS= 12) and gulls (SS=21), those that fitted best to changes in water level were medium-large (SS=51) and small-billed (SS=33) and migratory shorebirds (SS=51), while those that fitted best to changes in salinity were large non-migratory waders (SS=87) and small non-migratory shorebirds (SS=34). For two commercially targeted fish species, black bream and yelloweye mullet abundances fitted best to changes in water level (SS = 17 and 48, respectively), while changes in smallmouth hardyhead abundance fitted best to changes in Salt Creek flow (SS=98) (Figure 9, Table 6).

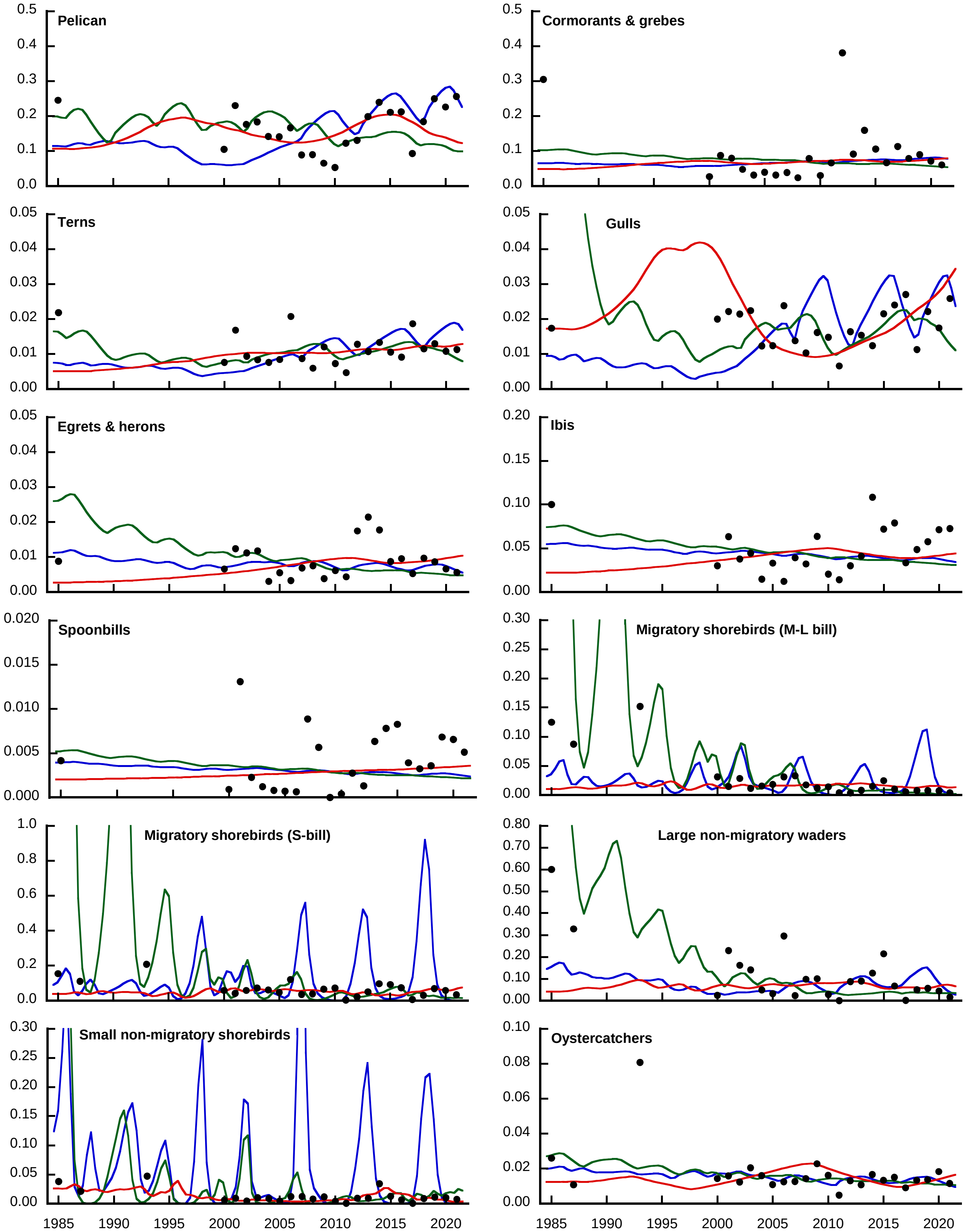


Figure 8. North Coorong ecosystem model fits of observed changes in the biomass (black dots) of trophic groups to environmental time-series data (solid lines, barrage flow – blue, water Level – green, salinity – red). Y-axis is biomass (t km^2).

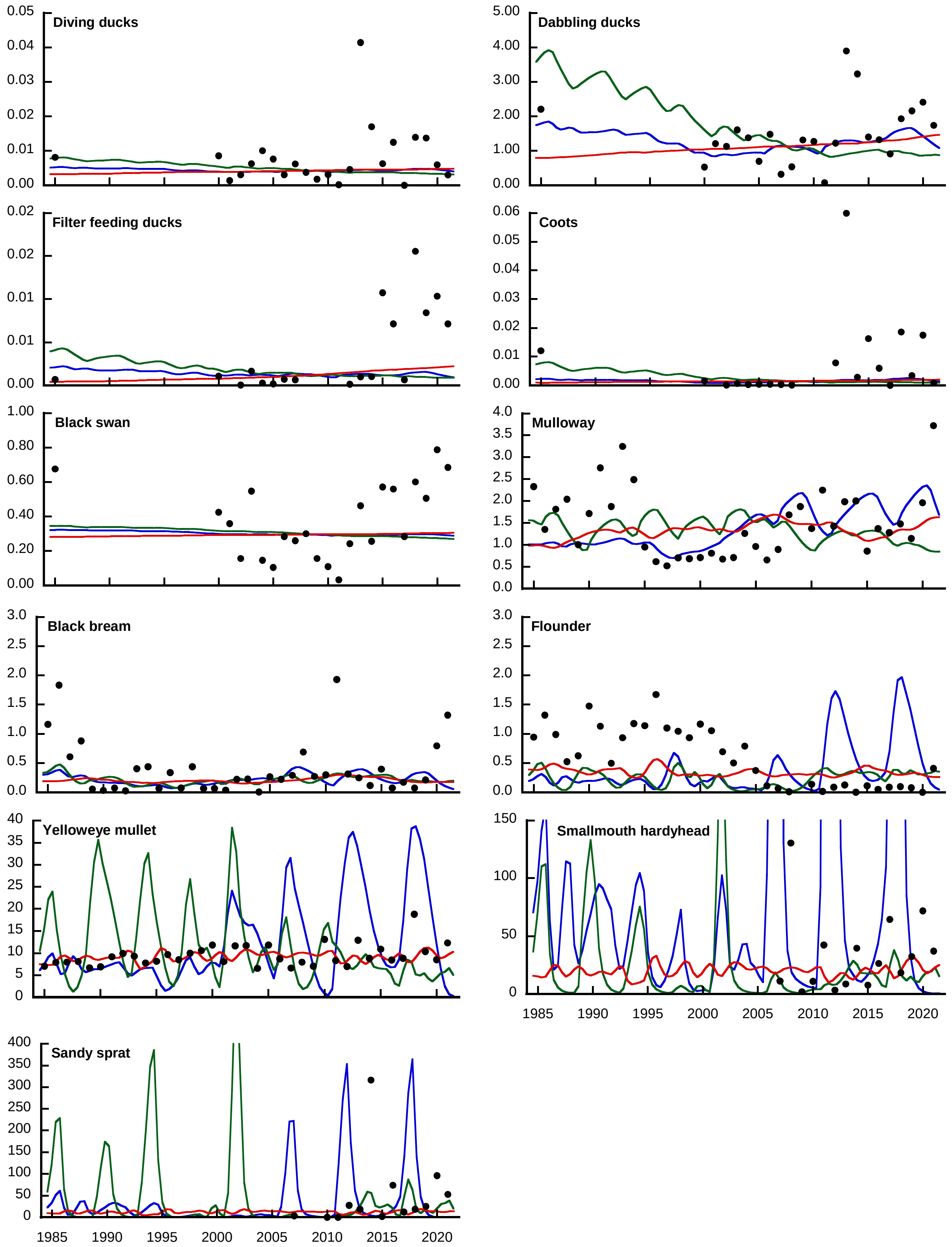


Figure 8. Cont.

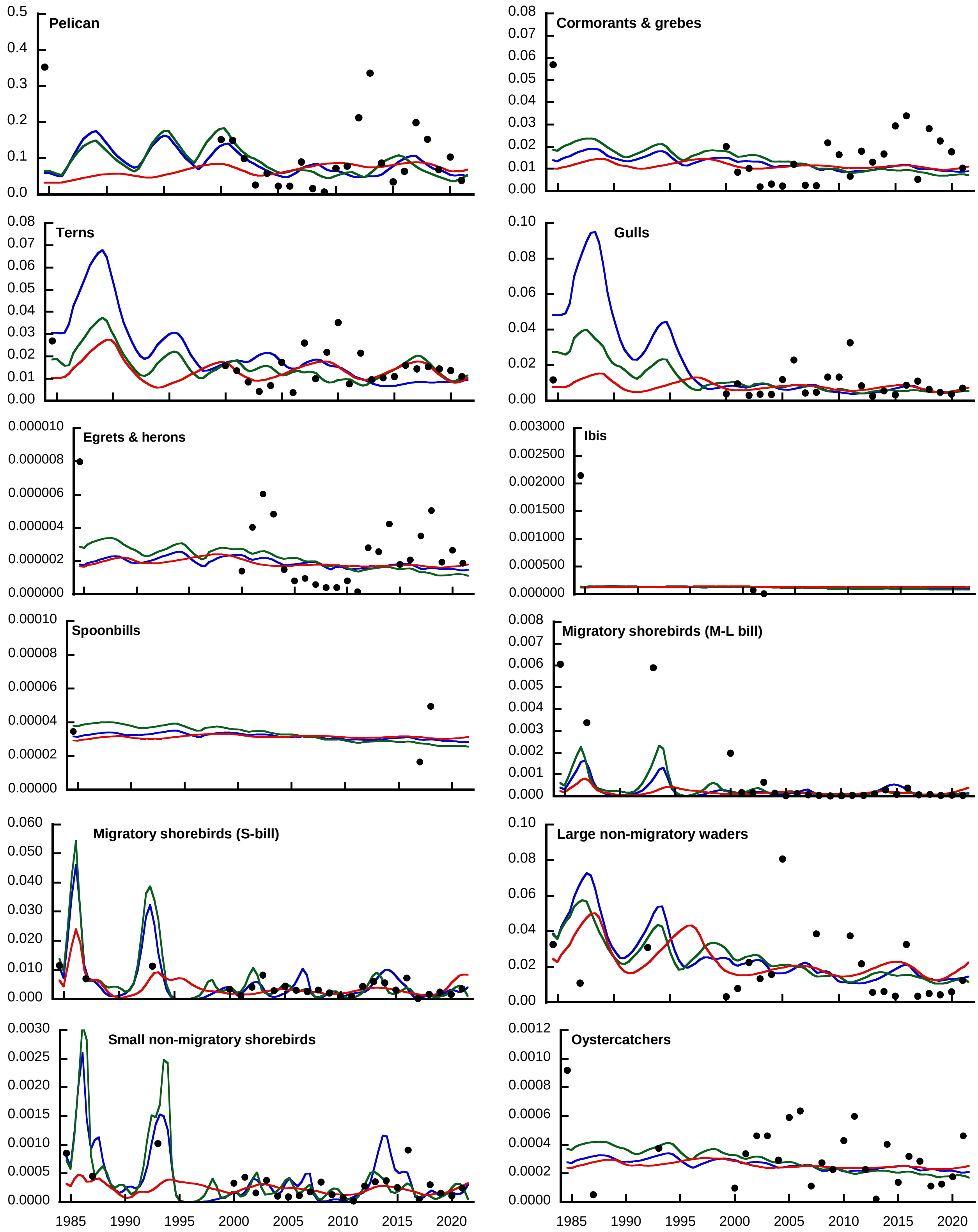


Figure 9. South Lagoon ecosystem model fits of observed changes in the biomass (black dots) of trophic groups to environmental time-series data (solid lines, barrage flow – blue, water Level – green, salinity – red). Y-axis is biomass (t km2).

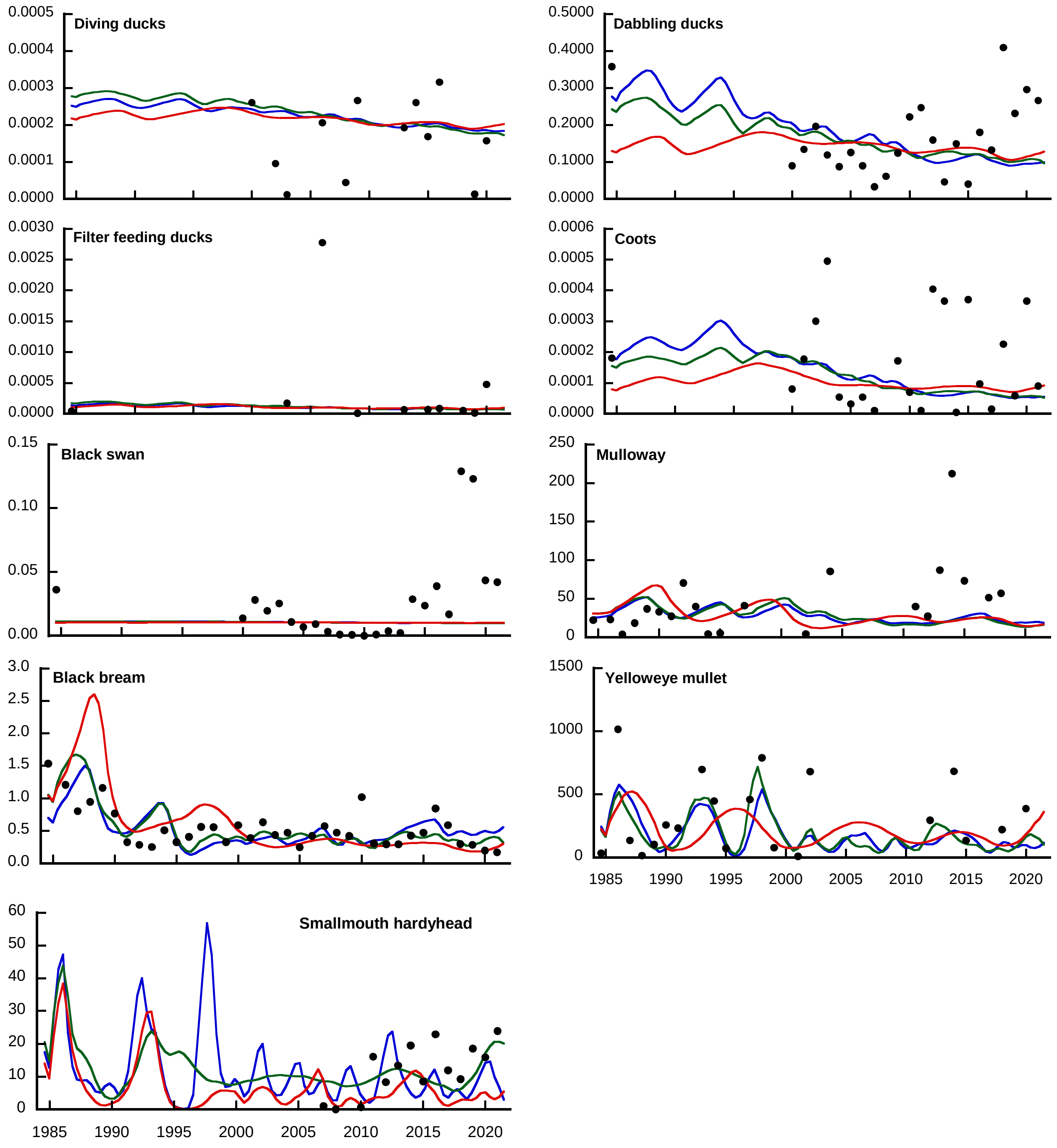


Figure 9. Cont.

Table 6. Sum of Square (SS) contribution of model fits to time-series data for trophic groups with different environmental forcing: flow (barrage flow BF, Salt Creek flow SCF), water level (WL) and salinity (SAL) in the North Coorong and South Lagoon ecosystem models. Values in blue text indicate lowest Sum of Squares as an indication of best fit of the three environmental parameters for each region.

TROPHIC GROUP	NORTH COORONG			SOUTH LAGOON		
	BF	WL	SAL	SCF	WL	SAL
Australian pelican	11	12	9	45	44	47
Cormorants & grebes	25	24	24	43	51	42
Terns	18	5	9	22	19	12
Gulls	26	10	7	31	25	21
Egrets & herons	35	19	16	42	43	44
Ibis	23	19	21			
Spoonbills	55	48	40			
Migratory shorebirds (M-L bill)	115	42	51	62	51	109
Migratory shorebirds (S bill)	212	78	45	36	33	34
L non-migratory waders	86	85	126	92	91	87
S non-migratory shorebirds	554	180	46	67	35	34
Oystercatchers	11	10	14	38	38	38
Diving ducks	94	95	96	114	114	113
Dabbling ducks	30	35	30	28	24	25
Filter feeding ducks	89	116	70	43	44	42
Coots	125	188	167	78	74	73
Black swan	25	27	26	128	127	127
Mulloway	24	28	21	67	70	61
Black bream	132	111	118	24	17	22
Flounder	216	337	251			
Yelloweye mullet	88	39	4	59	48	80
Smallmouth hardyhead	233	69	54	98	110	111
Sandy sprat	573	64	187			

5 Scenario development

The HCHB Coorong Infrastructure Investigations Project (CIIP) has evaluated several concepts for engineering interventions designed to improve the ecological health of the Coorong. These concepts have been examined broadly to assess the extent that they could reduce salinity and nutrients, and improve flows and water level, especially in the South Lagoon; however, the extent that each intervention would improve the ecological state of the Coorong remains uncertain. The *Ecosim* models constructed for the North Coorong and South Lagoon provide a means to compare these interventions within a trophic framework. Developing scenarios using the *Ecosim* models enables the examination of the likely ecological response of key bird and fish groups to changes in flow (barrage flow, Salt Creek flow), water level and salinity. For each base-model, a range of scenarios were developed that incrementally increased either freshwater flow, water level or salinity across the observed time-series range through the range of annual values (i.e. from their minimum to their maximum annual total for flow, and annual mean for water level and salinity).

Scenario time-series were extended an additional 50 years beyond the base-models (i.e. 87 years in total). Environmental time-series were scaled relative to the first year (1984-85), while the appropriate anomaly value for each scenario was derived from a regression model of the environmental time-series plotted against their anomaly. Model scenario runs confirmed that most variability in trophic group response had stabilised after 50 years. At the end of each model run, the end biomasses for each trophic group were collated, and their deviations from the mean base-case scenario were compared. The base-case scenario values used for the North Coorong were 3,784 GL (mean total annual barrage flow), +0.22 m AHD (mean annual water level), 41.8 g/L (salinity); and for South Lagoon were 10.7 GL (mean total annual Salt Creek flow), +0.16 m AHD (mean annual water level), and 103.4 g/L (salinity). Model scenarios essentially provided a sensitivity analysis to examine how responsive each trophic group was to changes in each environmental parameter (flow, water level and salinity). We only examined the ecological response of bird and some fish groups where abundance time-series were able to be fitted to *Ecosim* models (from 1984-85 onwards), as these were the only groups where the confidence in the response relationship could be evaluated (see Figures 8 and 9).

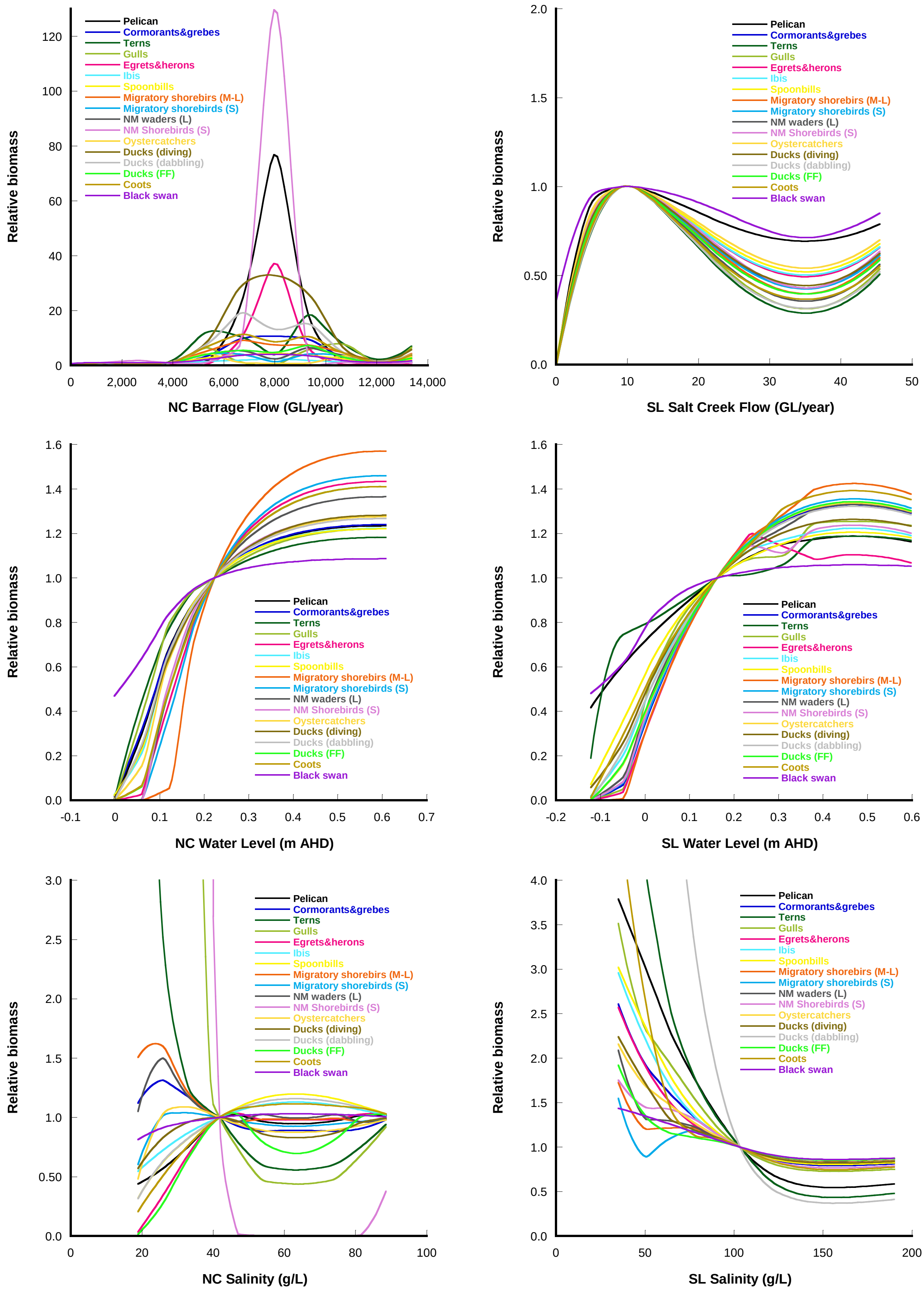


Figure 10. *Ecosim* scenarios for the North Coorong (NC) and South Lagoon (SL) models examining the projected response relationships for key bird groups to changing flow, water level and salinity. Biomass change of groups is plotted relative the average base-case scenario (mean annual total flow and mean annual water level/salinity).

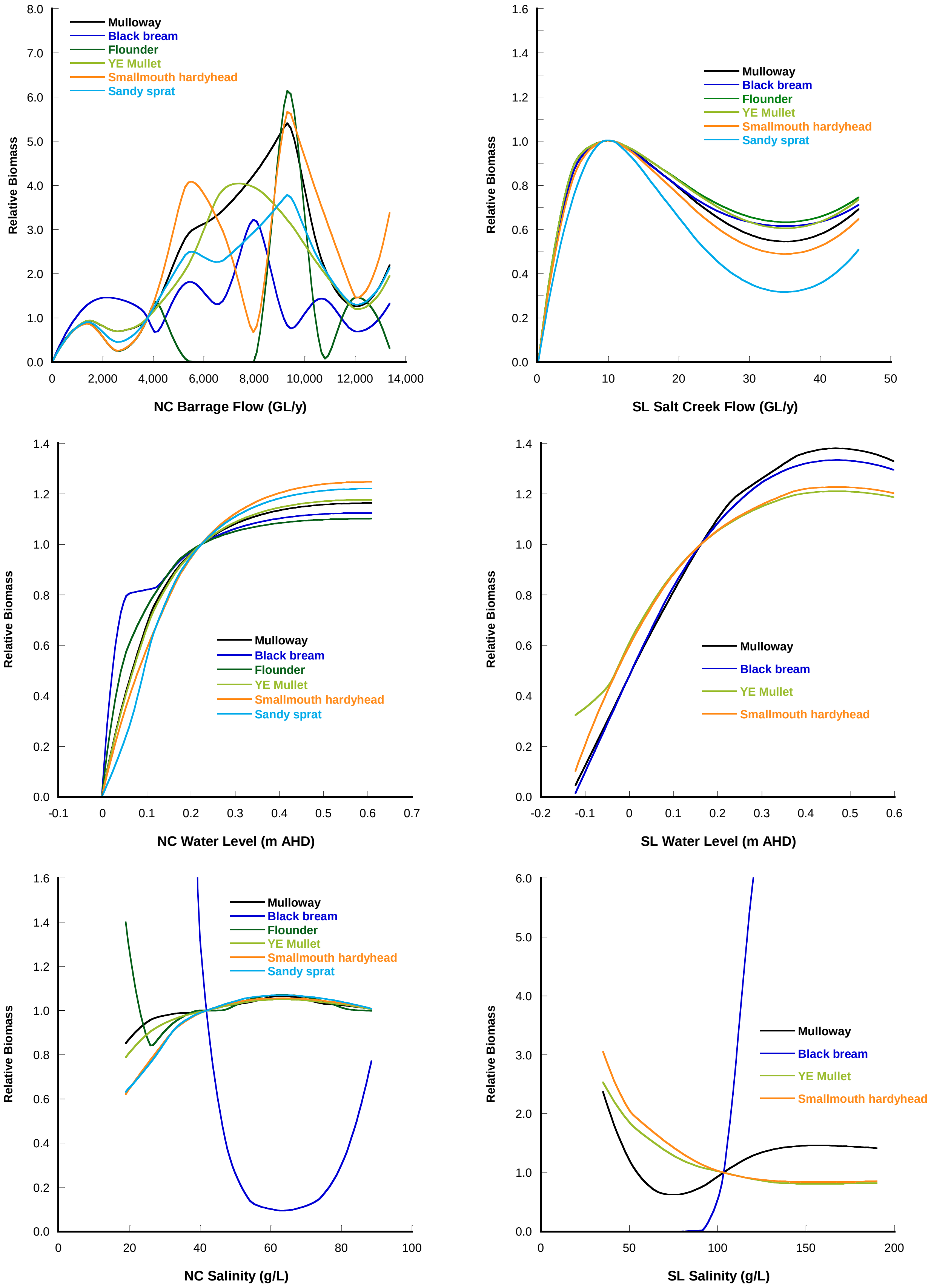


Figure 11. ***Ecosim*** **scenarios for the North Coorong (NC) and South Lagoon (SL) models examining the projected response relationships for key fish groups to changing flow, water level and salinity. Biomass change of groups is plotted relative the average base-case scenario (mean annual total flow and mean annual water level/salinity).**

The results for the North Coorong and South Lagoon scenario analyses from key bird and fish groups are presented in Figures 10 and 11. For the North Coorong ecosystem model, there was a strong response relationship between barrage flow and the relative biomass of bird groups with most group biomasses peaking when barrage flow rates were between 6,000 and 10,000 GL/y, although there was some variability in the response relationship of different bird groups. All bird groups demonstrated a strong positive response to increases in water level up to +0.6m AHD. The response relationship between bird groups and salinity was more complex, with migratory and non-migratory shorebirds and waders, cormorants and grebes, terns, gulls, and oystercatcher biomasses peaking at lower salinity levels; spoonbills, ibis, coots, and dabbling ducks peaking at higher salinity level; and egrets and herons and diving and filter feeding ducks peaking at both average and higher salinity levels.

For the South Lagoon ecosystem model, the response relationships between water level and the relative biomass of bird groups were positive, and similar to that for the North Coorong, although there was evidence that the optimal water levels for most groups were between +0.2 and +0.5m AHD, noting that our upper historical observed range was +0.6m AHD. Unlike the North Coorong, however, there was a consistent negative response relationship among all bird groups to salinity, with biomass trends generally increasing markedly as salinity reduced. The response relationship between bird biomass and Salt Creek flow was more complex. Relative biomasses of birds increased as flow increased from low to average levels, but then declined as flow increased from 10 to 35 GL/y, increasing again as flow exceeded 40 GL/y up until our maximum observed level of ~45 GL/y.

In general, the response relationship between fish groups and environmental factors were less clear than they were for bird groups (Figure 10 and 11). For example, in the North Coorong model, the response relationship with barrage flow was complex and variable among groups, with most group biomasses peaking between 6,000 and 10,000 GL/y. However, as detailed above the original model fits to barrage flow time-series were poor for several fish species, including black bream, flounder, smallmouth hardyhead and sandy sprat (see Figure 8 and Table 67). Hence, the response relationship for these species should be viewed with caution (Figure 10). The response to water level was more uniform across fish species, showing a general increase in biomass as water levels increased, likely due to an overall increase in productivity. For species where fits to salinity time-series were better (mulloway, yelloweye mullet, smallmouth hardyhead, Figure 8 and Table 6), response relationships suggest that they were tolerant of salinity increases up to ~80 g/l with peak biomasses around 60-70 g/L (Figure 10). This is a high level, approximately twice the salinity of seawater. Flounder and black bream response relationships at lower and high salinity levels likely say more about their poor fits to salinity time-series data than real response relationships (Figure 8 and 10).

For the South Lagoon, the response relationship between fish biomass and Salt Creek flow was similar to that for birds, suggesting a peak biomass around average Salt Creek flows (10.7 GL) There was also some indication that biomass may increase further beyond flow levels >40 GL/y (Figure 11). The response relationship between water level and the relative biomass of fish groups was positive, and similar to that for North Coorong, although there was evidence that the optimal water levels for most groups were between +0.4 and +0.5m AHD, i.e. close to the upper observed range of +0.6m AHD (Figure 11). Yelloweye mullet and smallmouth hardyhead biomasses tended to decrease with increasing salinity (Figure 11). Mulloway, biomass increased most under lower salinity conditions (Figure 11). A positive response relationship between salinities >100 g/l and black bream and mulloway biomasses is perplexing (see discussion).

6 Discussion

This project developed a quantitative food web model for the North Coorong and South Lagoon and applied these models in simulated scenarios of abundance responses by key bird and fish groups to changes in flow, water level and salinity, to inform the development of management strategies to restore a functioning South Lagoon food web. Both the model development and the simulations have improved our understanding of the key drivers of ecosystem health, and our capacity to evaluate the ecological benefits of different management options.

6.1 Model development

Ecosystem model development can be a lengthy process requiring extensive and detailed data on the biomass and production of predator and prey groups, and detailed knowledge of their diet. Ecosystem models are most representative and informative of their systems when the data sets that inform them have a high level of provenance. We have amassed and synthesised a considerable data set that has enabled us to provide the best estimates of key ecosystem parameters using local information where possible or derived empirical estimates of appropriate values calculated from similar ecosystems where in-situ data were not available. The synthesis and integration of these data into the first quantitative ecosystem models for the Coorong ecosystem is a key milestone and output of this study and represents a significant advancement on previous conceptual modelling approaches (Giatas and Ye 2016, Giatas et al. 2018). Previous modelling, although informative, provides limited predictive capacity.

Importantly, the *Ecopath* with *Ecosim* models developed for the North Coorong and South Lagoon, need to be viewed as prototypes, and the initial step in a longer development process. As such, the model outputs and scenarios need to be viewed as preliminary and should be interpreted with caution. They are indicative of the types of analyses and outputs that can be produced with further development. There are clearly many data gaps and uncertainties that should be evaluated and addressed, but there are others, including historical data gaps that may not be resolvable. These challenges are a normal part of ecosystem modelling, but we are confident that with further model developments, the potential of the models as a key decision support tool for managing the Coorong, will be enhanced.

There have been two key challenges to model development in this project. Firstly, due to the concurrent completion and reporting schedules of other HCHB T&I component activities, it was not possible to integrate all the new information collected during the T&I project into our models. Following the completion of the T&I project it will be important to identify the new knowledge, data and modelled time-series that could be integrated to improve and develop our models further.

Secondly, detailed and thorough analyses of our models are needed to evaluate the significance of data gaps, model estimations and assumptions, and where improvements to model structure and parametrisation are most needed. At this stage of model development, model inconsistencies are expected, in fact are welcomed, because they can identify potential problems with how the models have been parameterised. Where the biomasses of trophic groups had to be estimated by the model, we need to assess if these estimates are realistic and appropriate, and if not, whether they point to other issues including estimates of production, diet, or consumption. For example, through the model balancing exercise for the South Lagoon ecosystem, contemporary estimates of the biomasses of many invertebrate groups, were in most cases many orders of magnitude too low to enable the 1984/85 *Ecopath* model to balance. There could be many reasons as to why these estimates may not have facilitated model balancing. The discrepancy could be real and reflect that production, biodiversity and biomass of invertebrate groups was much greater in the 1980s, or that our generic Coorong diet matrices fail to adequately reflect current and past trophic relationships and flows in the South Lagoon ecosystem.

Invariably with ecosystem modelling, key insights can be found where model predications deviate from the data or expectations. This provides avenues to examine alternate hypotheses about key processes that could explain observed historical patterns. Such discrepancies are essential to identifying areas of further model development and refinement, but also for improving the accuracy of the primary data used (e.g. diet, biomass, and production of key groups). All these improvements and refinements ultimately help improve our knowledge and understanding of the structure and function of ecosystems and build confidence that model predictions reflect real changes in the functioning of ecosystems.

6.2 Time-series fitting

The integration and fitting of biological time-series data of trophic group abundances with environmental time-series using *Ecosim*, is a powerful advancement in ecosystem modelling that enables exploration of how an ecosystem responds to change and provides the ability to evaluate how alternate scenarios of change and management may impact an ecosystem. Availability of data has improved since the early 2000s, however, our study used a baseline of the mid 1980s, when the first annual catch and effort data were available for the Lakes and Coorong Fishery. Our rationale for this approach was to choose a time when the historical state of the South Lagoon ecosystem was more similar to the desired state which current managers and stakeholders wish to return it (DEW 2021a). As such, any time-series data on species abundances from this period (e.g. 1980s) potentially hold great value. Long reference time-series encompassing significant environmental change facilitates the fit to time-series features in *Ecosim*, and the identification of values, or ranges of values, or alternative hypotheses about key processes that could explain observed historical patterns (Christenson et al. 2008). A long reference time-series with high disturbance patterns will provide more insights than a short reference series with minimal variation. As argued by Christenson et al. (2008), the ability of a model to fit to a short time-series may be no test at all of its ability to make useful predictions about change, beyond what is represented in the reference data, and many model errors (structure and parameter values) will only reveal themselves (i.e. through strong departures from observed to predicted patterns) when the model is challenged to reproduce a very long time-series of responses.

Long time-series data can also bring challenges, especially where there are considerable data gaps. Our annual fishery catch and effort time-series encompassed the entire 37 year period of our *Ecosim* models, but bird count data were patchier. Although annual bird count data were available between 2000-01 and 2020-21, there were only 2-3 data points (for different groups) available in the preceding 15 years (1984-85 to 1999-2000). Additional fish catch sampling data were available for some species, but only since 2006-07. Model fits to time-series through periods with few observations need to be interpreted cautiously. Importantly, for both the North Coorong and South Lagoon models, fitting the environmental time-series, applied as a primary production forcing function to our reference time-series, significantly reduced model error. Time-series fits to salinity produced better model fits than water level, and water level produced better model fits than freshwater flows (barrage or Salt Creek). The model fits to environmental times series were generally better in the South Lagoon than the North Coorong model, and the variability in model fits to salinity, water level and flows was less for South Lagoon than for North Coorong.

There was, however, a high degree of variability in how well environmental time-series fitted to individual bird and fish groups in both Coorong models. In general, biomass change in bird groups fitted better than fish, with commercially caught species that had longer time-series (CPUE data) fitting better than species with shorter catch-sampling time-series. As commercial catch data is based on catches of fish of legal size (and thus often several years of age), many life history responses of fish populations to changing environmental conditions, such as recruitment, may take several years to be detected in changes to commercial fish catches. Such lag affects may confound model fitting and response relationships because the year in which a biomass change is detected may have had very different different environmental conditions from the year of recruitment.

The major reductions in migratory shorebird numbers between the 1980s and 2000s, did not fit well to changes in flow, water level or salinity in either the North Coorong or South Lagoon models. The inability of environmental time-series to fit to these marked declines suggests they may not have been the primary driver of change in migratory bird abundances in the Coorong. Other factors affecting the degradation of their breeding and foraging habitats along the East Asian - Australasian Flyway) have been significant (Bamford et al. 2008, Prowse et al. 2021). For many waterbird taxa, model fits to local environmental data will be confounded by national and global factors driving their trends in abundance (Prowse et al. 2021). For example, global reductions in the abundance of curlew sandpipers are reflected in local declines observed across Australia, including in the Coorong (Clemens et al. 2016, 2019, Paton et al. 2020).

6.3 Environmental response scenarios

Preliminary scenarios were developed that examined the response relationships between key bird and fish groups and changes in observed flow, water level and salinity. For the North Coorong, there was a strong response relationship between barrage flow and the relative biomass of bird groups with most peaking at flows between 6,000 and 10,000 GL/y. All bird groups also demonstrated a strong positive response to increases in water level up to +0.6m AHD (the maximum level in our annual time series), but the response relationships between bird groups and salinity were more complex. Migratory and non-migratory shorebirds and waders, cormorants and grebes, terns, gulls, and oystercatcher biomasses peaked at lower salinity levels; and the remaining bird groups peaked at higher salinity levels.

As in the North Coorong, the biomass of bird groups in the South Lagoon increased with water level, with optimal water level ranging between +0.2 and +0.5 m AHD for most groups. Also, the biomasses of bird groups decreased markedly as salinity increased, especially between 30 and 100 g/L. The response relationships between bird biomass and Salt Creek flows were more complex. Bird group biomasses peaked at average flow levels (~10 GL/y), but then declined as flow increased to 35 GL/y, increasing again as flow exceeded 40 GL/yr. Given the strong positive relationship between relative bird biomass and water level, and negative relationship with salinity in the South Lagoon, it was expected that as Salt Creek flow increased, water levels would rise and salinity levels decrease, both of which would increase bird biomass. The unexpected response relationship may indicate that the observed range of Salt Creek flows have been insufficient to raise water level or decrease salinity to a level that would elicit a positive response by bird groups in the South Lagoon. Overall, the broad-scale patterns in South Lagoon are more likely to be influenced by water exchange with North Lagoon and barrage flows.

The key outputs of our response scenario analyses for bird groups are broadly consistent with the findings of Prowse et al. (2021), despite the different modelling approaches undertaken. Prowse et al. (2021) also found a negative relationship between the abundance of some water bird groups (e.g. pelicans, terns and black swan) with salinity and a positive relationship with water level. However, for most waterbird species they identified that abundance decreased as water level increased, but it is noted that the water level range response in some of the Hurdle models go well above (i.e. +2.0 m AHD) the maximum used in the *Ecosim* models in this study (+0.6m AHD). Prowse et al. (2021) found that foraging by curlew sandpiper and red-capped plover was most intense in the South Lagoon at intermediate water levels (c. -0.2 to 0.6 m AHD), which encompasses the range in peak biomasses predicted by the *Ecosim* models herein (+0.2 to 0.5 m AHD). An optimal range in water levels makes sense, given that for shorebirds that forage on shallow mudflats, food availability would decrease as the area of available mudflat declines (Prowse 2020).

Clearly, how water level impacts the availability and suitability of habitat for water birds is important in understanding their distribution and abundance (Prowse et al. 2021). This was not incorporated into our *Ecosim* models, which instead examined how changes in freshwater flow, water level and salinity impact the biomass of trophic groups, driven through changes in primary production. To examine habitat availability or suitability using *Ecopath* with *Ecosim* models, we would need to employ the third component to the EwE software suite; *Ecospace* (Pauly et al. 2000). This was beyond the scope of this study. Application of this spatial and temporal extension package would facilitate analyses to examine how habitat availability and suitability change under different environmental conditions.

The environmental response relationships identified for fish groups were less clear than those for bird groups, which may be expected, given that the fits of time-series with environmental primary production forcing were poorer than for birds. Even so, the general pattern of increasing biomass with increasing water level was consistent between bird and fish groups, as were declines in biomass with increasing salinity in South Lagoon, at least for yelloweye mullet and smallmouth hardyhead biomass. There were two notable exceptions to these trends. Black bream and mulloway showed higher tolerance for hypersaline conditions, which is inconsistent with expectations. A potential reason for such unexpected relationships could be the annual scaling of the model. Simplifying the models to annual time-series was necessary given the limited data available for all groups but may have masked important sub-year environmental variability (i.e. seasonal or monthly). Annual averages may fail to correlate well with bird and fish abundances that can respond quickly to changing environmental conditions. The annual, spatially stratified, waterbird monitoring in the Coorong is conducted in January each year, so future analysis should examine how bird abundance varies in response to January flow, water level and salinity, rather than averaging these values across a 12-month period. Similarly, further model development could examine if the incorporation of monthly time-series helps tighten the modelled response relationships and improve model predictions. Using shorter time-series through periods with a greater number of observations may also provide some information on the extent to which time-series duration and data gaps affect time-series fitting.

6.4 Management implications and future directions

The ecosystem models developed as part of this study provide a basis to evaluate the extent that different infrastructure and management options being considered could influence the ecological state of the Coorong. Our preliminary models and outputs demonstrate how scenario analyses can be used to explore the likely quantum improvements in key bird and fish taxa that could be achieved under the projected salinity and water level endpoints for each infrastructure option.

Given the early stages of model development from this study, outputs need to be interpreted with caution. With further development, however, the capacity of the North Coorong and South Lagoon ecosystem models to provide decision support tools for the management of the Coorong will be enhanced. To facilitate this, we recommend the following as next steps:

- Identify new knowledge, data, and modelling products from other HCHB T&I activities not integrated into ecosystem models herein that could, if integrated, further develop and improve ecological models.
- Undertake a detailed analysis of our models to evaluate the significance of data gaps, model estimations and assumptions, and where improvements to model structure and parametrisation are most needed.
- Examine if better environmental response relationship for key species can be developed with models using monthly versus annual time-series, and if shorter time-series can improve model fits.
- Develop spatial and temporal models for the Coorong using *Ecospace* (*Ecopath* Pro, spatial extension) to more explicitly model how habitat availability and suitability of trophic groups change under different environmental conditions.
- Integration of ecosystem model outputs into the Coorong Dynamics Model (CDM) which has been further developed during the T&I project (Component 7 – Integration) (DEW 2021b).
- Use improved models to develop more specific scenarios to evaluate the potential ecological implications of management actions to improve the ecological health of the Coorong, particularly the South Lagoon.

6.5 Summary

This project has developed the first quantitative ecosystem models for the Coorong. The key outputs from model development, time-series fitting and preliminary environmental response scenarios, have improved our understanding of the key drivers of ecosystem health. The outputs of this project significantly contribute to delivering the core objectives of the HCHB Program, by providing a basis to evaluate the extent to which different infrastructure and management options being considered will improve the ecological state of the Coorong, especially for key bird and fish taxa. However, given the early stages of model development, outputs need to be interpreted with caution. Further development of ecosystem models will improve their utility as a decision support tool.

Glossary

AIC	Akaike information criterion is an estimator of prediction error
Aquatic Macrophyte	A submerged aquatic flowering plant, large enough to be seen by the naked eye
Autotrophs	An organism that can produce its own food using light, water, carbon dioxide, or other chemicals
Benthic	Of or associated with the sediment at the bottom of an estuarine or marine system
Bentho-pelagic	Living and feeding near the bottom, as well as mid-water or near the surface
Biomass	The total mass of living organisms (plants or animals) in a sampled area, measured as wet, dry or ash free dry mass
Chondrichthyan	A member of the diverse group of cartilaginous fishes that includes the sharks, skates, rays, and chimaeras.
CLLMM	Coorong, Lower Lakes and Murray Mouth
Copepod	A microcrustacean that is typically pelagic in habit, but may be benthic
CPUE	'Catch Per Unit Effort', a measure of abundance
Decapod	An order of crustacean that includes crabs, prawns and shrimps
Detritivore	A consumer that that feeds predominantly on detritus
EE	Ecotrophic efficiency, the proportion of the production within a trophic group that is utilised in the ecosystem (ranges between 0 and 1)
Filamentous algae	The green filamentous algal community which occurs in the Coorong, consisting of *Ulva paradoxa*, *Rhizoclonium* sp. and *Cladophora* sp. defined in Collier et al. 2017.
Fish, large-bodied	Fishes that have a maximum adult size typically >250 mm in total length
Fish, medium-bodied	Fishes that have a maximum adult size typically 150−250 mm in total length
Fish, small-bodied	Fishes that have a maximum adult size typically ≤150 mm in total length
Food web model, conceptual	Diagrammatic overview of the main concepts, current knowledge, and potential knowledge gaps of food webs
Food web model, quantitative	Data supported model based on multiple data sources to provide a plausible food web based upon different scenarios of ecosystem drivers (e.g. barrage flows)
Food web model, mass-balance	Models that include biomass, production (input and export), consumption, diet composition, and fisheries catch data to estimate flows throughout the food web by using linear equations and algebra to balance inputs and outputs
Foraging	The process of searching for food
HCHB	Healthy Coorong, Healthy Basin
Herbivore	A consumer that feeds predominantly on vegetation (plants and algae)

Hypersaline	High in salt concentration, i.e. salinity >60 psu
Intertidal	The area of the shore between the low and high water level that is regularly submerged and exposed by rising and falling tides
Insectivore	A consumer that that feeds predominantly on insects
LMG	Large-mesh gillnet
Macroinvertebrate	Invertebrate fauna that are retained on sieve mesh size greater than 0.5 mm
Macrophyte	An aquatic plant large enough to be seen by the naked eye, in this report specifically a flowering plant (angiosperm).
Mass balance models	Mass balance models describe the structure and flow of energy through an ecosystem and are commonly used for quantifying food web interactions in a "whole-ecosystem" context.
Microcrustacean	Crustacean that is small in size, typically less than 1 mm
Millennium Drought	An Australian drought which impacted the Murray-Darling Basin over the period 1996-2010, and substantially impacted the Coorong over the period 2001-2010
Obligate/obligatory (diet)	Obligatory is the reliance on a particular item or group of items, e.g. an obligate herbivore feeds exclusively on vegetation, while a facultative herbivore feeds predominantly on vegetation, but may also feed on other items, e.g. small animals
Omnivore	A consumer that that feeds on vegetation or detritus, and animal items
Opportunistic species	Species that can easily adapt to new habitats or environmental conditions. They usually produce many offspring and have high growth rates
Pelagic	Organisms that are mainly associated with the water column and do not interact as often with the bottom of an estuary
Piscivore	A consumer that feeds predominantly on fish
Planktivore	A consumer that primarily feeds upon the plankton
Plankton	Organisms that are found in the water column (pelagic) and are typically small in size (i.e. microscopic). This group includes phytoplankton and zooplankton
Productivity	Energy (e.g. calories) and its movement into, out of and within (e.g. across levels) food webs. The rate of secondary production which can be derived from annual production-to-biomass ratios
psu	Practical salinity unit
Region (geomorphic)	Spatial units, based on geomorphology, that divide the Coorong estuary. For the Coorong, moving from North to South, these are: the Murray Mouth and Estuary, North Lagoon and South Lagoon regions
Ruppia community	The multi species assemblage that has become established across the southern Coorong and includes *Ruppia tuberosa*, *Althenia cylindrocarpa* along with an as yet unresolved species of *Ruppia*.
Scat	Animal faeces
Shorebirds	A group of birds that forage on intertidal areas and/or the margins of wetlands, and typically they do not swim. Australia is home to non-migratory shorebirds which remain in Australia year-round, and also provides habitat for migratory shorebirds of

	the East Asian–Australasian Flyway, which inhabit the northern hemisphere in the austral winter and migrate to the southern hemisphere for the austral summer
Spatial	Refers to the dimension of space or area
SMG	Small-mesh gillnet
Spline point	Number of curve points selected when fitting a primary production forcing function to environmental time-series
SS	Sum of squares
Stable isotopes	Components of elements (e.g. carbon) that are not susceptible to radioactive decay, thus they are classified as stable
Subtidal	A spatial zone that describes an area of habitat that is always underwater, i.e. below the low water mark
T&I	Trials and Investigations
Taxa	Plural version of taxon. Group of organisms that are similar in structure and function, and characterised by common ancestors
Teleosts	The largest infraclass in the class Actinopterygii (ray-finned fishes) that make up 96% of all extant species of fish
Temporal	Refers to the dimension of time
Trophic	Feeding and nutrition of plants and animals and where they fit into niches and levels of the food web
Waterbirds	A group of birds that are aquatic, i.e. live around the water. This group includes shorebirds
Waterfowl	A group of waterbirds that are exclusively members of the Family Anatidae; they primarily feed on the leaves, flowers, and seeds of aquatic vegetation, and typically have webbed feet and a flattened bill for crushing their plant- or algae-based foods
Zooplankton	Animals (often microscopic) that either move by water currents or are weak swimmers in the water column and can spend partial or complete lives in the plankton
Zooplanktivore	A consumer that feeds predominantly on zooplankton
Zoobenthivore	A consumer that feeds predominantly on benthic invertebrates

References

Albouy C, Mouillot D, Rocklin D, Culioli JM and Le Loc'h F (2010). Simulation of the combined effects of artisanal and recreational fisheries on a Mediterranean MPA ecosystem using a trophic model. *Marine Ecology Progress Series*, 412: 207-221.

Allen KR (1971). Relation between production and biomass. *Journal of the Fisheries Board of Canada* 28: 1573-1581.

Atkins B (1984). Feeding ecology of *Nematolosa erebi* in the lower River Murray. BSc Honours Thesis (University of Adelaide, Adelaide).

Asanopoulos C, and Waycott M (2020). The growth of aquatic macrophytes (*Ruppia tuberosa spp. and Althenia cylindrocarpa*) and the filamentous algal community in the southern Coorong. Goyder Institute for Water Research Technical Report Series No. 20/13.

Balcombe SR, Bunn SE, McKenzie-Smith FJ and Davies PM (2005). Variability of fish diets between dry and flood periods in an arid zone floodplain river. *Journal of Fish Biology* 67: 1552-1567.

Balcombe SR, Lobegeiger JS, Marshall SM, Marshall JC, Ly D and Jones DN (2012). Fish body condition and recruitment success reflect antecedent flows in an Australian dryland river. *Fisheries Science* 78: 841-847.

Baring RJ, Lester RE and Fairweather PG (2018). Trophic relationships among animals associated with drifting wrack. *Marine and Freshwater Research* 69: 1248-1258 https://doi.org/10.1071/MF17274.

Becker A and Laurenson LJB (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. https://doi.org/10.1071/MF06135.

Beesley PL, Ross GJB and Glasby CJ (2000). *Polychaetes and allies: the southern synthesis*. Fauna of Australia. Volume 4 (Parts A and B). CSIRO Publishing: Melbourne.

Bice CM, Furst D, Lamontagne S, Oliver RL, Zampatti BP and Revill A (2016a). *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 CM, Zampatti BP and Mallen-Cooper M (2017). Paired hydraulically distinct vertical-slot fishways provide complementary fish passage at an estuarine barrier. *Ecological Engineering* 98: 246-256.

Bice CM, Wedderburn SD, Hammer MP, Ye Q and Zampatti BP (2018). *Fishes of the Lower Lakes and Coorong: A summary of life-history, population dynamics and management*. In: Natural History of the Coorong, Lower Lakes and Murray Mouth (eds L. Mosley, Q. Ye, S. Shepherd, S. Hemming , R. Fitzpatrick), pp. 371-399, Royal Society of South Australia, Adelaide.

Baeta A, Niquil N, Marques JC and Patricio J (2011). Modelling the effects of eutrophication, mitigation measures and an extreme flood event on estuarine benthic food webs. Ecological Modelling 222: 1209-1221.

Bamford M, Watkins D, Bancroft W, Tischler G and Wahl J (2008). Migratory shorebirds of the East Asian-Australasian Flyway: population estimates and important sites. Wetlands International – Oceania, Canberra.

Baring RJ, Lester RE and Fairweather PG (2018). Trophic relationships among animals associated with drifting wrack. *Marine and Freshwater Research* 69: 1248-1258. https://doi.org/10.1071/MF17274.

Briggs SV, Maher MT and Palmer RP (1985). Bias in food habits of Australian waterfowl. *Australian Wildlife Research* 12: 507-514. https://doi.org/10.1071/WR9850507.

Bundy A (2001). Fishing on ecosystems: the interplay of fishing and predation in Newfoundland-Labrador. *Canadian Journal of Fisheries and Aquatic Sciences* 58, 6, 1153-1167.

Carseldine L and Tibbetts IR (2005). Dietary analysis of the herbivorous hemiramphid *Hyporhamphus regularis ardelio*: an isotopic approach. *Journal of Fish Biology* 66: 1589-1600.

Chapman F (1963). The pelican in South Australia with special reference to the Coorong Islands. *The South Australian Ornithologist*, 24: 6-14.

Chapman A, Morgan DL, Beatty SJ, Gill HS (2006). Variation in life history of land-locked lacustrine and riverine populations of *Galaxias maculatus* (Jenyns 1842) in Western Australia. *Environmental Biology of Fishes* 77: 21-37.

Christensen V, and Pauly D (1992). *ECOPATH* II – a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling* 61: 169-185.

Christensen V, and Walters CJ (2004). *Ecopath* with *Ecosim*: methods, capabilities and limitations. *Ecological Modelling* 172: 109-139. https://doi.org/10.1016/j.ecolmodel.2003.09.003.

Christensen V, Walters CJ, Pauly D, Forrest R (2008) *Ecopath* with *Ecosim* version 6 User Guide, November 2008. Lenfest Ocean Futures Project 2008.

Clemens R, Rogers DI, Hansen BD, Gosbell K, Minton CDT, Straw P, Bamford M, Woehler EJ, Milton DA, Weston MA, Venables B, Wellet D, Hassell C, Rutherford B, Onton K, Herrod A, Studds CE, Choi C-Y, Dhanjal-Adams KL, Murray NJ, Skilleter GA and Fuller RA (2016). Continental-scale decreases in shorebird populations in Australia. *Emu - Austral Ornithology* 116(2): 119-135. 10.1071/MU15056.

Clemens R, Driessen J and Ehmke G (2019). Australian bird index phase 2 – Developing waterbird indices for national reporting. Unpublished report for the Department of the Environment. BirdLife Australia, Melbourne.

Crawford CM (1984). An ecological study of Tasmanian flounder. PhD Thesis, University of Tasmania, Hobart.

Cruz-Escalona VH, Arreguin-Sanchez F and Zetina-Rejon M (2007). Analysis of the ecosystem structure of Laguna Alvarado, western Gulf of Mexico, by means of a mass balance model. Estuarine, Coastal and Shelf Science 72: 155-167.

Coll M, Palomera I and Tudela S (2009). Decadal changes in a NW Mediterranean Sea food web in relation to fishing exploitation. Ecological Modelling 220: 2088-2102.

Conover MR and Caudell JN (2009). Energy budgets for eared grebes on the great Salt Lake and implications for harvest of brine shrimp. *The Journal of Wildlife Management* 73(7): 1134-1139.

Cottingham A, Hall NG, Hesp SA and Potter IC (2018). Differential changes in production measures for an estuarine-resident sparid in deep and shallow waters following increases in hypoxia. *Estuarine, Coastal and Shelf Science* 202: 155-163. https://doi.org/10.1016/j.ecss.2017.12.014.

Currie DR and Sorokin SJ (2010). A preliminary evaluation of the distribution and trophodynamics of demersal fish from Spencer Gulf. Report to the South Australian Department for the Environment and Heritage. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000088-1. SARDI Research Report Series No. 424. 179 pp.

Daly K (2007). The diet and guild structure of the small pelagic fish community in the eastern Great Australian Bight, South Australia. Honours Thesis. Adelaide University. 42 pp.

Dann P (1999). Foraging behaviour and diets of red-necked stints and curlew sandpipers in south-eastern Australia. *Wildlife Research* 27: 61-68. https://doi.org/10.1071/WR98050.

Davies BR, 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 (6), 613-620.

Deegan BM, Lamontagne S, Aldridge KT and Brookes JD (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, Canberra.

Delroy LB (1974). The food of waterfowl (Anatidae) in the southern Coorong saltwater habitat of South Australia. *South Australian Ornithologist* 26: 157-163.

Debus SJS (2008). Biology and diet of the white-bellied sea-eagle *Haliaeetus leucogaster* breeding in northern inland New South Wales. *Australian Field Ornithology*. 25: 165–193.

DEW (2021a). State of the Southern Coorong – Discussion paper building a shared understanding of current scientific knowledge, June 2021. https://cdn.environment.sa.gov.au/environment/docs/Southern-Coorong-desired-state-discussion-paper-June-2021.pdf

DEW (2021b). Ecological Investigations Findings report – Phase 2, CIIP DEW Technical report 2020/21, Government of South Australia, Department for Environment and Water, Adelaide

Dittmann S, Rolston AN, Benger SN and Kupriyanova EK (2009). *Habitat requirements, distribution and colonisation of the tubeworm Ficopomatus enigmaticus in the Lower Lakes and Coorong*. Report to the South Australian Murray-Darling Basin Natural Resources Management Board (Adelaide).

Dittmann S, Baring R, Baggalley S, Cantin A, Earl J, Gannon R, Keuning J, Mayo A, Navong N, Nelson M, Noble W and Ramsdale T (2015). Drought and flood effects on macrobenthic communities in the estuary of Australia's largest river system. *Estuarine, Coastal and Shelf Science* 165: 36-51. https://doi.org/10.1016/j.ecss.2015.08.023.

Dittmann S, Rolston A and Baring R (2018). *Estuarine and lagoon macro-invertebrates: Patterns and processes.* In: Natural History of the Coorong, Lower Lakes and Murray Mouth (eds. L. Mosley, Q. Ye, S.A Shepherd, S. Hemming, R. Fitzpatrick), pp. 332-348, Royal Society of South Australia, Adelaide.

Dittmann S, Ye Q, Furst D, Newbery A, Nitschke J, Bucater L, Pyke W, Kent J, Schroder L, Henkens J, Baring R, Lam-Gordillo O, Brookes J and Short D (2022). Food resource availability, energy content and nutritional value of major food sources for key fish and waterbird species under varying environmental conditions in the Coorong. Goyder Institute for Water Research Technical Report Series No. 22/xx

Dostine P and Morton S (1989). Feeding ecology of the whiskered tern, *Chlidonias-Hybrida*, in the Alligator Rivers region, Northern-Territory. *Wildlife Research* 16(5): 549-562.

Earl J (2014). Population biology and ecology of the greenback flounder (*Rhombosolea tapirina*) in the Coorong estuary, South Australia. PhD Thesis (Flinders University, Adelaide).

Earl J (2015). Fishery statistics for the South Australian Lakes and Coorong Fishery (1984/85 – 2013/14). Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000669-6. SARDI Research Report Series No. 831. 18pp.

Earl J (2020). *Assessment of the South Australian Lakes and Coorong Fishery in 2018/19*. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2020/000208-01. SARDI Research Report Series No. 1059. 81pp.

Earl J and Ferguson GJ (2013). Yelloweye mullet (*Aldrichetta forsterii*) Stock Assessment Fishery Stock Assessment for PIRSA Fisheries and Aquaculture. Research Report Series No 737. Report No. F2013/001048- 1 (SARDI Aquatic Sciences, West Beach).

Earl J, Fowler AJ and Dittmann S (2011). Temporal variation in feeding behaviour and trophic ecology of the temperate hemiramphid, *Hyporhamphus melanochir*. *Environmental Biology of Fishes* 90: 71-83. https://doi.org/10.1007/s10641-010-9719-5.

Earl J, Ward T M and Ye Q (2016). Black Bream *(Acanthopagrus butcheri)* Stock Assessment Report 2014/15. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2008/000810-2. SARDI Research Report Series No. 885.

Eckert, J. (1971). Birds of the Franklin Islands and Eyre Island, South Australia. *Emu* 71: 61–64.

Edgar, G. J. 1990. The use of the size structure of benthic macrofaunal communities to estimate faunal biomass and secondary production. *Journal of Experimental Marine Biology and Ecology* 137:195-214.

Ellis H. and Gabrielsen GW (2002). Energetics of free-ranging seabirds. In: Schreiber BA and Burger J (Eds). Biology of Marine Birds. CRC Press, Boca Raton, Florida, USA, pp. 359-407.

Fenton GE (1986). *Ecology and taxonomy of Mysids* (Mysidacea: Crustacea). PhD thesis. University of Tasmania.

Ferguson GJ (2010). Gear interaction of non-targeted species in the Lakes and Coorong commercial and recreational fisheries of South Australia. Final report to FRDC for Project No. 2005/061. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010-000239-1, SARDI Research Report Series No. 436. 56 pp.

Ferguson GJ and Ward TM (2011). *Mulloway (Argyrosomus japonicus) Fishery*. Fishery Stock Assessment Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000898-2. SARDI Research Report Series No. 573. 104pp.

Fjeldså J (1988). *Comparative ecology of the Australasian grebes (Aves: Podicipedidae).* Royal Australiasian Ornithologists Union. Report 54. pp. 30.

Froese R, and Binohlan C (2000). Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *Journal of Fish Biology* 56:758-773.

Froese R and Pauly D (2021). FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2021).

Fulton EA and Smith DM (2004). Lessons learnt from a comparison of three ecosystem models for Port Phillip Bay, Australia. African Journal of Marine Science 26: 219-243.

Fulton EA, Goldsworthy SD, Bulman CM, Pethybridge, HR and Rogers, P. (2017). *Knowledge integration of socio-ecological systems of the Great Australian Bight: Ecosystem Modelling. Final Modelling Report GABRP Project 7.1.* Great Australian Bight Research Program, GABRP Research Report Series Number 29, 184ppGeddes MC (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 MC and Butler AJ (1984). Physiochemical and biological studies on the Coorong Lagoons, South Australia, and the effects of salinity on the distribution of the macrobenthos. *Transactions of the Royal Society of South Australia* 108: 51-62.

Geddes MC and Francis J (2008). *Trophic ecology pilot study in the River Murray estuary at Pelican Point*. SARDI Research Report Series No. 274. SARDI Publication No. F2007/001193-1 (SARDI Aquatic Sciences, Adelaide).

Geers T, Pikitch E and Frisk M (2016). An original model of the northern Gulf of Mexico using *Ecopath* with Ecosim and its implications for the effects of fishing on ecosystem structure and maturity. *Deep Sea Research Part II: Topical Studies in Oceanography*, 129: 319-331.

Giatas G (2012). *Diet of the yelloweye mullet (*Aldrichetta forsteri*) in the River Murray estuary and Coorong Lagoon, South Australia*. BSc Honours Thesis (Flinders University, Adelaide).

Giatas GC, 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*. SARDI Research Report Series No. 858. SARDI Publication No. F2015/000479-1 (SARDI Aquatic Sciences, Adelaide).

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

Giatas G, Lamontagne S, Bice C, Ye Q and Paton D (2018). *Food webs of the Coorong*. In: Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe) (eds L. Mosley, Q. Ye, S. Shepherd, S. Hemming, R. Fitzpatrick), pp. 422-441, Royal Society of South Australia, Adelaide.

Giatas G, Catalano S, Dittmann S, Ye Q, Jackson M, Mott R and Markos K (2022). *Primary food resources for key waterbird and benthic fish in the Coorong.* Goyder Institute for Water Research Technical Report Series No. 22/02.

Gibbs M, Joehnk K, Webster I and Heneker T (2018). *Hydrology and hydrodynamics of the Lower Lakes, Coorong and Murray Mouth*. In: Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe) (eds L. Mosley, Q. Ye, S. Shepherd, S. Hemming, R. Fitzpatrick), pp. 197-216, Royal Society of South Australia, Adelaide.

Giere O (2006). Ecology and biology of marine oligochaeta – an inventory rather than another review. *Hydrobiologia* 564: 103-116. https://doi.org/10.1007/s10750-005-1712-1.

Gill HS, Wise BS, Potter IC and Chaplin JA (1996). Biannual spawning periods and resultant divergent patterns of growth in the estuarine goby *Pseudogobius olorum*: temperature-induuced? *Marine Biology* 125: 453-466.

Gillanders BM, Elsdon TS and Gannon R (2008). A marine habitat and biodiversity inventory for AMLR region: chlorophyll *a* and fish. Report to the South Australian Department of Environment and Heritage. University of Adelaide.

Giri K and Hall K (2015). *South Australian Recreational Fishing Survey 2013/14*. Fisheries Victoria, Internal Report Series No. 62. 66pp.

Goldsworthy SD and Page B (2007). A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries. Biological Conservation 139: 269-285.

Goldsworthy SD, Bulman C, He X, Larcombe J and Littnan C (2003) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In: Gales N, Hindell M, Kirkwood R (eds) Marine Mammals and Humans: Fisheries, tourism and management. CSIRO Publishing, Melbourne.

Goldsworthy SD, Page B, Rogers PJ, Bulman C, Wiebkin A, McLeay LJ, Einoder L, Alastair MM, Baylis AMM, Braley M, Caines R, Daly K, Huveneers C, Peters K, Lowther AD and Ward TM (2013). Trophodynamics of the eastern Great Australian Bight ecosystem: ecological change associated with the growth of Australia's largest fishery. *Ecological Modelling* 255: 38-57.

Goldsworthy SD, Bailleul F, Shaughnessy PD, Stonnill M, Lashmar K and Mackay AI (2017a). *Monitoring of Seal Bay and other pinniped populations on Kangaroo Island: 2016/2017.* Report to the Department of Environment, Water and Natural Resources. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000322-4. SARDI Research Report Series No. 951. 40pp.

Goldsworthy SD, Loo M, Fowler A, Steer M and Noell C (2017b). *A trophic model for Gulf St Vincent: Balancing exploitation of three fisheries in an EBFM framework.* Final report to the Fisheries Research and Development Corporation, Project 2013/031, 104 pp.

Goldsworthy SD, Bailleul F, Nursey-Bray M, Mackay I, Oxley A, Reinhold S-L and Shaughnessy PD (2019) *Assessment of the impacts of seal populations on the seafood industry in South Australia, Adelaide, February.* Final report to Fisheries Research and Development Corporation, Project 2013/011. 315pp

Gomon M, Bray D and Kuiter R (2008) *Fishes of Australia's Southern Coast*. Museum Victoria. New Holland Publishers Pty Ltd, Sydney.

Gooderham J and Tsyrlin E (2003). *The Waterbug Book: a guide to the freshwater macroinvertebrates of temperate Australia*. CSIRO Publishing, Collingwood.

Griffiths SP, Young JW, Lansdell MJ, Campbell RA, Hamption J, Hoyle SD, Langley A, Bromhead D and Hinton MG (2010). Ecological effects of longline fishing and climate change on the pelagic ecosystem off eastern Australia. Reviews in Fish Biology and Fisheries 20: 239-272.

Guenette S, Christensen V and Pauly D (2008). Trophic modelling of the Peruvian upwelling ecosystem: Towards reconciliation of multiple datasets. Progress in Oceanography 79: 326-335.

Guillemain M, Fritz H, Guillon N and Simon G (2002). Ecomorphology and coexistence in dabbling ducks: the role of lamellar density and body length in winter. *Oikos*, 98(3): 547-551.

Hall DA (1981). *The feeding ecology of the European carp (Cyprinus carpio L.) in Lake Alexandrina and the lower River Murray, South Australia*. BSc Honours Thesis (University of Adelaide, Adelaide).

Hansen BD, Minton CD, Jessop R and Collins P (2009). Biometrics, sexing criteria, age-structure and moult of Sooty Oystercatchers in south-eastern and north-western Australia. *Emu-Austral Ornithology*, 109(1): 25-33.

Harrison S (2009). Interactions between Silver Gulls (*Larus novaehollandiae*) and Southern Bluefin Tuna (*Thunnus maccoyii*) aquaculture in the Port Lincoln area. PhD. Flinders University. 311 pp.

Harvey CJ, Williams GD and Levin PS (2012). Food web structure and trophic control in central Puget Sound. *Estuaries and Coasts*, 35(3): 821-838.

Hemming S (2018). *Ngarrindjeri Nation Yarluwar-Ruwe Plan: Caring for Ngarrindjeri Country and Culture* In: History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe) (eds L. Mosley, Q. Ye, S. Shepherd, S. Hemming, R. Fitzpatrick), pp. 3-20, Royal Society of South Australia, Adelaide.

Higgins PJ and Davies SJJF (1996). *Handbook of Australian, New Zealand and Antarctic birds*. Vol. 3 Snipes to Pigeons., Melbourne.

Hossain A, Aktar S and Qin JG (2016) Salinity stress response in estuarine fishes from the Murray Estuary and Coorong, South Australia. *Fish Physiology and Biochemistry* 42: 1571-1580.

Hossain A, Hemraj DA, Ye Q and Leterme SC (2017). Diet overlap and resource partitioning among three forage fish species in Coorong, the largest inverse estuary in Australia. *Environmental Biology of Fishes* 100: 639-654. https://doi.org/10.1007/s10641-017-0592-3.

Humphries P, Hyndes GA and Potter IC (1992). Comparisons between the diets of distant taxa (teleost and cormorant) in an Australian Estuary. *Estuaries* 15: 327-334. https://doi.org/10.2307/1352780.

Hughes JM, Stewart J, Lyle JM and Suthers IM (2014). Top-down pressure on small pelagic fish by eastern Australian salmon *Arripis trutta*; estimation of daily ration and annual prey consumption using multiple techniques. *Journal of Experimental Marine Biology and Ecology* 459, 190-198.

James KF, Bourman RP, Harvey N (2015). Rapid evolution of a flood tidal deltaic island in the River Murray Estuary, South Australia: A canary in the cage of river management. *Journal of Coastal Research* 31 (5), 1103-1119.

Jones GK (1990). Growth and mortality in a lightly fished population of garfish (*Hyporhamphus melanochir*), in Baird Bay, South Australia. Trans. Royal Soc. S. Aust. 114(1):37-45.

Karpouzi VS, Watson R and Pauly D (2007). Modelling and mapping resource overlap between seabirds and fisheries on a global scale: a preliminary assessment. *Marine Ecology Progress Series*, 343: 87-99.

King AJ (2005). Ontogenetic dietary shifts of fishes in an Australian floodplain river. *Marine and Freshwater Research* 56: 215-225. https://doi.org/10.1071/MF04117.

Kirkwood R and Goldsworthy SD (2013). Fur seals and Sea Lions. CSIRO Publishing, Collingwood, Victoria.

Knight M and Tsolos A (2009) South Australian wild fisheries information and statistics report. SARDI Aquatic Sciences Publication No F2008/000804-1. SARDI Research Report Series No. 305.

Knuckey I, Sen S, Ward TM, Koopman M, Earl J, McPhail J, MacDonald N and Fistr A (2015). *Developing management frameworks and harvest strategies for small-scale, multi-species, multi-method, community-based fisheries, using the South Australian Lakes and Coorong Fishery as a case study*. FRDC Project 2013/225. Fishwell Consulting.

Koehn LE, Essington TE, Marshall KN, Kaplan IC, Sydeman WJ, Szoboszlai AI and Thayer JA (2016). Developing a high taxonomic resolution food web model to assess the functional role of forage fish in the California Current ecosystem. *Ecological Modelling*, 335: 87-100.

Kraaijeveld-Smit F, Minton C, Jessop R and Collins P (2001). Sexing criteria, age structure, biometrics, and moult of the Pied Oystercatcher, *Haematopus longirostris* in Victoria. *The Stilt*, 40: 29-37.

Lamontagne S, Geddes MC, 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.

Lamontagne S, Deegan BM, Aldridge KT, Brookes JD and Geddes MC (2016). Fish diets in a freshwater-deprived semiarid estuary (The Coorong, Australia) as inferred by stable isotope analysis. *Estuarine Coastal and Shelf Science* 178: 1-11. https://doi.org/10.1016/j.ecss.2016.05.016.

Lamprell K and Whitehead T (1992). *Bivalves of Australia*, Vol. 1, Crawford House Press, Bathurst, NSW.

LaSalle MW and Bishop DT (1990). Food habits of two larval files (Dolichopodidae: diptera) in two Gulf coast oligohaline tidal marshes. *Estuaries* 13: 341-348.

Lauro B and Nol E (1995). Feeding behavior, prey selection, and bill size of Pied and Sooty Oystercatchers in Australia. *The Wilson Bulletin*: 629-640.

Leterme SC, Oliver R, Shiel R, Hemraj D, Geddes M, Furst D, Aldridge K, Barnes T and Wedderburn SO (2018). *Plankton communities of the Coorong, Lower Lakes and Murray Mouth.* In: Natural History of the Coorong, Lower Lakes and Murray Mouth (eds. L. Mosley, Q. Ye, SA Shepherd, S Hemming, R Fitzpatrick), pp. 273-291, Royal Society of South Australia, Adelaide.

Li Y, Chen Y, Olson D, Yu N, Chen L (2009). Evaluating ecosystem structure and functioning of the East China Sea Shelf ecosystem, China. *Hydrobiologia*, 636, 331-351.

Lindsay MCM and Meathrel CE (2008). Where, when and how? Limitations of the techniques used to examine dietary preference of pacific gulls (*Larus pacificus*) using non-consumed parts of prey and regurgitated pellets of prey remains. *Waterbirds*, 31: 611-619.

Ling JK (1999). Exploitation of fur seals and sea lions from Australian, New Zealand and adjacent subantarctic islands during the eighteenth, nineteenth and twentieth centuries. *Australian Zoologist*, 31: 323-350.

Lloyd M (2010). Spatial variation in growth of snapper (*Chrysophrys auratus*) in South Australia gulf waters: An investigation of diet as a contributing factor. Honours Thesis. The University of Adelaide. 66 pp.

Lui LC (1969). Salinity tolerance and osmoregulation in *Tanomembrus microstomus* (Gunther, 1861 (Pisces: Mugiliformes: Atherinidae from Australian salt lakes. *Marine and Freshwater Research* 20: 157-162.

McNally J (1957). The feeding habits of cormorants in Victoria. Victorian Fish Game Dep. Fauna Contrib. No. 6.

McDowell RM (1980) *Freshwater fishes of South-eastern Australia* (AH & AW Reed Pty Ltd, Sydney).

McGlennon D, Jones GK, Baker J, Jackson WB and Kinloch MA (2000). Ageing, catch-at-age and relative year-class strength for snapper (*Pagrus auratus*) in northern Spencer Gulf, South Australia. Marine and Freshwater Research 51: 669-677.

Marchant S and Higgins PJ (1990a). *Handbook of Australian, New Zealand and Antarctic Birds*. Vol 1 Ratites to Ducks. Part B. Australian Pelican to Ducks, Melbourne

Marchant S and Higgins PJ (1990b). *Handbook of Australian, New Zealand and Antarctic Birds*. Vol. 1 Ratites to Ducks. Part A. Ratites to Petrels, Melbourne

Marchant S and Higgins PJ (1993). *Handbook of Australian, New Zealand and Antarctic Birds*. Vol. 2 Raptors to Lapwings, Vol. Oxford University Press, Melbourne

Matthews TG and Fairweather PG (2003). Grow rates of the infaunal bivalve *Soletellina alba* (Lamarck, 1818) (Bivalvia: Psammobiidae) in an intermittent estuary of southern Australia. *Estuarine Coastal and Shelf Science* 58: 873-885. https://doi.org/10.1016/j.ecss.2003.07.003.

Maurer BA (1998). The evolution of body size in birds. II. The role of reproductive power. Evolutionary Ecology, 12(8): 935-944.

McLeay LJ, Page B., Goldsworthy S, Ward T and Paton D (2009). Size matters: variation in the diet of chick and adult crested terns. *Marine Biology*, 156(9): 1765-1780.

McNab BK (2009). Ecological factors affect the level and scaling of avian BMR. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 152(1): 22-45.

McNeill DG, Westergaard S, Cheshire KJM, Noell CJ 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 (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-4. SARDI Research Report Series No. 700. 26pp.

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

Meakin CA and Qin JG (2020). Evaluation of food competition and resource partitioning of recruiting fish with permanent residents in a seagrass habitat. *New Zealand Journal of Marine and Freshwater Research* 54: 149–166.

Morton RM, Pollock BR and Beumer JP (1987). The occurrence and diet of fished in a tidal inlet to a saltmarsh in southern Moreton Bay, Queensland. *Australian Journal of Ecology* 12: 217-237. https://doi.org/10.1111/j.1442-9993.1987.tb00945.x.

Moreau J, Mavuti K and Daufresne T (2001). A synoptic *Ecopath* model of biomass flows during two different static ecological situations in Lake Nakuru (Kenya). *Hydrobiologia*, 458(1): 63-74.

Mosley LM, Priestley S, Brookes J, Dittmann S, Farkaš J, Farrell M, Ferguson AJ, Gibbs M, Hipsey M, Huang J, Lam-Gordillo O, Simpson SL, Teasdale PR, Tyler JJ, Waycott M, Welsh DT (2020). *Coorong water quality synthesis with a focus on the drivers of eutrophication*. Goyder Institute for Water Research Technical Report Series No. 20/10.

Mullen GR and Hribar LJ (1988). Biology and feeding behaviour of ceratopogonid larvae (diptera: Ceratopogonidae) in North America. *Bull. Soc. Vector Ecol.* 13: 60-81.

Murawski S and Serchuk FM (1982). *Atlantic surf clam, Spisula solidissima*. In: Fish Distribution MESA New York Bight Atlas. Eds. MD, Grosslein, TR, Azarovitz. New York Sea Grant Institute, Albany.

Nagy KA, Girard IA and Brown TK (1999). Energetics of free-ranging mammals, reptiles, and birds. *Annual review of nutrition*, 19(1): 247-277.

Noell CJ, Ye Q, Short DA, Bucater LB and Wellman NR (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.

Norris JV, Tregonning JE, Lenanton RCJ and Sarre G (2002). *Biological synopsis of the black bream,* Acanthopagrus butcheri *(Munro) (Teleostei: Sparidae) in Western Australia with reference to information from other southern states*. Department of Fisheries Western Australia, Fisheries Research Division, Fisheries Research Report No. 93.

O'Connor JA, Rogers DJ and Pisanu P (2013). Modelling waterbird responses to ecological conditions in the Coorong, Lower lakes, and Murray Mouth Ramsar site. South Australian Department of Environment, Water and Natural Resources, Adelaide.

O'Donnell CFJ (1982). Food and feeding behaviour of the southern crested grebe on the Ashburton Lakes. *Notornis* 29: 151–156.

O'Gorman E (2016). The pelican slaughter of 1911: a history of competing values, killing and private property from the Coorong, South Australia. *Geographical Research*, 54(3): 285-300.

Oliver R, Lorenz Z and Mosley L (2015) *Utilizing the Coorong, Lower Lakes and Murray Mouth Water Quality and Microalgae monitoring data to evaluate indicators for the Ecological Character Description*. CSIRO Land and Water Flagship, Australia.

Olsen J, Fuentes E and Rose AB (2006). Trophic relationships between neighbouring white-bellied sea-eagles (*Haliaeetus leucogaster*) and wedge-tailed eagles (*Aquila audax*) breeding on rivers and dams near Canberra. *Emu-Austral Ornithology*, 106: 193-201.

Olsen J, Osgood M, Maconachie M, Dabb G and Butterfield M (2010). Little Eagles, Whistling Kites and Swamp Harriers in the Australian Capital Territory in 2009. *Canberra Bird Notes*, 35: 81-84.

Olsen J, Debus SJ, Rose A and Judge D (2013). Diets of white-bellied sea-eagles *Haliaeetus leucogaster* and whistling kites *Haliastur sphenurus* breeding near Canberra, 2003–2008. *Corella*, 37: 13-18.

Ortiz O, Avendo M, Cantillanez M, Berrios F and Campos L (2010). Trophic mass balanced models and dynamic simulations of benthic communities from La Rinconada Marine Reserve off northern Chile: network properties and multispecies harvest scenario assessments. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20: 58-73.

Page B, Goldsworthy SD, McLeay L, Wiebkin A, Peters K, Einoder L, Rogers P, Braley M, Gibbs S, McKenzie J, Huveneers C, Caines R, Daly K, Harrison S, Baylis A, Morrice M, Gill P, McIntosh R, Bool N and Ward T (2011). The diets of the marine predators in southern Australia: assessing the need for ecosystem-based management of the South Australian sardine fishery. In: Goldsworthy SD, Page B, Rogers P and Ward T (Eds). Establishing ecosystem-based management for the South Australian Sardine Fishery: developing ecological performance indicators and reference points to assess the need for ecological allocations. Final Report to the Fisheries Research and Development Corporation. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000863-1. SARDI Research Report Series No. 529. 173pp.

Paton DC (2010). *At the End of the River: The Coorong and Lower Lakes* (ATF Press, Adelaide).

Paton DC, Rogers DJ, Hill BM, Bailey CP and Ziembicki M (2009). Temporal changes to spatially stratified waterbird communities of the Coorong, South Australia: implications for the management of heterogenous wetlands. *Animal Conservation* 12: 408-417. https://doi.org/10.1111/j.1469-1795.2009.00264.x.

Paton P (1982). Biota of the Coorong. A study for the Cardwell Buckingham Committee. South Australian Department of Environment and Planning, S.A.D.E.P. 55.

Paton DC, Paton FL and Bailey CP (2020). Condition monitoring of the Lower Lakes, Murray Mouth and Coorong Icon Site: Waterbirds in the Coorong and Lower Lakes 2019. The University of Adelaide and The Department for Environment and Water, Adelaide.

Patricio J and Marques JC (2006). Mass balanced models of the food web in three areas along a gradient of eutrophication symptoms in the south arm of the Mondego estuary (Portugal). *Ecological Modelling* 197, 21-34.

Pauly D (1980). On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil International pour l'Exploration de la Mer*, 39 (2): 175-192.

Pauly D, Christensen V and Walters C (2000). *Ecopath*, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* 57, 697-706.

Pedler RD, Ribot RFH and Bennett ATD (2018). Long-distance flights and high-risk breeding by nomadic waterbirds on desert salt lakes. *Conservation Biology*, 32(1): 216-228.

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.

Piroddi C, Bearzi G, and Christensen V (2010). Effects of local fisheries and ocean productivity on the northeastern Ionian Sea ecosystem. *Ecological Modelling* 221: 1526-1544.

Platell ME, Orr PA and Potter IC (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. https://doi.org/10.1111/j.1095-8649.2006.01098.x.

Ponder WF, Colgan DJ and Clark GA (1991). The morphology, taxonomy and genetic structure of Tatea (Mollusca: Gastropoda: Hydrobiidae), estuarine snails from temperate Australia. *Australian Journal of Zoology* 39: 447-97.

Poore GCB (2004). *Marine decapod Crustacea: a guide to identification*. CSIRO Publishing, Collingwood.

Polovina JJ (1984). The *Ecopath* model and its application to French frigate shoals. *Coral Reefs* 3: 1-11.

Pranovi F, Libralato S, Raicevich S, Granzotto A, Pastres R, Giovanardi O (2003). Mechanical clam dredging in Venice lagoon: ecosystem effects evaluated with a trophic mass-balance model. *Marine Biology* 143: 393-403.

Prowse TAA (2020) *Review of the ecology, status and modelling of waterbird populations of the Coorong South Lagoon*. Goyder Institute for Water Research Technical Report Series No. 20/12.

Prowse T, Delean S, Mott R, Jackson M, Hunt B, Brookes J and Cassey P (2021) *Response models for key waterbird species of the Coorong*. Goyder Institute for Water Research Technical Report Series No. 21/xx.

Puckridge JT and Walker KF (1990). Reproductive Biology and Larval Development of a Gizzard Shad, *Nematalosa erebi* (Giinther) (Dorosomatinae : Teleostei), in the River Murray, South Australia. *Marine and Freshwater Research* 41: 695-712.

Reid J (2009). Australian pelican: flexible responses to uncertainty. In: Robin L, Heinsohn R and Joseph L (Eds). Boom & Bust: Bird Stories for a Dry Country. CSIRO Publishing, Collingwood, VIC.

Riordan J and Johnston G (2013). Morphological sex determination in Black-faced Cormorants (*Phalacrocorax fuscescens*). *Waterbirds*, 36(1): 94-101.

Richardson AJ, Uribe-Palomino J, Slotwinski A, Coman F, Miskiewicz AG, Rothlisberg PC, Young JW and Suthers IM (2019). Coastal and marine zooplankton: identification, biology and ecology. In: Plankton*, A Guide to Their Ecology and Monitoring for Water Quality*, 2nd Edition, Eds. IM Suthers, D Rissik, AJ Richardson. CSIRO Publishing, CRC Press, Florida.

Roach AC and Lim RP (2000). Variation in the population dynamics of the intertidal pulmonated gastropod Salinator solida Martens (Gastropoda: Amphibolidae) at Towra Point, NSW, Australia. *Wetlands Ecology and Management* 8: 53-69. http://dx.doi.org/10.1023/A:1008420104621.

Robertson AI (1984). Trophic interactions between the fish fauna and macrobenthos of an eelgrass community in Western Port, Victoria. *Aquatic Botany* 18: 135-153. https://doi.org/10.1016/0304-3770(84)90084-6.

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

Rogers PJ, Geddes M, Ward TM (2003) Blue sprat *Spratelloides robustus* (Clupeidae: Dussumieriinae): a temperate clupeoid with a tropical life history strategy? *Marine Biology* 142: 809-824.

Rogers PJ, Huveneers C, Page B, Hamer DJ, Goldsworthy SD, Mitchell JG and Seuront L (2012). A quantitative comparison of the diets of sympatric pelagic sharks in gulf and shelf ecosystems off southern Australia. *ICES Journal of Marine Science* 69: 1382–1393.

Rothery P (2000). *Basic Concepts. In: Statistics in Ecotoxicology*. Ed. Sparks T. John Wiley and Sons, London 320pp.

Ryan DD (2018). *The Role of Climate in Shaping the Coorong, Lower Lakes and Murray Mouth* In: History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe) (eds L. Mosley, Q. Ye, S. Shepherd, S. Hemming, R. Fitzpatrick), pp. 167-196, Royal Society of South Australia, Adelaide.

Rysgaard S, Christensen PB, Nielsen LP (1995). Seasonal variation in nitrification and denitrification in estuarine sediment colonized by benthic microalgae and bioturbating infauna. *Marine Ecology Progress Series*. 126:111-21.

Schilling HT, Hughes JM, Smith JA, Everett JD, Stewart JS and Suthers IM (2017). Latitudinal and ontogenetic variation in the diet of a pelagic mesopredator (*Pomatomus saltatrix*), assessed with a classification tree analysis. *Marine Biology* 164: 75, DOI 10.1007/s00227-017-3105-1.

Shannon LJ, Neira S, and Taylor M (2008). Comparing internal and external drivers in the southern Benguela and the southern and northern Humboldt upwelling ecosystems. African Journal of Marine Science 30: 63-84.

Shaughnessy PD, Goldsworthy SD and Mackay AI (2014). Status and trends in abundance of New Zealand fur seal populations in South Australia. SARDI Publication No. F2014/000338-1. SARDI Research Report Series No. 781. 33pp.

Shaughnessy PD, Goldsworthy SD and Mackay AI (2015). The long-nosed fur seal in South Australia in 2013-14; abundance, status and trends. *Australian Journal of Zoology* 63: 101-110.

Shiel RJ and Aldridge KT (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*, Adelaide, Department of Environment and Natural Resources and the Department for Water.

Shiel RJ and Tan LW (2013). *Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth October 2011-April 2012*. Final report to Department of Environment, Water & Natural Resources. Adelaide.

Simpfendorfer CA , Goodreid A and McAuley RB (2001). Diet of three commercially important shark species from Western Australian waters. *Marine and Freshwater Research* 52: 975–985.

Silvester L, Dittmann S and Beyer K (unpublished). *Temporal and spatial variability in the population structure and diet of small-mouthed hardyhead* Atherinosoma microstoma *and Tamar goby* Afurcagobius tamarensis *after habitat reconnection in the Murray River Estuary, Australia*. (Flinders University: Adelaide).

Sinnickson D, Chagaris D and Allen M (2021) Exploring Impacts of River Discharge on Forage Fish and Predators Using *Ecopath* with *Ecosim*. *Frontiers in Marine Science* 8:689950. doi: 10.3389/fmars.2021.689950

Smith BB (2005) *The state of the art: a synpopsis of information on common carp (*Cyprinus carpio*) in Australia*. Final Technical Report, SARDI Aquatic Sciences Publication No. RDO4/0064-2; SARDI Research Report Series No. 77, prepared by the South Australian Research and Development Instititute (Aquatic Sciences), Adelaide. 68 pp.

Stocks JR, Scott KF and Gilligan DM (2019) Daily age determination and growth rates of freshwater fish throughout a regulated lotic system of the Murray-Darling Basin Australia. *Journal of Applied Ichthyology*, 35: 457-464.

Stockwell S (2019). The foraging ecology of Caspian Terns (*Hydroprogne caspia*) on Peel-Harvey Estuary, south-western Australia. Murdoch University.

Thomas DG and Dartnall AJ (1971). Ecological aspects of the feeding behaviour of two calidritine sandpipers wintering in south-eastern Tasmania. *Emu* 71: 20-26. https://doi.org/10.1071/MU971020.

Tibbets IR and Carseldine L (2005). Trophic shifts in three subtropical Australian halfbeaks (Teleostei: Hemiramphidae). *Marine and Freshwater Research* 56: 925-932. https://doi.org/10.1071/MF04305.

Tulp I and de Goeij P (1994). Evaluating wader habitats in Roebuck Bay (North-western Australia) as a springboard for northbound migration in waders, with a focus on Great Knots. *Emu* 94: 78-95. https://doi.org/10.1071/MU9940078.

Veale L, Coulson P, Hall N, Hesp A, Potter IC (2015) Age and size compositions, habitats, growth and reproductive characteristics of a terapontid (*Pelates octolineatus*) in coastal waters. *Marine and Freshwater Research* 66: 535-548.

Vestjens WJM (1977). *Status, habitats and food of vertebrates at Lake Cowal*, NSW, Canberra, Australia.

Walters C, Christensen V, Pauly D (1997) Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Reviews in Fish Biology and Fisheries* 7: 139-172. https://doi.org/10.1023/A:1018479526149.

Wedderburn SD, Bice CM and Barnes TC (2014). Prey selection and diet overlap of native golden perch and alien redfin perch under contrasting hydrological conditions. *Australian Journal of Zoology* 62: 374-381. https://doi.org/10.1071/ZO14018.

Wells FE and Threlfall TJ (1982). Reproductive strategies of *Hydrococcus brazieri* (Tenison Woods, 1876) and Arthritica semen (Menke, 1843) in Peel Inlet, Western Australia. *Journal of the Malacological Society of Australia* 5: 157-166. https://doi.org/10.1080/00852988.1982.10673947.

Weston MA, Ehmke GC and Maguire GS (2009). Manage one beach or two? Movements and space-use of the threatened hooded plover (*Thinornis rubricollis*) in south-eastern Australia. *Wildlife Research*, 36(4): 289-298.

White SA (1918). A visit to the breeding grounds of swan and pelican on the Coorong. *South Australian Ornothologist* 3: 198-200.

Ye Q, Bucater L, Short D, 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. 81pp.

Ye Q, Bucater L and Short D (2013). *Coorong fish condition monitoring 2008-2013: Black bream (Acanthopagrus butcheri), greenback flounder (Rhombosolea tapirina) and smallmouth 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. 99pp.

Ye Q, Bucater L and Short D (2017). *Coorong fish condition monitoring 2015/16: Black bream (Acanthopagrus butcheri), greenback flounder (Rhombosolea tapirina) and smallmouth hardyhead (Atherinosoma microstoma) populations*. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-5. SARDI Research Report Series No. 943. 89pp.

Ye Q, Dittmann S, Giatas G, Baring R, Nitschke J, Bucater L and Furst D (2019). The current state of food resources supporting waterbird and fish populations in the Coorong. Goyder Institute for Water Research Technical Report Series No. 19/33.

Ye Q, Giatas G, Dittmann S, Baring R, Bucater L, Deane D, Furst D, Brookes J, Rogers D and Goldsworthy S (2020a) *A synthesis of current knowledge of the food web and food resources for waterbird and fish populations in the Coorong*. Goyder Institute for Water Research Technical Report Series No. 20/11.

Ye Q, Bucater L, Short DA and Giatas GC (2020b). *Coorong fish condition monitoring 2008-2019: Black bream (Acanthopagrus butcheri), greenback flounder (Rhombosolea tapirina) and smallmouth hardyhead (Atherinosoma microstoma) populations*. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-7. SARDI Research Report Series No. 1066. 97pp.

Ye Q, Earl J, Bucater L, Cheshire KJM, McNeil D, Noell CJ and Short DA (2013). *Flow related fish and fisheries ecology in the Coorong, South Australia*. FRDC Project 2006/45 Final Report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Research Report Series No. 698, SARDI Publication No. F2009/000014-2.

Appendix A – Description of trophic groups, data sources, methods, and assumptions in parameter estimation

Marine mammals

Long-nosed fur seal

Abundance and biomass: Sealing was the first colonial industry in South Australia, with sealers arriving on Kangaroo Island within a year of its discovery by Nicolas Baudin and Matthew Flinders in 1802, with more than 100,000 skins (probably long-nosed fur seals, *Arctocephalus forsteri*) likely to have been taken from Kangaroo Island and other offshore islands by the 1830s, by which time populations had been so decimated that commercial sealing was no longer viable (based on a 0 to -0.2 m AHD foraging limit, Kirkwood and Goldsworthy 2013, Ling 1999). It's interesting to note that the earliest colonial accounts of fur seals in the Coorong come from this period when fur seal populations would have been at their historically lowest point. Fur seals were observed to frequent the lower parts of Lake Alexandrina, by Charles Sturt in 1830 on his exploration of the Murray River (Sturt 1834).

In South Australia, seal numbers remained very low over the next 150 years, due to continued harvests and incidental killing, until their protection in 1975 under the Commonwealth *National Parks and Wildlife Act (1975)* in Commonwealth waters and under various legislations in State waters. The main period of recovery in South Australia commenced in the early 1980s from about 5,600 in 1989-90, to 20,400 in 2013-14, more than a trebling in numbers in 24 years (Shaughnessy *et al.* 2015). Although the overall growth in pup production has been at around 5.5% per year across South Australia, some populations such as Cape Gantheaume on Kangaroo Island have increased at an average of 9% per year, based on annual surveys undertaken for 29 years to 2016-17 (Goldsworthy *et al.* 2017a). There are 29 breeding sites in South Australia, which account for most (>80%) of Australia's population of LNFS (Shaughnessy *et al.* 2015). Populations of LNFS continue to grow and their breeding and non-breeding distributions are expanding.

In the past, fur seals have probably been occasional visitors into the Coorong estuary at times when food is concentrated and plentiful, however, since 2007, they have become more frequent visitors, and are known to interact with Lakes and Coorong fishers, depredating fish caught in their nets (Goldsworthy *et al.* 2019). The fur seals are largely juvenile and subadult males and are most abundant throughout winter months. Regular surveys of the numbers of fur seals in the upper Coorong since August 2015 indicate annual peak numbers in June, July and August (Department for Environment and Water unpublished data).

Diet: Dietary data for long-nosed fur seal were based on 64 scat samples from Tauwitchere barrage in the Coorong (Goldsworthy *et al.* 2019). Their diet in the Coorong is composed entirely of fish.

Biomass and consumption: Biomass and consumption estimates for long-nosed fur seals were based on those estimated in previous ecosystem models developed for the Great Australian Bight, Spencer Gulf and Gulf St Vincent (Fulton *et al.* 2017, Goldsworthy *et al.* 2003, Goldsworthy *et al.* 2017b, Goldsworthy *et al.* 2013) (Q/B = 47.525; P/B = 1.184).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.00	0.00104	47.525	1.184	-
SL	N/A	N/A	N/A	N/A	-

*Estimated by *Ecopath*

Birds

The biomass (*B*) of bird groups were calculated using estimates of abundance in 1984-85 multiplied by the average body mass of individual species.

Consumption (*Q*) was estimated using bioenergetic models developed to estimate daily food intake (modified from, Karpouzi *et al.* 2007):

$$DFI = \frac{ER}{ED} \times \frac{1}{AE}$$

where *DFI* denotes daily food intake (kg d^{-1}), *ER* is the daily energy requirement (kJ d^{-1}), *ED* is the mean energy density of prey (kJ g^{-1}) and *AE* is the assimilation efficiency. *ER* was estimated from direct estimates of basal (BMR) or field metabolic rate (FMR), or using allometric equations developed by Nagy et al. (1999), Ellis and Gabrielsen (2002) and McNab (2009) for different bird families. ED of prey was estimated from calorific analyses of fish, invertebrate and aquatic plant species sampled in the North Coorong and South Lagoon of the Coorong, with the mean ED of prey estimated as the weighted mean based on the proportion of fish, invertebrate and aquatic plant species in the diet (Dittmann et al. 2022).

The mean North Coorong and South Lagoon estimates of prey group energy densities (kJ g^{-1} wet-weight) used were:

PREY GROUP	AVERAGE (kJ g^{-1})	NORTH COORONG (kJ g^{-1})	SOUTH LAGOON (kJ g^{-1})
Fish	5.484	5.484	5.416
Invertebrates	2.196	1.964	3.696
Plant	1.551	1.551	1.551

Production (P) was estimated using the allometric equation of Maurer (1998)

$$P = \frac{6.31M^{0.75}0.2M^{-0.25}}{6.31M^{0.75} + 0.2M^{-0.25}}$$

where *P* is the production of energy invested into offspring, and *M* is body mass (kg).

Estimates of Q/B and P/B were obtained by dividing consumption or production by adult mass.

Raptors

Abundance and biomass: Annual surveys of birds in North Coorong and South Lagoon between 2000 and 2020 recorded raptors when seen (Prowse *et al.* 2021). Three species, white-bellied sea eagle (*Haliaeetus leucogaster*)(41% of raptor sightings), whistling kite (*Haliastur sphenurus*) (29%) and swamp harrier (*Circus approximans*) (27%) made up most of the sightings, while spotted harrier (*C. assimilis*) and osprey (*Pandion cristatus*) were irregularly observed (single sighting of each species) and are not considered further here. Most raptors sightings (97%) were in the North Lagoon. As no data exist on the abundance of raptors in the Coorong throughout the 1980s or 1990s, initial abundances were based the minimum pairs of adults that could account for the maximum birds surveyed in any year between 2000 and 2020 (Prowse *et al.* 2021). This resulted in a single pair of white-bellied sea eagle, whistling kite and swamp harrier in the South Lagoon, and two pairs of white-bellied sea eagle, whistling kite and a single pair of swamp harrier for the North Lagoon.

Diet: There are no comprehensive diet data for raptors in the Coorong region. Diet for white-bellied sea eagle was based on amalgamated food remains/pellet dietary data from a marine (Franklin Island, South Australia) and an inland freshwater system (northern New South) to best represent an estuarine diet (Debus 2008, Eckert 1971). However, other studies, including those of the diets of white-bellied sea eagle, whistling kites and swamp harriers would suggest that some of the diet in the Coorong would include waterfowl and small mammals (import) (Olsen *et al.* 2013, Olsen *et al.* 2006, Olsen *et al.* 2010).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.397	0.362
Invertebrates	0.000	0.000
Plants	0.000	0.000
Birds	0.232	0.211
Mammals	0.371	0.427

Both the mammal component and 13% of the fish component were considered to be imports, the latter composed of freshwater piscivores and cyprinids (i.e. total import = 50%).

Consumption and production: The mean mass of white-bellied sea eagle, whistling kite and swamp harrier were estimated to be 3.500, 0.770 and 0.747 kg, respectively (Marchant and Higgins 1993, Olsen *et al.* 2013, Olsen *et al.* 2006). Combined with estimated abundances the mean biomass of raptors was estimated as 0.019 t (0. 00019 t km^{-2}) and 0.010 t (0.00010 t km^{-2}) in the North Coorong and South Lagoon, assuming all aquatic areas are available habitat. Daily *ER* were estimated using the mean BMR for Falconiformes by McNab (2009). *DFI* was calculated as assuming an assimilation efficiency of 0.75, and a mean prey energy density of 6.32 kJ g^{-1} based on the prey composition detailed above and average energy densities of 7.18 kJ g^{-1} for mammals and 6.36 kJ g^{-1} for waterfowl (Glowaciński and Profus 1997, Long 2009). Total annual prey consumption in 1984-85 was estimated to be 0.385 t and 0.214 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption would be derived from areas outside of our modal domains (see below). Based on these estimates, *Q/B* was 20.929. Based on allometric models of production (Maurer 1998), *P/B* was estimated to be 0.020 and 0.0217 for North Coorong and South

Lagoon, respectively. This is lower than the estimate of 0.314 used for raptor (bald eagles) in a Puget Sound *Ecopath* model (Harvey *et al.* 2012).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.00	0.00019	20.926	0.020	-
SL	1.00	0.00010	20.926	0.022	-

*Estimated by *Ecopath*

Australian pelican

Abundance and biomass: The population size of the Australian pelican is unknown but is considered to number around 300,000 to 500,000 (Reid 2009). Pelicans range widely across Australia and can move large distances. They are colonial breeders and nest annually on some small islands in coastal and subcoastal regions where they form small colonies (tens to few thousand). This contrasts markedly with the massive, but infrequent and episodic breeding aggregations (tens of thousands of pairs) associated with inland floodwaters and ephemeral lakes (Reid 2009). In the Coorong, pelicans are known to have nested in most years on the 'Pelican Islands' (the group of 6 islands in the South Lagoon) since the early colonial period (Chapman 1963, O'Gorman 2016). Since at least the 1870s through to the 1960, the breeding population has been subject to unregulated culling referred to as 'annual raids', 'slaughter' and 'massacres' (Chapman 1963, O'Gorman 2016). Pelicans were seen as a pest and competitor of establishing fisheries in the lakes and Coorong and were added to the list of 'fish enemies' (enemies of fishermen) in state legislation (*Fisheries Act Amendment 1909*), culminating in a bounty (penny per bird) and the slaughter of ~2000 birds in 1911 (O'Gorman 2016). The most recent surveys of the abundance and numbers of breeding pairs on North Pelican Island was monitored over three consecutive breeding seasons using drones (Hodgson unpublished thesis). Maximum abundance declined considerably over these three seasons from 3,953 (2017) to 305 (2019) individuals, as did the number of chicks (Hodgson unpublished thesis).

Annual abundance estimates of pelicans in the North Coorong and South Lagoon are available from 2000 to 2020 (Prowse *et al.* 2021). Estimates for their abundance in the 1985 were based on a single survey of the South Lagoon in 1985 (6,045) (Paton *et al.* 2009). An estimate of 3,302 for the North Lagoon was based on this survey, assuming North Lagoon numbers make up 35% of the total North Coorong and South Lagoon absence (based on 65% of total birds being on South Lagoon in the 2000 survey, pre-Millennium Drought). Based on the above abundances, and estimated average body mass of 6.1 kg (Marchant and Higgins 1990) we estimate the biomass of Australian pelicans in the North Coorong and South Lagoon in 1985 to be 20.142 and 36.875 t.

Diet: was based on estimated composition data from DNA metabarcoding (COI gene) of eight scat samples from Tauwitchere Barrage and Noonameena in the Coorong. The diet of pelicans in North Coorong and South Lagoon was estimated to be entirely composed of fish species.

Consumption and production: Daily *ER* was estimated using the mean BMR for Pelecaniformes by McNab (2009) ($kJ.h^{-1} = 0.1343m^{0.705}$, m is mass in grams). *DFI* was calculated (as detailed above) assuming an assimilation efficiency of 0.75, and a fish prey energy density of 5.48 and 5.42 kJ g^{-1} in the North Coorong and South Lagoon, respectively. Total annual prey consumption in 1984-85 was estimated to be 440.4 t (0.24474 t/km^2) and 816.3 t yr^{-1} t (0.40477 t/km^2) with a habitat fraction of 0.86 and 0.87 for birds that use the North Coorong and South Lagoon, respectively, assuming most pelican feeding occurs in water depth deeper than 0.2 m. We note that some of this consumption would occur outside of our modal domains (see dietary import below). *Q/B* was estimated to be 22.042.

The P/B for Australian pelicans has not been directly estimated. The allometric P/B was estimated to be and 0.007, based on Maurer (1998), which is much lower than values used for other pelican species which have ranged between 0.1 and 1.25 (Geers *et al.* 2016, Koehn *et al.* 2016, Moreau *et al.* 2001). We used a P/B of 0.2 based on that used by (Koehn *et al.* 2016). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.86	0.24474	22.042	0.200	-
SL	0.87	0.40477	22.042	0.200	-

*Estimated by *Ecopath*

Cormorants & Grebes

Abundance and biomass: Cormorants and grebes are aquatic diving birds. There are five species of cormorant (great, little black, pied, little pied and black-faced) and three species of grebe (great crested, hoary-headed and Australasian) that occur in the Coorong ecosystem. The average weight of these species ranges from 0.2 to 2.2 kg (Marchant and Higgins 1990, Riordan and Johnston 2013).

Annual abundance estimates of cormorants and grebes in the North Coorong and South Lagoon are available from 2000 to 2020 (Coorong waterbird summaries) (Prowse *et al.* 2021). Estimates for their abundance in the 1984-85 were based on a single survey of the South Lagoon in 1985 (Paton *et al.* 2009). North Lagoon numbers in 1985 were estimated based on the ratio of species counts in the North Coorong and South Lagoon from the 2000 (pre-Millennium Drought) surveys applied to 1985 South Lagoon numbers. Based on these number the total biomass of cormorants and grebes in 1984 was estimated to be 0.30524 t/km^2 in the North Coorong and 0.06535 t/km^2 in the South Lagoon, assuming all areas of habitat are available to this group. The dominant species in terms of biomass in the North Coorong were great (49%) and little black cormorants (29%), while in South Lagoon they were hoary headed grebes (65%), little black (13%) and black-faced cormorants (13%).

Diet: There are no comprehensive diet data for cormorant or grebe species from the Coorong region. Information from cormorants was taken instead from stomach content data available for great cormorant (5 samples), little black cormorant (23 samples) and little pied cormorant (21 samples) from another temperate estuary (the Wilson Inlet in Western Australia, Humphries *et al.* 1992), and for black-faced cormorant based on amalgamated stomach content data from coastal South Australia (4 stomachs – White 1918, in Marchant and Higgins 1990) and Victoria (20 stomachs – McNally 1957, in Marchant and Higgins 1990). Diet data for grebes were based on feeding observations of great crested grebe in inland New Zealand (47 observations, O'Donnell 1982), amalgamated stomach content data for hoary-headed grebe from inland New South Wales (19 stomachs – Fjedsa 1988, 9 stomachs – Barker and Vestens unpublished, in Marchant and Higgins 1990).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.735	0.306
Invertebrates	0.261	0.682
Plants	0.004	0.012

Consumption and production: *DFI* were calculated using the methods detailed above for birds, with *ER* estimates of cormorants based on the allometric equations of BMR for Pelecaniformes developed by Ellis and Gabrielsen (2002), and an average BMR of 0.023 kJ/g/day for grebes (Conover and Caudell 2009). The average ED of prey was estimated to be 4.55 and 4.20 kJ g-1 in North Coorong and South Lagoon, respectively, based on dietary breakdown and mean energy densities of prey within each model domain (see below). This provided a total annual prey consumption estimate by cormorants and grebes of 1028 and 330 t in North Coorong and South Lagoon, respectively, if most cormorants and grebes feed below -0.2 m AHD (0.86 and 0.87 habitat fraction, respectively). Q/B was estimated to be 43.799.

The estimated proportion of consumption by species by model domain was estimated to be:

REGION	HOARY-HEADED GREBE	GREAT CRESTED GREBE	BLACK-FACED CORMORANT	GREAT CORMORANT	LITTLE BLACK CORMORANT	LITTLE PIED CORMORANT	PIED CORMORANT
NC	0.053	0.038	0.013	0.491	0.289	0.032	0.083
SL	0.645	0.048	0.130	0.006	0.133	0.000	0.037

The P/B was estimated to be 0.0366 and 0.1551, for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). The marked difference between the values for each model domain reflects the marked difference in biomass of larger body-sized cormorants in North Coorong (91%) and smaller body-sized grebes in South Lagoon (80%). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.86	0.29526	43.799	0.0366	-
SL	0.87	0.06417	43.799	0.1551	-

*Estimated by *Ecopath*

Terns



Abundance and biomass: There are seven tern species found in the Coorong, four are common (whiskered, crested, fairy and Caspian), three are uncommon (common, gull-billed and little). Annual abundance estimates of these tern species in the North Coorong and South Lagoon are available from 2000 to 2021 (Prowse *et al.* 2021). Estimates for their abundance in the 1984-85 were based on a single survey of the South Lagoon in 1985 (Paton *et al.* 2009). North Coorong numbers in 1985 were estimated based on the ratio of species counts in the North Coorong and South Lagoon from the 2000 (pre-Millennium Drought) surveys applied to 1985 South Lagoon numbers. Based on the 20 year abundance data, whiskered (53.4%) and crested (38.3%) terns were the most abundant, followed by Caspian (5.3%) and fairy (2.9%) (99.8% collectively) (Prowse *et al.* 2021). As the remaining uncommon tern species (common, gull-billed and little) made up just 0.2% of total tern abundance, they have been excluded from further analyses.

Average weights of the four main tern species are: whiskered (0.085 kg, Higgins and Davies 1996), crested (0.340 kg, McLeay *et al.* 2009), fairy (0.070 kg, Higgins and Davies 1996), and Caspian (0.700 kg, Higgins and Davies 1996). Based on these weights and abundance values, the biomass of terns in 1984 was estimated to be 2.098 t (0.02187 t/km^2) in the North Coorong and 2.823 t (0.02688 t/km^2) in the South Lagoon, assuming all areas are available for foraging (habitat fraction = 1). In terms of biomass, Caspian (48%), crested (35%) and whiskered terns (16%) were the most important species in North Coorong, while crested (81%) terns were more important in South Lagoon.

Diet: The biomass and consumption of terns in the Coorong is dominated by crested and Caspian terns (see below). Dietary data for crested tern were based on 2,938 regurgitates from South Australia detailed in McLeay *et al.* (2009), summarised in Page *et al.* (2011). Information for Caspian tern was taken from a study of 145 regurgitates from a temperate estuary (the Peel–Harvey Estuary) in Western Australia (Stockwell 2019). Information for whiskered tern was taken from data based on 55 stomach samples from the Alligator River, Northern Territory (Dostine and Morton 1989).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.996	0.997
Invertebrates	0.004	0.003
Plants	0.000	0.000

Consumption and production: *DFI* were calculated using the methods detailed above for birds, with *ER* estimated based on the average BMR for six non-polar tern species (0.0231 kJ g^{-1} hr^{-1}) (Ellis and Gabrielsen 2002). The mean ED of prey was estimated to be 5.470 and 5.411 kJ g-1 in North Coorong and South Lagoon, respectively based on dietary breakdown and mean energy densities of prey within each model domain (see below). This provides a total annual prey consumption estimate by terns of 103.6 and 141.0 t in North Coorong and South Lagoon, respectively, and a Q/B of 49.705.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	WHISKERED TERN	CRESTED TERN	FAIRY TERN	CASPIAN TERN
NC	0.162	0.346	0.011	0.482
SL	0.080	0.805	0.033	0.082

P/B was estimated to be 0.185 and 0.267, for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are summarised below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	0.02187	49.705	0.185	-
SL	1.0	0.02688	49.705	0.267	-

*Estimated by *Ecopath*

Gulls


Abundance and biomass: There are two species of gull that occur in the Coorong, the silver gull (*Chroicocephalus novaehollandiae*) and the Pacific gull (*Larus pacificus*). The most abundant species is the silver gull, Pacific gulls are comparatively uncommon. Estimates of the size of gull populations in the Coorong region were based on annual abundance survey data for North Coorong and South Lagoon are available from 2000 to 2020 (Prowse *et al.* 2021). Estimates of abundance in 1984-85 were based on a single survey of the South Lagoon in 1985 (Paton *et al.* 2009). Pacific gulls were not been sighted in South Lagoon surveys between 2000 and 2020, so gull abundance in South Lagoon is based on silver gulls surveys in 1985 (4,090, Paton *et al.* 2009). Silver gull numbers in North Coorong have remained relatively constant between 2000 and 2020 (Prowse *et al.* 2021), as such the average of the annual surveys was used to estimate silver gull abundance (5,524). The maximum number of Pacific gulls recorded is just 11, and an estimate of 7 was used for 1984-85.

With a mean estimated mass of 0.3 kg for silver gulls and 1.04 kg for Pacific gulls (Lindsay and Meathrel 2008) the combined biomass estimate was 1.663 t (or 0.017346 t km^{-2}) and 1.227 t (or 0.011696 t km^{-2}) in North Coorong and South Lagoon, respectively, assuming all areas are available habitat (habit fraction = 1.0).

Diet: Dietary data for silver gull were based 108 stomach samples from southern Spencer Gulf, South Australia detailed in Harrison (2009), summarised in Page *et al.* (2011).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.996	0.991
Invertebrates	0.004	0.009
Plants	0.000	0.000

Consumption and production: An estimated daily energy requirement of 213.5 kJ d^{-1} was used for silver gulls, based on the average BMR of nine similar sized gull species (0.02966 kJ.g^{-1}.hr^{-1}), and 458.1 kJ d^{-1} for Pacific gulls, based on a BMR of 0.0183 kJ.g^{-1}.hr^{-1} (Ellis and Gabrielsen 2002). Assuming an assimilation efficiency of 0.75, a mean prey density of 5.45 (NC) and 5.40 kJ g^{-1} (SL) total prey consumption was estimated to be 106.5 (NC) and 78.7 t yr^{-1} (SL). Q/B was estimated to be 64.084.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	PACIFIC GULL	SILVER GULL
NC	0.002	0.998
SL	0.000	1.000

P/B was estimated to be 0.301 and 0.304, for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE
NC	1.0	0.01735	64.084	0.301	-
SL	1.0	0.01169	64.084	0.304	-

*Estimated by *Ecopath*

Egrets & Herons



Abundance and biomass: There are five species of egret and heron that occur in the Coorong, great (*Ardea modesta*), little (*Egretta garzetta*), and cattle egret (*Ardea ibis*), white-faced (*Egretta novaehollandiae*) and Nankeen night heron (*Nycticorax caledonicus*) and one darter (*Anhinga melanogaster*). White face-heron (65%), great (28%) and little egrets (7%) are the most numerous, species, collectively making up almost 100% of species counted within this group during 2000 to 2020 annual bird surveys (Prowse *et al.* 2021). Cattle egret, Nankeen night heron and darters made up just 0.4% of these surveys, and as such are not evaluated further here. Estimates of abundance in 1984 were based on a single survey of the South Lagoon in 1985 that only included white-faced heron, as this study only reported on species that numbered more than 100 (Paton *et al.* 2009). The expected number of great and little egrets present in 1984-85 was estimated from the number of individuals of these species counted between 2000 and 2020 (Prowse *et al.* 2021), as a proportion of white-faced herons. A similar approach was used for the North Coorong, where the initial abundance of white-faced here was based on the mean of 2000-2020 counts (113) which have remained relatively constant over this period.

The estimated mean mass of white face-heron (0.55 kg), great (0.95 kg) and little egrets (0.35 kg) (Marchant and Higgins 1990) with estimated abundances were used to derive a combined biomass of 0.087 t (or 0.000092 t km^{-2}) and 0.124 t (or 0.000057 t km^{-2}) in the North Coorong and South Lagoon, respectively, assuming a habitat area fraction of 0.15 and 0.14, respectively (optimal foraging depth between between -5 cm and -30 cm, O'Connor *et al.* 2013).

Diet: There are no comprehensive diet data for herons and egrets from the Coorong region. Information was taken instead from stomach content data available for white-faced heron (8 samples, mass data) from a temperate intertidal zone in southern Australia – Western Port, Victoria (Lowe 1983, in Marchant and Higgins 1990); and for great egret (5 samples, frequency data) and little egret (3 samples, frequency data) from a temperate inland system – Lake Cowal, New South Wales (Vestjens 1977, Higgins and Davies 1996).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.229	0.162
Invertebrates	0.771	0.838
Plants	0.000	0.000

Consumption and production: Daily *ER* was estimated using the mean BMR estimated for Pelecaniformes by McNab (2009) (kJ.h^{-1} = 1.665$m^{0.705}$, *m* is mass in grams). *DFI* was then calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey density of 2.77 and 3.97 kJ g^{-1} in North Coorong and South Lagoon, respectively, based on the proportion of main prey types in the diet in each model domain (see below), and the energy density of prey. Total prey consumption was estimated to be 10.20 and 5.22 t yr^{-1} in North Coorong and South Lagoon, respectively (in 1984). Based on these estimates, *Q/B* was 73.182.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	WHITE-FACED HERON	GREAT EGRET	LITTLE EGRET	CATTLE EGRET
NC	0.536	0.415	0.049	0.000
SL	0.828	0.150	0.023	0.000

P/B was estimated to be 0.104 and 0.127, for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.15	0.000092	73.182	0.104	-
SL	0.14	0.000057	73.182	0.127	-

*Estimated by *Ecopath*

Ibis

Abundance and biomass: There are two common ibis species that occur in the Coorong, the Australian white ibis (*Threskiornis moluccus*) and straw-neck Ibis (*Threskiornis spinicollis*). A third species, the glossy Ibis (*Plegadis falcinellus*) is uncommon, and has only been recorded in one year of the 20-year annual surveys (2000 to 2020) in the North Coorong (Prowse *et al.* 2021). It is not considered further here. Australian white ibis (87%) are more common than the straw-necked ibis (13%) based the 20-year annual surveys in North Coorong and South Lagoon (Prowse *et al.* 2021).

The estimated mean mass of Australian white (1.80 kg) and straw-necked ibis (1.35 kg) (Marchant and Higgins 1990) combined with estimated abundances in 1984 were used to estimate a biomass of 1.791 t (or 0.10006 t km^{-2}) and 0.210 t (or 0.01129 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.19 and 0.18, respectively (based on the assumption that most foraging occurs from 0 to -30cm AHD).

Diet: was based on diet of Australian white ibis as this is the most abundant member of this trophic group in the Coorong. There are no published diet data for this species from the Coorong region, so information was based on 7 stomach samples (mass data) from a temperate intertidal zone in southern Australia – Western Port, Victoria (Lowe 1978, in Marchant and Higgins 1990).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.168	0.168
Invertebrates	0.832	0.832
Plants	0.000	0.000

Consumption and production: Daily *ER* was estimated using the mean BMR for Pelecaniformes by McNab (2009) (kJ.h^{-1} = 1.665$m^{0.705}$, m is mass in grams). *DFI* was then calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey density of 2.56 kJ g^{-1} (NC) and 3.98 kJ g^{-1} (NC). Total prey consumption in 1984-85 was estimated to be 120.96 t and 9.83 t yr^{-1} in the North Coorong and South Lagoon, respectively. Based on these estimates, *Q/B* was 65.4.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	AUSTRALIAN WHITE IBIS	STRAW-NECKED IBIS
NC	0.951	0.049
SL	0.032	0.968

P/B was estimated to be 0.034 and 0.047, for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.18	0.10006	65.4	0.034	-
SL	0.19	0.01129	65.4	0.047	-

*Estimated by *Ecopath*

Spoonbills


Abundance and biomass: There are two spoonbill species found in the Coorong, the royal (*Platalea regia*) and yellow-billed spoonbill (*Platalea flavipes*). Royal spoonbills are the most numerous species and are most numerous in the North Coorong (98% of annual counts in both North Coorong and South Lagoon between 2000 and 2020) (Prowse *et al.* 2021). Spoonbills are rarely seen in the South Lagoon and made up <1% of spoonbills sighted. No data on available on the abundance of spoonbills and North Coorong and South Lagoon in the 1980s or 1990s. As such the starting abundances in 1984-85 were taken as the means of the 2000 to 2020 data. The estimated mean mass of royal (1.73 kg) and yellow-billed spoonbills (1.90 kg) (Marchant and Higgins 1990) combined with their estimated abundances in 1984-85 were used to estimate a biomass of 0.088 t (or 0.00415 t km^{-2}) and 0.004 t (or 0.00016 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.22 in North Coorong and South Lagoon (limited to feeding in <0.40 m AHD, O'Connor *et al.* 2013).

Diet: was based on diet of royal spoonbill as this is the most frequently occurring member of this trophic group in the Coorong. There are no published diet data for this species from the Coorong region, so information was based on 10 stomach samples (mass data) from a temperate intertidal zone in southern Australia – Western Port, Victoria (Lowe 1978, in Marchant and Higgins 1990).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.252	0.252
Invertebrates	0.748	0.748
Plants	0.000	0.000

Consumption and production: Daily *ER* was estimated using the mean BMR for Pelecaniformes by McNab (2009) (kJ.h^{-1} = 1.665$m^{0.705}$, m is mass in grams). *DFI* was then calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey density of 2.85 kJ g^{-1} (NC) and 4.13 kJ g^{-1}. Total prey consumption in 1984-85 was estimated to be 5.387 t and 0.151 t yr^{-1} in the North Coorong and South Lagoon, respectively, and *Q/B* was estimated to be 60.2.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	ROYAL SPOONBILL	YELLOW-BILLED SPOONBILL
NC	0.979	0.021
SL	0.484	0.516

P/B was estimated to be 0.035 and 0.033, for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.22	0.00415	60.2	0.035	-
SL	0.22	0.00016	60.2	0.033	-

*Estimated by *Ecopath*

Migratory Shorebirds (medium-long-bill)

Abundance and biomass: this group consists of eleven species of migratory shorebirds with medium-long bills and includes: black-tailed (*Limosa limosa*) and bar-tailed godwits (*Limosa lapponica*), eastern curlew (*Numenius madagascariensis*), common greenshank (*Tringa nebularia*), and curlew (*Calidris ferruginea*), terek (*Xenus cinereus*), common (*Actitis hypoleucos*) and marsh sandpipers (*Tringa stagnatilis*), whimbrel

(*Numenius phaeopus*), little curlew (*Numenius minutus*) and great knot (*Calidris tenuirostris*). All species breed in the northern hemisphere and have a general Palaearctic distribution, and move into the southern hemisphere during their non-breeding period, arriving in Australia from mid-August, remaining for ~ 6 months before migrating back to the northern hemisphere between late February to May (Higgins and Davies 1996).

The numbers of birds of each species present in 1984-85 was based on surveys by the AWSG (1981, 1982) for both North Coorong and South Lagoon, and Paton et al. (2009) for 1985 (South Lagoon only). Abundances for South Lagoon were based on Paton et al. (2009) for species where >100 were surveyed, or the average of 1981 and 1982 AWSG surveys for other species. For North Coorong, the averages of 1981 and 1982 AWSG surveys were used as estimates of abundance in 1984. Based on these surveys, curlew sandpipers make up 97.2% of the total birds in this group, common greenshanks make up 2.3%, with black-tailed (0.44%) and bar-tailed godwits (0.02%) and eastern curlews (0.02%) made up most of the remainder. The remaining six species were uncommon (<0.03% combined abundance) and are not considered further here.

The estimated mean mass of five main species were: black-tailed (0.228 kg) and bar-tailed godwits (0.338 kg), eastern curlew (0.900 kg), common greenshank (0.170 kg), and curlew sandpiper (0.063 kg) (Marchant and Higgins 1990). Combined with estimated abundances in 1984-85, total biomass was estimated as 1.702 t (or 0.12514 t km^{-2}) and 0.647 t (or 0.04656 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.14 and 0.13 in North Coorong and South Lagoon, respectively (based on a 0 to -0.2 m AHD foraging limit, Paton 2010).

Diet: was based on the diets of curlew sandpiper and common greenshank as this is the most abundant member of this trophic group in the Coorong. Diet for curlew sandpiper was based on amalgamated data from 2 stomach samples from the South Lagoon of the Coorong (frequency data, Paton 1982) and, due to low sample sizes in the Coorong, stomach samples from Western Port, Victoria (11 samples, volumetric data, Dann 2000) and southeast Tasmania (58 samples, frequency data, Thomas and Dartnall 1971). Diet of common greenshank was based on frequency data from 3 stomachs from Lake Cowal, New South Wales (Vestjens 1977, summarised in Higgins and Davies 1996). The residence time in the Coorong for these migratory birds was assumed to be about 6months, as such dietary import was estimated to be 0.5.

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.070	0.070
Invertebrates	0.726	0.726
Plants	0.203	0.203

Consumption and production: Daily *ER* was estimated using the mean BMR for Charadriiformes by McNab (2009) (kJ h^{-1} = $1.645m^{0.705}$, m is mass in grams). *DFI* was calculated (as detailed above) assuming an assimilation efficiency of 0.75, and a mean prey energy density of 2.13 kJ g^{-1} (NC) and 3.38 kJ g^{-1} (SL). Total annual prey consumption was estimated to be 357.1 and 85.6 t for birds that use the North Coorong and South Lagoon, respectively, noting that at least half of this consumption would occur outside of our modal domains in the northern hemisphere breeding areas and migratory flyways, (see below for estimates of dietary import). Based on these estimates, *Q/B* was 188.456.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	COMMON GREENSHANK	EASTERN CURLEW	BAR-TAILED GODWIT	BLACK-TAILED GODWIT	CURLEW SANDPIPER
NC	0.027	0.005	0.001	0.015	0.952
SL	0.063	0.000	0.000	0.000	0.937

P/B was estimated to be 1.480 and 1.639 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.14	0.12514	188.456	1.480	-
SL	0.13	0.04656	188.456	1.639	-

*Estimated by *Ecopath*

Migratory Shorebirds (short-bill)



Abundance and biomass: this group consists of twelve species of migratory shorebirds with short bills and includes sharp-tailed sandpipers (*Calidris acuminate*), red-necked Stints (*C. ruficollis*), sanderling (*C. alba*), red knot (*C. canutus*), ruff (*C. pugnax*), ruddy turnstone (*Arenaria interpres*), wood sandpiper (*Tringa glareola*), red-necked phalarope (*Phalaropus lobatus*), Pacific golden plover (*Pluvialis fulva*), grey plover (*P. squatarola*), oriental plover (*Charadrius veredus*), and lesser sand plover (*C. mongolus*). Most of these species breed in Siberia, and move into the southern hemisphere during their non-breeding period, arriving in Australia from mid-August, and start returning to the northern hemisphere in late June (most in August) (Higgins and Davies 1996).

Abundances for South Lagoon in 1984-85 were based on Paton et al. (2009) for species where >100 were surveyed, or for the average of 1981 and 1982 AWSG surveys for other species and North Coorong. Based on these surveys, the most abundant species in this group are red-necked stints (78.9%); sharp-tailed sandpipers (20.2%); sanderlings (0.6%) and Pacific golden plovers (0.3%). The remaining eight species were uncommon (<0.01% combined abundance) and are not considered further here.

The estimated mean mass of species used were: sharp-tailed sandpipers (0.068 kg); red-necked stints (0.027 kg); sanderling (0.059 kg) and Pacific golden plover (0.059 kg) (Marchant and Higgins 1990). Combined with estimated abundances in 1984, total biomass was estimated as 3.277 t (or 0.15384 t km^{-2}) and 1.198 t (or 0.05188 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.22 in the North Coorong and South Lagoon (based on the assumption the most foraging occurs between 0 and -0.07 m AHD, Rogers and Paton 2009) .

Diet: was based on data for sharp-tailed sandpiper from DNA metabarcoding of 39 scat samples from North Coorong and South Lagoon sites in the Coorong (Giatas *et al.* 2022). Dietary data for red-necked stint were based on amalgamated data from Giatas *et al.* (2022)(estimated composition by DNA metabarcoding of 20 scat samples, South Lagoon) and Paton (1982) (frequency of occurrence data from 4 stomach samples, North Coorong and South Lagoon). The residence time in the Coorong for these migratory birds was assumed to be about 6months, as such dietary import was estimated to be 0.5.

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.000	0.000
Invertebrates	0.716	0.698
Plants	0.284	0.302

Consumption and production: Daily *ER* was estimated using the mean BMR for Charadriiformes by McNab (2009) ($kJ.h^{-1} = 1.645m^{0.705}$, m is mass in grams). *DFI* was calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.85 kJ g^{-1} (NC) and 3.05 kJ g^{-1} (SL). Total annual prey consumption in 1984 was estimated to be 872.1 t and 211.2 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that at least half of this consumption would occur outside of our modal domains in the northern hemisphere breeding areas and migratory flyways (see below for estimates of dietary import). Based on these estimates, *Q/B* was 242.056.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	SHARP-TAILED SANDPIPER	RED-NECKED STINT	SANDERLING	GOLDEN PLOVER
NC	0.587	0.397	0.008	0.007
SL	0.284	0.716	0.000	0.000

P/B was estimated to be 2.169 and 2.931 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.22	0.15384	242.056	2.169	-
SL	0.22	0.05188	242.056	2.931	-

*Estimated by *Ecopath*

Large Non-migratory Waders



Abundance and biomass: this group consists of three species of large non-migratory, nomadic waders, including the banded (*Cladorhynchus leucocephalus*) and black-winged stilt (*Himantopus himantopus*) and red-necked avocet (*Recurvirostra novaehollandiae*). Abundances for South Lagoon were based on Paton et al. (2009), for North Coorong, the averages of 1981 and 1982 AWSG surveys were used as estimates of abundance in 1984-85. Based on these surveys, the most abundant species were: banded stilt (86.6%); black-winged stilt (1.2%) and red-necked avocet (12.2%).

The estimated mean mass of the species were: banded stilt (0.242 kg); black-winged stilt (0.176 kg) and red-necked avocet (0.314 kg) (Marchant and Higgins 1990, Pedler *et al.* 2018). Combined with estimated abundances in 1984-85, total biomass was estimated as 11.567 t (or 0.54307 t km^{-2}) and 3.775 t (or 0.16340 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.13 and 0.12 in the North Coorong and South Lagoon, respectively (based on the assumption the most foraging occurs between 0.0 and -0.2m AHD)(Paton 2010).

Diet: was based on the stomach samples from six banded stilt (South Lagoon) and four red-necked avocets (North Coorong and South Lagoon) from the Coorong (Paton 1982). There are no published data on the diet of black-winged stilt from the Coorong region.

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.241	0.301
Invertebrates	0.310	0.325
Plants	0.449	0.374

Consumption and production: Daily *ER* was estimated using the mean BMR for Charadriiformes by McNab (2009) (kJ.h^{-1} = 1.645$m^{0.705}$, m is mass in grams). *DFI* was calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey energy density of 2.63 kJ g^{-1} (NC) and 3.41 kJ g^{-1}. Total annual prey consumption in 1984-85 was estimated to be 950.3 t and 324.3 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that as nomadic species, this consumption would also include that from areas outside of our modal domains. Based on these estimates, *Q/B* was 106.747.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	BANDED STILT	BLACK-WINGED STILT	RED-NECKED AVOCET
NC	0.932	0.012	0.056
SL	0.417	0.002	0.582

P/B was estimated to be 0.387 and 0.324 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.13	106.747	0.387	106.747	-
SL	0.12	106.747	0.324	106.747	-

*Estimated by *Ecopath*

Small Non-migratory Shorebirds



Abundance and biomass: this group consists of three species of small non-migratory waders, including the red-capped plover (*Charadrius ruficapillus*), black-fronted dotterel (*Elseyornis melanops*) and hooded plover (*Thinornis rubricollis*). Abundances for South Lagoon were based on Paton et al. (2009), for North Coorong, the averages of 1981 and 1982 AWSG surveys were used as estimates of abundance in 1984-85. Based on these surveys, red-capped plovers made up almost all sightings (99.33%); followed by hooded plovers (0.64%) and black-fronted dotterels (0.02%).

The estimated mean mass of species were: red-capped plover (0.044 kg); black-fronted dotterel (0.033 kg) and hooded plover (0..096 kg) (Marchant and Higgins 1990, Weston *et al.* 2009). Combined with estimated abundances in 1984-85, total biomass was estimated as 0.112 t (or 0.03835 t km^{-2}) and 0.095 t (or 0.02833 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.03 in the North Coorong and South Lagoon, based on red-capped plover foraging observations, where no foraging was observed in water depths >2 cm (Paton 2010).

Diet: was based on data for red-capped plover from DNA metabarcoding of 69 scat samples from South Lagoon sites (Parnka North, Villa de Yumpa, Salt Creek) in the Coorong (Giatas *et al.* 2022).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.000	0.000
Invertebrates	1.000	1.000
Plants	0.000	0.000

Consumption and production: Daily *ER* was estimated using the mean BMR for Charadriiformes by McNab (2009) (kJ.h^{-1} = 1.645$m^{0.705}$, m is mass in grams). *DFI* was calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.96 kJ g^{-1} (NC) and 3.70 kJ g^{-1} (SL). Total annual prey consumption in 1984-85 was estimated to be 15.4 t and 13.0 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption would be derived from areas outside of our modal domains. Based on these estimates, *Q/B* was 137.241.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	RED-CAPPED PLOVER	BLACK-FRONTED DOTTEREL	HOODED PLOVER	RED-KNEED DOTTEREL
NC	0.990	0.000	0.007	0.003
SL	0.999	0.000	0.000	0.001

P/B was estimated to be 2.753 and 2.787 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.03	0.03835	137.241	2.753	-
SL	0.03	0.02833	137.241	2.787	-

*Estimated by *Ecopath*

Oystercatchers

Abundance and biomass: two species of oystercatcher occur in the Coorong, the pied (*Haematopus longirostris)* and sooty (*H. fuliginosus*). Abundances for South Lagoon were based on Paton et al. (2009), for North Coorong, the averages of 1981 and 1982 AWSG surveys were used as estimates of abundance in 1984-85. Based on these surveys, pied oystercatchers were most abundant (96.5%), with sooty oystercatchers largely sighted in North Coorong.

The estimated mean mass of pied oystercatchers was 0.713 kg (Kraaijeveld-Smit *et al.* 2001), and sooty oystercatchers was 0.792 kg (Hansen *et al.* 2009). Combined with estimated abundances in 1984-85, total biomass was estimated as 0.131 t (or 0.01840 t km^{-2}) and 0.101 t (or 0.02587 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.05 in the North Coorong and South Lagoon, based on a 0 to -15cm foraging limit observed by Rutten et al. (2010).

Diet: There are no comprehensive diet data for pied and sooty oystercatchers from the Coorong region. Diet was taken instead based on amalgamated feeding observations data for pied oystercatcher from the Furneaux Island, Tasmania (Lauro and Nol 1995) and from Roebuck Bay in Western Australia (Tulp and Degoeij 1994), and for sooty oystercatchers from the Furneaux Island, Tasmania (Lauro and Nol 1995).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.000	0.000
Invertebrates	0.945	0.945
Plants	0.055	0.055

Consumption and production: Daily *ER* was estimated using the mean BMR for Charadriiformes by McNab (2009). *DFI* was calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.94 kJ g^{-1} (NC) and 3.58 kJ g^{-1} (SL). Total annual prey consumption in 1984-85 was estimated to be 15.0 t and 6.3 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption would be derived from areas outside of our modal domains. Based on these estimates, *Q/B* was 92.084.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	PIED OYSTERCATCHER	SOOTY OYSTERCATCHER
NC	0.996	0.004
SL	1.000	0.000

P/B was estimated to be 0.106 and 0.105 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.05	0.02587	92.084	0.106	-
SL	0.05	0.01840	92.084	0.105	-

*Estimated by *Ecopath*

Diving Ducks

Abundance and biomass: there are three species of diving ducks that occur in the Coorong, the hardhead (*Aythya australis*), musk duck (*Biziura lobate*), blue-billed duck (*Oxyura australis*). No data exist on the abundance of these species throughout the 1980s. Instead, the average annual number recorded in between 2000 and 2020 (Prowse *et al.* 2021) were used as an estimate of abundance in 1984-85. Based on these surveys, hardhead was the most abundant (67.3%), followed by musk duck (31.1%) and blue-billed duck (1.5%).

The estimated mean mass of for the species was 0.870 kg (hardhead), 1.975 (musk duck) and 0.850 kg (blue-billed duck) (Marchant and Higgins 1990). Combined with estimated abundances the mean biomass was estimated as 0.704 t (or 0.00856 t km^{-2}) and 0.0048 t (or 0.00053 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.86 and 0.87, respectively (assuming most foraging occurs below -0.2m AHD).

Diet: There are no comprehensive diet data for diving ducks from the Coorong region. Information was taken instead from gizzard content data available for hardhead (amalgamated volume data, 193 and 283 samples – Frith 1959, Frith et al. 1969, in Marchant and Higgins 1990), musk duck (amalgamated data: 544 samples, frequency data – Gamble 1966, 399 samples, volume data – Frith et al. 1969, in Marchant and Higgins 1990) and blue-billed duck (546 samples, volume data – Frith et al. 1969, in Marchant and Higgins 1990) from inland New South Wales.

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.014	0.028
Invertebrates	0.284	0.395
Plants	0.702	0.578

Consumption and production: Daily *ER* was estimated using the mean BMR for Anseriformes by McNab (2009). *DFI* was calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.72 kJ g^{-1} (NC) and 2.50 kJ g^{-1} (SL). Total annual prey consumption in 1984-85 was estimated to be 73.0 t and 3.2 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption would be derived from areas outside of our modal domains. Based on these estimates, *Q/B* was 44.8.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	HARDHEAD	BLUE-BILLED DUCK	MUSK DUCK
NC	0.5722	0.0010	0.4268
SL	0.0609	0.1880	0.7511

P/B was estimated to be 0.046 and 0.035 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.86	0.00856	101.235	0.046	-
SL	0.87	0.00053	101.235	0.035	-

*Estimated by *Ecopath*

Dabbling Ducks



Abundance and biomass: there are six species of dabbling ducks that occur in the Coorong, the chestnut teal (*Anas castanea*), grey teal (*A. gracilis*), Pacific black duck (*A. superciliosa*), mallard (*A. platyrhynchos*), Australian shelduck (*Tadorna tadornoides*) and the freckled duck (*Stictonetta naevosa*). The mallard and freckled duck were uncommon and are not considered further. No data exist on the abundance of these species throughout the 1980s or 1990s, except for a single survey of South Lagoon in 1985 (59,113 grey teal; 6,059 Australian shelduck; 660 chestnut teal, Paton *et al.* 2009). The proportion of each species in North Coorong and South Lagoon in 2000 and 2001 (Prowse *et al.* 2021), was used to estimate the number of birds in North Coorong in 1984-85, based on South Lagoon data. Based on the 2000 to 2020 surveys (Prowse *et al.* 2021), the most abundant dabbling ducks were grey teal (59%), Australian shelduck (24%) and chestnut teal (16%).

The estimated mean mass of for the species was 1.340 kg (mallard), 1.045 (pacific black duck), 1.425 (Australian shelduck), 0.808 (Australian wood duck), 0.638 kg (chestnut teal) and 0.470 (grey teal) (Marchant and Higgins 1990). Combined with estimated abundances the mean biomass was estimated as 30.8 t (2.20492 t km^{-2}) and 3608 t (2.55007 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.15 and 0.14, respectively, assuming most foraging occurs between -5 and -30cm (Guillemain *et al.* 2002).

Diet: for dabbling ducks was based on estimated diet composition data for grey and chestnut teal (species undifferentiated) from DNA metabarcoding of 56 scat samples from Murray Estuary, North Coorong and South Lagoon sites in the Coorong (Giatas *et al.* 2022)and amalgamated volumetric data from the oesophagus contents of 36 grey teal, 14 Australian shelduck and 7 chestnut teal from the South Lagoon of the Coorong (Delroy 1974). The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.016	0.021
Invertebrates	0.043	0.056
Plants	0.941	0.924

Consumption and production: Daily *ER* was estimated using the mean BMR for Anseriformes by McNab (2009). *DFI* was calculated as detailed above, assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.72 kJ g^{-1} (NC) and 2.50 kJ g^{-1} (SL). Total annual prey consumption in 1984-85 was estimated to be 1,973.7 t and 4,701.3 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption would be derived from areas outside of our modal domains. Based on these estimates, *Q/B* was 98.731.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	MALLARD	PACIFIC BLACK DUCK	AUSTRALIAN SHELDUCK	AUSTRALIAN WOOD DUCK	CHESTNUT TEAL	GREY TEAL
SL	0.000	0.000	0.181	0.000	0.011	0.807
NC	0.000	0.020	0.362	0.000	0.052	0.566

P/B was estimated to be 0.113 and 0.112 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.15	2.20492	98.731	0.113	(0.01)
SL	0.14	2.55007	98.731	0.112	(0.003)

*Estimated by *Ecopath*

Filter Feeding Ducks

Abundance and biomass: there are two species of filter feeding ducks that occur in the Coorong, the Australasian shoveler (*Anas rhynchotis*) and pink-eared duck (*Malacorhynchus membranaceus*). No data exist on the abundance of these species throughout the 1980s or 1990s. Annual survey data are available for each species in North Coorong and South Lagoon between 2000 and 2020 (Prowse *et al.* 2021). With the absence of data from the 1980s, initial abundances were based on the mean of four years (2000 to 2003), to address multiple zero-year counts. Based on the 2000 to 2020 surveys (Prowse *et al.* 2021), the most abundant filter feeding ducks were shovelers (74%) and pink-eared ducks (26%).

The estimated mean mass of the species was 0.652 kg (shoveler), 0.384 (pink-eared duck) (Marchant and Higgins 1990). Combined with estimated abundances the mean biomass was estimated as 0.057 t (0.00069 t km^{-2}) and 0.005 t (0.00005 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat area fraction of 0.86 and 0.87, respectively, and assuming most foraging occurs below -0.2 m AHD is accessible.

Diet: There are no comprehensive diet data for filter-feeding ducks from the Coorong region. Information was taken instead from gizzard content data available for Australian shoveler (47 samples, volume data – Frith 1969, in Marchant and Higgins 1990)and pink-eared duck (12 samples, mass data, Briggs *et al.* 1985) from inland, western New South Wales. The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.000	0.000
Invertebrates	0.533	0.485
Plants	0.467	0.515

Consumption and production: Daily *ER* were estimated using the mean BMR for Anseriformes by McNab (2009). *DFI* was calculated as assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.77 kJ g^{-1} (NC) and 2.59 kJ g^{-1} (SL). Total annual prey consumption in 1984-85 was estimated to be 6.99 t and 0.43 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption would be derived from areas outside of our modal domains. Based on these estimates, *Q/B* was 121.125.

The estimated proportion of consumption by species by model domain is estimated below.

REGION	AUSTRALASIAN SHOVELER	PINK-EARED DUCK
SL	0.191	0.809
NC	0.967	0.033

P/B was estimated to be 0.119 and 0.191 for North Coorong and South Lagoon, respectively, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.86	0.00069	121.125	0.119	-
SL	0.87	0.00005	121.125	0.119	-

*Estimated by *Ecopath*

Coots

Abundance and biomass: the coots group is composed of six species of crakes, rails and moorhens that includes the Australian spotted crake (*Porzana fluminea*), spotless crake (*P. tabuensis*), black-tailed native hen (*Tribonyx ventralis*), buff-banded rail (*Gallirallus philippensis*), dusky moorhen (*Gallinula tenebrosa*), and Eurasian coot (*Fulica atra*). Most of these species' forage around the margins of wetlands and are not considered further here. The only aquatic feeding species is the Eurasian coot. No data exist on the abundance of these species throughout the 1980s or 1990s in the Coorong. However, annual survey data are available for North Coorong and South Lagoon between 2000 and 2020 (Prowse *et al.* 2021). With the absence of data from the 1980s, initial abundances were based the average of 2010 to 2020 annual surveys (as counts were low throughout the Millennium Drought period).

The mean mass Eurasian coots was estimated to be 0.565 kg (Marchant and Higgins 1993). Combined with estimated abundance the mean biomass was estimated as 1.152 t (0. 01201 t km^{-2}) and 0.019 t (0.00018 t km^{-2}) in the North Coorong and South Lagoon, assuming all aquatic areas are available habitat (species can dive to -9 m).

Diet: The diet of the Eurasian coot has not been investigated in The Coorong, and was based on that described by Collinge (1936).

The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.024	0.024
Invertebrates	0.083	0.083
Plants	0.893	0.893

Consumption and production: Daily *ER* were estimated using the mean BMR for Gruiformes by McNab (2009). *DFI* was calculated as assuming an assimilation efficiency of 0.75, and a mean prey energy density of 1.68 kJ g^{-1} (NC) and 1.61 kJ g^{-1} (SL). Total annual prey consumption in 1984-85 was estimated to be 155.28 t and 0.61 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively. Based on these estimates, *Q/B* was 133.966.

P/B was estimated to be 0.141 for both North Coorong and South Lagoon, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates for North Coorong and South Lagoon model areas are detailed below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.00	0.01201	133.966	0.140	-
SL	1.00	0.00018	133.966	0.140	-

*Estimated by *Ecopath*

Black swan (*Cygnus atratus*)

Abundance and biomass: The black swan (*Cygnus atratus*) is a large bodied and largely sedentary waterbird. There is limited data on their abundance throughout the 1980s or 1990s in the Coorong, except for a single survey of South Lagoon in 1985 (Paton *et al.* 2009). Annual survey data are available for North Coorong and South Lagoon between 2000 and 2020 (Prowse *et al.* 2021). The proportion of black swan in North (85%) Lagoon in 2000 and 2001 (Prowse *et al.* 2021), was used to estimate the number of birds in North Coorong (3,716) in 1985, based on South Lagoon data (676).

The mean mass black swans was estimated to be 5.685 kg (Marchant and Higgins 1990). Combined with estimated abundances the mean biomass was calculated as 21.125 t (0.67491 t km^{-2}) and 3.843 t (0.10616 t km^{-2}) in the North Coorong and South Lagoon, assuming a habitat fraction of 0.33 and 0.34, respectively, based upon areas between -0.3 m and -1.0 m being optimal for black swan feeding (O'Connor *et al.* 2013).

Diet: Dietary data for black swan were based on gizzard samples from Barren Box Swamp in western New South Wales (Frith et al. 1969, in Marchant and Higgins 1990). The estimated proportional breakdown by main prey-type in each model domain was estimated to be:

PREY TYPE	NC PROPORTION	SL PROPORTION
Fish	0.000	0.000
Invertebrates	0.001	0.001
Plants	0.999	0.999

Consumption and production: Daily *ER* were estimated using the mean BMR for Anseriformes by McNab (2009). *DFI* was calculated as assuming an assimilation efficiency of 0.75, and a mean prey energy density of 2.26 kJ g^{-1} in both North Coorong and South Lagoon, assuming a diet composed entirely of aquatic plants (shoots and algae). Total annual prey consumption in 1984-85 was estimated to be 1,071.5 t and 194.9 t yr^{-1} for birds that use the North Coorong and South Lagoon, respectively, noting that some of this consumption could be derived from areas outside of our modal domains. Based on these estimates, *Q/B* was 50.722. P/B was estimated to be 0.008 for both North Coorong and South Lagoon, based on the allometric equation of Maurer (1998). Habitat fraction, Biomass in habitat, Q/B and P/B estimates used in the North Coorong and South Lagoon model areas are summarised below.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	0.33	0.67491	76.452	0.008	-
SL	0.34	0.10616	76.452	0.008	-

*Estimated by *Ecopath*

Fish

Fish model estimation parameters

All fish species (n = 113) identified from previous ecological monitoring datasets were collated (Bice et al. 2018, Ye et al. 2020). For those fish species, trophic level, production per biomass (P/B) and consumption per unit of biomass (Q/B) values were calculated based on standard equations in FishBase using global baselines for asymptotic growth ($L\infty$ cm) and preferred water temperature (mean °C) (Christensen and Pauly 1992).

Production per biomass (P/B) can be estimated by the instantaneous total mortality rate Z (Allen 1971). Based on equations used in FishBase (Christensen and Pauly 1992), P/B values are equal to total mortality rates (Z = F + M), where F is the mean fishing mortality and M is the rate of natural mortality (Goldsworthy et al. 2017). Predictive equations were used to establish indirect natural mortality rates and was derived from the empirical model of Pauly (1980):

$$M = K^{0.65} L_\infty^{-0.279} T^{0.463}$$

where *K* and L_∞ (cm) refer to the curvature and asymptotic length parameters of the von Bertalanffy growth function, respectively, and *T* is the mean annual water temperature in Celsius (Goldsworthy et al. 2017).

Consumption per unit of biomass was calculated according to the empirical regression of Christensen and Pauly (1992):

$$Q/B = 10^{6.37} 0.0313^{Tk} W_\infty^{-0.168} 1.38^{Pf} 189Hd$$

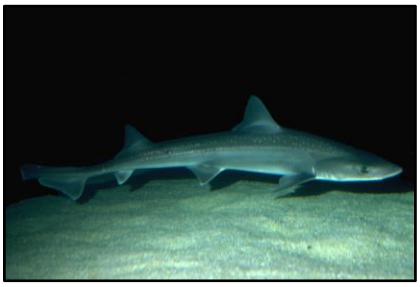
where W_∞ is the asymptotic body weight in grams, calculated from L_∞ using published length-weight regressions; *Tk* is the mean annual temperature expressed as 1000/T°C + 2.731); *Pf* equals one for predators and zooplankton feeders and zero for others; and *Hd* equals one for herbivores and zero for carnivores (Christensen and Pauly 1992, Goldsworthy et al. 2017).

Further refinement of P/B and Q/B values were conducted for key fish species based upon localised asymptotic growth (L_{00} Total Length) values from previous studies in the Coorong ecosystem. A revised water temperature value for the calculation of Q/B and trophic level was also established for the Coorong ecosystem as a median value of 17.5°C (range of 10 – 25°C) between the years of 1999 to 2014 as determined by Oliver et al. (2015). The median water temperature value, as opposed to the mean, was the most appropriate option for the Coorong ecosystem as it is less affected by extreme data values (e.g. drought and flood) (Rothery 2000). For final P/B and Q/B value estimates of each trophic group, median were calculated based on the species within each group.

Diets of many key fish species in the Coorong have been previously assessed, primarily through the identification and quantification of gut contents (e.g. Geddes and Francis 2008, Deegan et al. 2010, Giatas and Ye 2015, Hossain et al. 2017) and stable isotope approaches (e.g. Lamontagne et al. 2016). The knowledge of the diets of common freshwater species (e.g. bony herring *Nematalosa erebi*), whose abundances are temporally variable in the Coorong, was obtained from studies (e.g. Hall 1981, Atkins 1984, Wedderburn et al. 2014) in freshwater habitats of the lower MDB (i.e. Lower Lakes and Lower Murray River). Dietary information for some fish groups that are less common or abundant in the Coorong, Lower Lakes and Murray Mouth region was not available (e.g. river garfish, *Hyporhamphus regularis*; bluespot goby, *Pseudogobius olorum*; marine Australian herring; *Arripis georgianus*), thus information was obtained from studies in locations elsewhere in Australia.

Fish – Chondrichthyans

Sharks



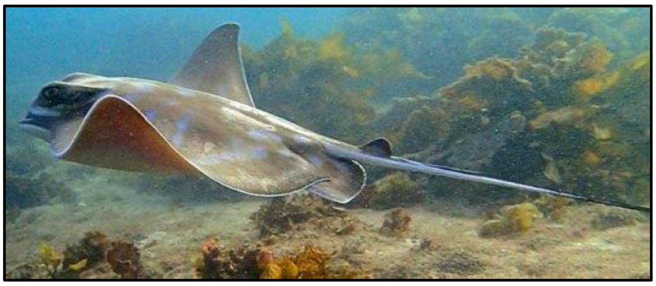
All eight shark species recorded in the Coorong are not found in large abundances and include; bronze whaler shark (*Carcharhinus brachyurus*), broadnose shark (*Notorynchus cepedianus*), Southern smooth hammerhead (*Sphyrna zygaena*), gummy shark (*Mustelus antarcticus*), school shark (*Galeorhinus galeus*), Southern sawshark (*Pristiophorus nudipinnis*), common saw shark (*Pristiophorus cirratus*) and goblin shark (*Mitsukurina owstoni*). Of those shark species, the pelagic bronze whaler and demersal gummy sharks are the most common. Zero shark species are targeted by commercial fisheries in the Coorong and incidental bycatch has not exceeded 4 tonnes per year between 1984 and 2014 (Earl 2015). Recreational catch rates of sharks in the Coorong are unknown.

P/B and Q/B estimates of 0.32 and 2.56 for sharks were based on the median values of bronze whaler and gummy sharks that were calculated for a trophic model of the Gulf St Vincent ecosystem (Goldsworthy et al. 2017b). No biomass data were available, so these parameters were estimated by *Ecopath*. The bronze whaler shark and gummy shark are considered to occur more frequently in the Coorong than the other species in this trophic group, although data are limited. Therefore, diet for this group was based on stomach content data from 250 bronze whalers from the gulfs and ocean waters of South Australia (biomass estimates; Rogers et al. 2012) and 923 gummy sharks from the marine waters off Western Australia (numerical counts; Simpfendorfer et al. 2001). The relative biomass of these shark species in the Coorong is poorly understood, and so diet composition data for this group were calculated as 0.5:0.5 bronze whaler:gummy shark. Most prey species from this group are teleosts, cephalopods, and decapods (Simpfendorfer et al. 2001, Rogers et al. 2012).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	2.56	0.32	0.95
SL	1.0	-	2.56	0.32	0.95

*Estimated by the *Ecopath*

Rays and skates



The Southern eagle ray (*Myliobatis australis*) is the only representative of the rays and skates trophic group but it is not found in the Coorong in large abundances and is rarely captured (Ye et al. 2012). The species is not targeted by commercial fishers in the Coorong and recreational catch rates are unknown (Earl 2015). No biomass data were available for this species with parameters estimated by *Ecopath*. P/B and Q/B estimates of 0.18 and 2.3 were based on the total length (TL) of 190 cm for the Australian population (Gomon et al. 2008). Diet data for Southern eagle ray were based on 173 stomach samples (volumetric estimates) from marine waters off south-western Australia (Sommerville et al. 2011). Diet of Southern eagle ray is carnivorous and mostly consists of molluscs, benthic crustaceans and polychaetes (Sommerville et al. 2011).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	2.3	0.18	0.95
SL	1.0	-	2.3	0.18	0.95

*Estimated by *Ecopath*

Fish - Teleosts

Medium Zoobenthivores/Piscivores

Five species of Medium Zoobenthivores/Piscivores are found in the Coorong ecosystem and include; Australian herring (*Arripis georgianus*), silver trevally (*Pseudocaranx georgianus*), blackspotted gurnard perch (*Neosebastes nigropunctatus*), common gurnard perch (*Neosebastes scorpaenoides*) and reef ocean perch (*Heliocolenus percoides*). Australian herring (*Arripis georgianus*) is the most common species of the Medium Zoobenthivores/Piscivores group and are only found in the North Coorong (Ye et al. 2012). The species is only captured by commercial fishers outside of the Coorong using purse seine nets, gill-nets, haul-nets and handlines and after capture the species is used for recreational fishing bait and human consumption (Goldsworthy et al. 2017). No data exists for recreational catch and effort of Australian herring in the Coorong.

Biomass for Medium Zoobenthivores/Piscivores was estimated in *Ecopath*. P/B and Q/B estimates of 1.64 and 6.32 were based on calculations for Gulf St Vincent (Goldsworthy et al. 2017). Diet for this group was based on diet of Australian herring as this is the most frequently occurring member of this trophic group in the Coorong. Diet was based on volumetric data from 238 stomach samples from a temperate estuary – the Wilson Inlet in Western Australia (Platell et al. 2006). Diet of Australian herring is carnivorous and mostly consists of benthic crustaceans (e.g. shrimp), teleosts and polychaetes (Platell et al. 2006).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	6.32	1.64	0.95
SL	1.0	-	6.32	1.64	0.95

*Estimated by *Ecopath*

Mulloway

Mulloway (*Argyrosomus japonicus*) are a large, migratory teleost fish with predominately adult life stages found in the Coorong (Earl 2020). They are a commercially targeted species that is captured in the Coorong using multiple fishing gears including mesh, swinger and haul nets, and set lines with large fluctuations in average yearly commercial catches ranging from 21 – 45 t (2003 - 2011) to 115 t (2013) (Knuckey et al. 2015; Earl 2020).

Biomass for mulloway was estimated by the *Ecopath* model. P/B and Q/B estimates were 0.22 and 2.5, respectively, based on established asymptote total length (TL) of 138 cm from mulloway Von Bertalanffy growth parameters for the Murray Mouth estuary (Froese and Pauly Binohlan 2000; Ferguson and Ward 2011). Diet of mulloway were sourced from 265 stomach samples from Murray Mouth estuary and North Lagoon sites (Giatas and Ye 2015). Diet is mainly carnivorous and consists of teleosts (e.g. *Aldrichetta forsteri*) and decapod crustaceans (i.e. collectively 74.8 % of diet), but opportunistic feeding also occurs when other crustaceans, annelid worms and insect larvae are consumed (Giatas and Ye 2015).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	2.5	0.22	0.95
SL	1.0	-	2.5	0.22	0.95

*Estimated by *Ecopath*

Medium Marine Demersal Piscivore

Three species of Medium Marine Demersal Piscivores have been recorded in the Coorong ecosystem: red gurnard, Chelidonichthys kumu; Southern sand flathead, *Platycephalus bassensis* and; blue-spotted flathead, *Platycephalus speculato*r. Although rare in the Coorong, of the Medium Marine Demersal Piscovore group, red gurnard and blue-spotted flathead are the two main species that are occasionally found. Neither species are targeted by the Lower Lakes and Coorong fishery. However, blue-spotted flathead are a targeted recreational fishery species elsewhere in South Australia, but there are no recreational fisheries assessments of the species in Coorong waters. The diet of this group (platycephalids and triglids) is mostly teleosts and decapod crustaceans.

Biomass for Medium Marine Demersal Piscivores was estimated in *Ecopath*. P/B and Q/B estimates of 0.46 and 5.1 were median values calculated for red gurnard and blue-spotted flathead in FishBase (Froese and Pauly 2021). Diet data (estimated biomass) for the Medium Marine Demersal Piscivore group were based on the analyses of stomach contents from 6 Blue-spotted flathead, 2 red gurnard and 31 tiger flathead (another platycephalid) from Spencer Gulf, South Australia (Currie and Sorokin 2010). Diet composition data for this group were calculated as 1:1:1 due to the unknown relative biomass of species within this trophic group in the Coorong and the inclusion of data from a platycephalid that has not been recorded in the Coorong.

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	5.1	0.46	0.95
SL	1.0	-	5.1	0.46	0.95

*Estimated by *Ecopath*

Small Demersal Zoobenthivores/Piscivores

Six species of Small Demersal Zoobenthivores/Piscivores have been previously recorded in the Coorong ecosystem: flat-headed gudgeon, *Philypnodon grandiceps*; dwarf Flat-head gudgeon, *Philypnodon macrostomus*; flathead sandfish, *Lesueurina platycephala*; southern crested weedfish, *Cristiceps australis*; Ogilby's weedfish, *Heteroclinus heptaeolus*; longnose weedfish, *Heteroclinus tristis*. flat-headed gudgeon, is the main representative species of the Small Demersal Zoobenthivores/Piscivores found in the Coorong. None of the species in this group are targeted by commercial or recreational fisheries. The diet of this group, based on flat-headed gudgeon, is primarily composed of algae, annelids and crustaceans.

Biomass for Small Demersal Zoobenthivores/Piscivores was estimated by *Ecopath*. P/B and Q/B estimates of 1.32 and 11 were calculated for flat-headed gudgeon in FishBase (Froese and Pauly 2021). Diet for this group was based on diet of flathead gudgeon as this is the most frequently occurring member of this trophic group in the Coorong. Diet was based on volumetric data from 2080 stomach samples from a south-eastern Australian temperate estuary – the Surrey River estuary (Becker and Laurenson 2007).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	11	1.32	0.95
SL	1.0	-	11	1.32	0.95

*Estimated by *Ecopath*

Large Zoobenthivores/Piscivores

The only representative of Large Zoobenthivores/Piscivores found in the Coorong is snapper (*Chrysophrys auratus*), but they are not common. This demersal species is part of a high-value commercial fishery in southern Australia and is targeted by handlines and longlines but is not targeted in Coorong waters (Knight and Tsolos 2009, McGlennon et al. 2000). In the recreational fishing sector, the total number of snapper caught were 487,329 with 52.5 % of those fish released during 2013-14 across South Australia, but few of those are likely to have been captured in Coorong waters (Giri and Hall 2015). Diet for snapper is diverse but mostly consists of benthic decapods (e.g. crabs) and teleosts.

Biomass for Large Zoobenthivores/Piscivores was estimated by *Ecopath*. P/B and Q/B estimates of 0.49 and 3.8 for snapper were based on estimates for Port Phillip Bay and Gulf St Vincent (Fulton and Smith 2004, Goldsworthy et al. 2017, Froese and Pauly 2021). Diet for this group was based on volumetric data from 735 snapper gut samples from the Gulf St. Vincent in South Australia (Lloyd 2010).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	3.8	0.49	0.95
SL	1.0	-	3.8	0.49	0.95

*Estimated by *Ecopath*

Western Australian Salmon

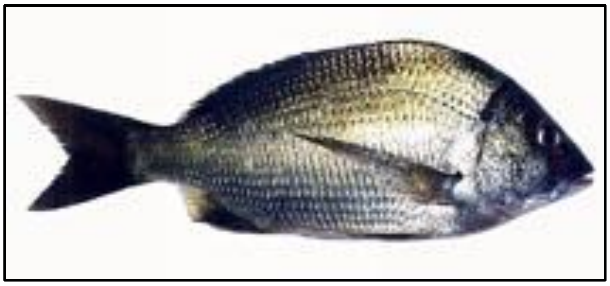
Pelagic mesopredators that occur in the Coorong consist of the Western Australian salmon (*Arripis truttaceus*) (Schilling et al. 2017). Western Australian salmon are common throughout the Coorong, within the Murray Mouth and Coorong regions. Overall, they are a non-targeted species in the Coorong fishery and commercial catches have been low with < 10 tonnes captured in 70 % of years between 1984 to 2014 (Earl 2015).

No biomass data were available for this species. P/B and Q/B estimates were 0.4 and 3.6, respectively, based on established asymptote total length (TL) of 79.9 cm from South-East Australian growth parameters for the species (Froese and Pauly 2021), which also has similar estimates to the Eastern Australian salmon (Hughes et el. 2014). Diet data for Western Australian salmon were based on 78 stomach samples from Murray Estuary sites in the Coorong (Giatas and Ye 2015). Diet of Western Australian salmon is dominated (90% by weight) by teleosts (e.g. smallmouth hardyhead and sandy sprat), but also includes small crustaceans (e.g. amphipods and mysid shrimp) and bivalves (Giatas and Ye 2015).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	3.6	0.4	0.95
SL	1.0	-	3.6	0.4	0.95

*Estimated by *Ecopath*

Black Bream



Black bream (*Acanthopagrus butcheri*) are a temperate sparid species that are common in estuaries and bays across southern temperate Australia (Norriss et al. 2002). Black bream are a popular recreational fishing target and contribute to a small proportion of the Coorong commercial fishery (Ye et al. 2020b). In 2018-19 total commercial catch of black bream from gillnets was 0.7 t and has not been greater than 3 t since 2007 (Earl 2020, Earl et al. 2016, Ye et al. 2020b).

No biomass data were available for blackbream with parameters estimated by the *Ecopath* model. P/B and Q/B estimates were 0.44 and 4.5 respectively (Froese and Pauly 2021, Cottingham et al. 2018). Diet of Black bream were sourced from 14 stomach samples obtained from North Coorong sites (Mundoo, Goolwa and Pelican Point) in March 2007 (Deegan et al. 2010). Diet of black bream is broad, indicative of an opportunistic feeding strategy, with prey including crabs, small-bodied fish (e.g. gobies) other macroinvertebrates (e.g. polychaetes, crustaceans, molluscs) and algae (Lamontagne et al. 2007, Geddes and Francis 2008, Deegan et al. 2010, Giatas and Ye 2015, Lamontagne et al. 2016). In the Coorong population there is clear diet partitioning of small (< 200 mm body length; small-bodied fish and macroinvertebrate prey) versus large size (> 200 mm body length; primarily small-bodied fish) individuals (Lamontagne et al. 2016).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	4.5	0.44	0.95
SL	1.0	-	4.5	0.44	0.95

*Estimated by *Ecopath*

Syngnathids

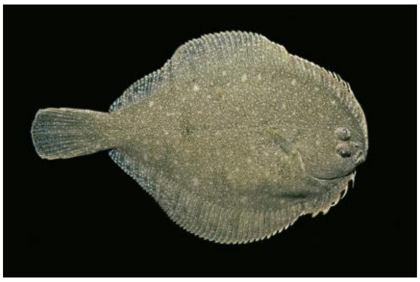

Syngnathid species are not commonly found and only limited to the North Coorong, thus they were removed from the South Lagoon model. The seven species that have occurred in the North Coorong include: rhino pipefish, *Histiogamphelus cristatus*; common seadragon, *Phyllopteryx taeniolatus*; spotted pipefish, *Stigmatapora argus*; potbelly seahorse, *Hippocampus bleekeri*; Verco's pipefish, *Vanacampus poecilolaemus*; big belly seahorse, *Hippocampus abdominalis* and; pug-nose pipefish, *Pugnaso curtirostris*. The Syngnathid group are not commercially or recreationally targeted in the Coorong ecosystem.

No biomass data were available for Syngnathids with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 1.45 and 5.3 were calculated in FishBase (Froese and Pauly 2009). Diet data (estimated biomass) were based on the analysis of 10 stomach samples from several syngnathids (4 common seadragon *Phyllopteryx taeniolatus*, 3 big belly seahorse *Hippocampus abdominalis*, 2 leafy seadragon *Phycodurus eques* and 1 brushtail pipefish *Leptoichthys fistularius*) from Spencer Gulf, South Australia (Currie and Sorokin 2010). The diet of Syngnathids are mostly small crustaceans (e.g. mysids) (Currie and Sorokin 2010).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	5.3	1.45	0.95
SL	N/A	N/A	N/A	N/A	N/A

*Estimated by *Ecopath*

Flounder

Flounder as a group of flatfish in the Coorong consists of two species, greenback flounder (*Rhombosolea tapirina*) and longsnout flounder (*Ammotretis rostratus*). The more common of the two species, *R. tapirina*, is represented by juvenile to adult size classes in the Coorong. The species is targeted by recreational (0.27 t from all South Australian waters in 2013-14), traditional (unknown catch rate) and commercial fisheries (0.27 t in 2014-15 for Coorong waters) (Earl and Ye 2016). Flounder in the Coorong are targeted using multiple fishing gears including mesh, haul and ring nets, and hand-held spears in the recreational and traditional fisheries sectors (Earl and Ye 2016).

No biomass data were available for Flounder with parameters estimated by the *Ecopath* model. P/B and Q/B estimates were 1.44 and 12.8, respectively, based on established asymptote total length (TL) of 34 cm from greenback flounder growth curves for the Coorong ecosystem (Earl 2014, Froese and Pauly 2021). Diet of greenback flounder were sourced from 398 stomach samples from Murray Mouth estuary and North Lagoon sites (Earl 2014). Diet for longsnout flounder was based on amalgamated volumetric data from 3 gut samples from Godfrey's Landing and Long Point in the Coorong (Giatas et al. 2022) and, due to low sample sizes in the Coorong, 54 gut samples from Frederick Henry Bay in Tasmania (Crawford 1984). Diet composition data for this group were calculated as 0.95:0.05 greenback flounder:longsnout flounder as this was estimated to be the biomass ratio of the two major species within this trophic group. Diet of greenback flounder in the Coorong ecosystem varies ontogenetically and mainly consists of amphipods, copepods and bivalves for juvenile size classes, and the polychaete species *Nephtys australiensis*, amphipods and bivalves for adult size classes (Earl 2014). Longsnout flounder have a similar diet in the Coorong, which is dominated by amphipods (Giatas et al. 2022).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	12.8	1.44	0.95
SL	1.0	-	12.8	1.44	0.95

*Estimated by *Ecopath*

Yelloweye mullet

Yelloweye mullet (*Aldrichetta forsteri*) are pelagic, marine opportunists and are represented by all size classes as one of the most abundant fish species in the Coorong (Noell et al. 2009, McNeil et al. 2013, Ye et al. 2013). In the recreational fishing sector, yellow-eye mullet is an important target species and in 2013-14 19.4 t (71, 278 fish) were retained and 29, 458 fish caught and released across South Australia (Giri and Hall 2015, Earl 2020). The commercial catch of yelloweye mullet in the Coorong has fluctuated across the years since the early 1990s (346 t) to early 2000s (110 t), 2007 to 2011 (206 – 243 t) and mid 2010s (121 t) (Earl 2020).

No biomass data were available for Yelloweye mullet with parameters estimated by the *Ecopath* model. P/B and Q/B estimates were 1.3 and 14.2, respectively, based on established asymptote total length (TL) of 27 cm from Yelloweye mullet Von Bertalanffy growth parameters for the Coorong (Froese and Pauly 2021, Earl and Ferguson 2013). Diet of Yelloweye mullet were sourced from 101 stomach samples from Murray Mouth estuary and, North and South Lagoon sites (Giatas 2012).Diet of yelloweye mullet was based on the amalgamation of volumetric data from 101 gut samples from Murray Estuary, North Lagoon and South Lagoon sites during a high flow period (Giatas 2012) and frequency of occurrence data from 135 gut samples from Murray Estuary sites (Goolwa, Mundoo and Pelican Point) during a drought period (Deegan et al. 2010) to best represent a broad range of environmental conditions. Yelloweye mullet diet is omnivorous, largely consisting of detritus, algae, polychaetes (e.g. *Capitella* spp.), amphipods, copepods, and chironomid larvae (Lamontagne et al. 2007, Giatas 2012).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	14.2	1.3	0.95
SL	1.0	-	14.2	1.3	0.95

*Estimated by *Ecopath*

Smallmouth hardyhead

Smallmouth hardyhead are a small-bodied euryhaline species found in estuaries, embayments and lagoons from New South Wales to Spencer Gulf in South Australia (Lui 1969, McDowall 1980, Molsher et al. 1994, Ye et al. 2017). This species adapts well to hypersaline conditions in the Coorong and has been observed in parts of the Coorong with salinity levels up to 130 psu (Noell et al. 2009). The species is not targeted by commercial or recreational fisheries.

No biomass data were available for Smallmouth hardyhead with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 1.53 and 22.5 were based on the TL of 10 cm that they can reach in their one-year lifespan (Froese and Pauly 2021, Ye et al. 2013, Ye et al. 2017). Detailed diet information for smallmouth hardyhead is available from the Coorong. For spatial and temporal resolution, diet of this species was based on the amalgamation of importance (IRI) data from 546 gut samples from Murray Estuary and Lower Lakes sites during a high flow period (Silvester et al. unpublished, presented in Ye et al. 2020b), and frequency of occurrence data from 266 gut samples from Murray Estuary, North Lagoon and South sites (Hossain et al. 2017) and from 41 gut samples from Murray Estuary sites (Goolwa, Mundoo and Pelican Point) during a drought period (Deegan et al. 2010), in the Coorong.

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	26.1	1.5	0.95
SL	1.0	-	22.5	1.5	0.95

*Estimated by *Ecopath*

Medium Zoobenthivores


Twelve species of Medium Zoobenthivores occur in the North Coorong and include: soldier, *Gymnapistes marmoratus*; estuary cobbler, *Cnidoglanis macrocephalus*; yellowfin whiting, *Sillago schomburgkii*; King George whiting, *Sillaginodes punctatus*; Southern school whiting, *Sillago bassensis*; Eastern school whiting, *Sillago flindersi*; little weed whiting, *Neodax balteatus*; longray weed whiting, *Siphonognathus radiatus*; magpie perch, *Cheilodactylus nigripes*; old wife, *Enoplosus armatus*; ornate cowfish, *Aracana ornate*; blue weed whiting, *Haletta semifasciata*. Medium Zoobenthivores do not historically occur in the South lagoon and were not included in the model for that domain. Soldier is the main representative of this trophic group and occurs relatively frequently in the Coorong compared to the other species within this trophic group. None of the species in this group are targeted by the Coorong Lower Lakes Fishery, but some are occasionally captured by recreational fishers (e.g. *Sillaginodes punctatus*, *Sillago* spp.).

No biomass data were available for Medium Zoobenthivores with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 0.5 and 6.6 were calculated as median values for soldier and King George whiting in FishBase (Froese and Pauly 2009). Diet data for this group were based on the stomach analysis of 20 juvenile soldiers from Barker Inlet, South Australia (frequency of occurrence data; Meakin and Qin 2020). However, to capture the diet diversity of this broad group, diet data was also included from the stomach content analysis of a sillaginid, King George whiting (19 samples, biomass data) from Spencer Gulf, South Australia (Currie and Sorokin 2010). Diet composition data for this group were calculated as 0.8:0.2 soldier:other (Sillagnidae) as this was estimated to be the biomass ratio of the species within this trophic group. Diet mostly consists of benthic crustaceans (e.g. amphipods), but also includes copepods and annelids.

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	6.6	0.5	0.95
SL	N/A	N/A	N/A	N/A	N/A

*Estimated by *Ecopath*

Toadfishes and Leatherjackets


The oadfishes and Leatherjackets found in the North Coorong consists of three Toadfish and eight Leatherjacket species: smooth toadfish, *Tectractenos glaber*; prickly toadfish, *Contusus brevicaudus*; barred toadfish, *Contusus richei*; bridled leatherjacket, *Acanthalateres spilamelanurus*; southern pygmy leatherjacket, *Brachaluteres jacksonianus*; gunn's leatherjacket, *Eubalichthys gunnii*; sixspine leatherjacket, *Mueschenia freycineti*; rough leatherjacket, *Scobinichthys granulatus*; toothbrush leatherjacket, *Acanthalateres vitteger*; brownstriped leatherjacket, *Mueschenia australis*; velvet leatherjacket, *Mueschenia scaber*. Smooth and prickly toadfishes are the two most frequently occurring members of this trophic group in the North Coorong (Ye et al. 2012). They have not historically been recorded as occurring in the South Lagoon and were removed from that model domain. Toadfishes and Leatherjackets are not a targeted species by commercial or recreational fisheries in the Coorong.

No biomass data were available for Toadfishes and Leatherjackets with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 1.06 and 18.5 were based on the median values of smooth and prickly toadfishes calculated from FishBase (Froese and Pauly 2021). Diet data were sourced from South Australian coastal waters and based on stomach analyses of 40 smooth toadfish from Basham beach and Long Beach (volumetric, Baring et al. 2018) and 7 prickly toadfish from Spencer Gulf (mass, Robertson 1984). Biomass data were estimated by the *Ecopath* model. Diet composition data for this group were calculated as 0.8:0.2 smooth toadfish:prickly toadfish as this was estimated to be the biomass ratio of the two major species within this trophic group. The diet of these species is primarily composed of benthic crustaceans.

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	18.5	1.06	0.95
SL	N/A	N/A	N/A	N/A	N/A

*Estimated by *Ecopath*

Small demersal omnivore/zoobenthivore

The Small Demersal Omnviore/Zoobenthivores found in the Coorong consists of four species: bluespot goby, *Pseudogobius olorum*; bridled goby, *Arenigobius bifrenatus*; Southern longfin goby, *Favonigobius lateralis*; Tasmanian blenny, *Parablennius tasmanianus*. The bluespot and bridled gobies are the two most frequently occurring members of this trophic group in the Coorong (Ye et al. 2012). Small Demersal Omnivore/Zoobenthivores are not a group that are targeted by commercial or recreational fisheries in the Coorong.

P/B and Q/B estimates of 2.19 and 43.8 were based on the median TL for bluespot and bridled gobies (4.3 cm and 10.1 cm TL) found in the Coorong and L∞ 4.3 cm for bluespot gobies in the Swan estuary, Western Australia (Christensen and Pauly 1992; Gill et al. 1996; Bice et al. 2017). Volumetric data were sourced from temperate estuaries and bays in south-eastern Australia and based on stomach analysis of 613 bluespot goby from the Surrey River estuary (Becker and Laurenson 2007) and 188 bridled goby from Western Port (Robertson 1984). Biomass data were estimated by the *Ecopath* model. Diet composition data for this group were calculated as 0.7:0.3 bluespot goby:bridled goby as this was estimated to be the biomass ratio of the two major species within this trophic group. The diets of these species are composed of algae, detritus, and a diversity of benthic invertebrates (e.g. small crustaceans (amphipods, ostracods) gastropods, insects and polychaetes) (Robertson 1984, Becker and Laurenson 2007).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	43.8	2.19	0.72
SL	1.0	-	43.8	2.19	0.94

*Estimated by *Ecopath*

Small Demersal Zoobenthivores

Small Demersal Zoobenthivores consist of three species that are all regularly found in the Coorong: congolli, *Pseudaphritis urvillii*; Tamar goby, *Afurcagobius tamarensis* and lagoon goby, *Tasmanogobius lasti* (Ye et al. 2012). None of the three species are targeted by commercial or recreational fisheries in Coorong waters.

No biomass data were available for Small Demersal Zoobenthivores with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 1.53 and 22.5 were based on the median values of congolli, and Tamar and lagoon gobies, with recalculations for lagoon Goby based on data from the Coorong population (8 cm TL; Hossain et al. 2016). Diet for this group was based on the gut content analyses of congolli, Tamar goby and lagoon goby from the Coorong. Volumetric data for congolli (255 samples, Giatas and Ye 2015) and lagoon goby (91 samples, Giatas et al. 2022) were from sites in the Murray Estuary and North Lagoon. Diet for Tamar goby was based on the amalgamation of importance (IRI) data from 305 samples from Murray Estuary and Lower Lakes sites (Silvester et al. unpublished, presented in Ye et al. 2020) and frequency of occurrence data from 118 samples from Murray Estuary, North Lagoon and South sites (Hossain et al. 2017). Diet composition data for this group were calculated as 0.4:0.4:02 congolli:Tamar goby:lagoon goby as this was estimated to be the biomass ratio of the major species within this trophic group. Diet of congolli, Tamar goby and lagoon goby in the Coorong is predominately amphipods (Giatas and Ye 2015, Giatas et al. 2022, Silvester et al. unpublished), although congolli consume greater proportions of teleosts and polychates (Giatas and Ye 2015).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	22.5	1.53	0.95
SL	1.0	-	22.5	1.53	0.95

*Estimated by *Ecopath*

Sandy sprat (*Hyperlophus vittatus*)

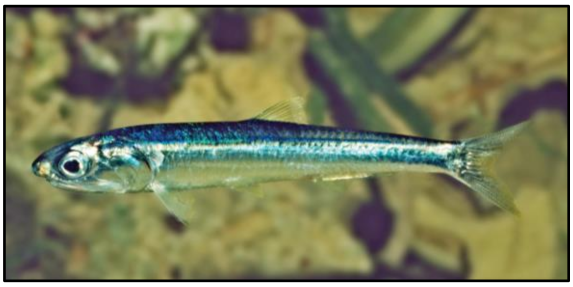
Sandy sprat that occur in the Coorong are estuarine opportunists (Ye et al. 2012) and are also found at all life stages in Spencer Gulf and Gulf St Vincent estuaries (Rogers and Ward 2007). Commercial beach-seine fisheries exist for sandy sprat in Western Australia, New South Wales and Queensland, but the species is not commercially targeted in South Australia (Rogers and Ward 2007).

Biomass data were estimated by the *Ecopath* model. P/B and Q/B estimates of 1.89 and 12.6 for sandy sprat were based on the asymptotic growth (L_{00} Total Length) for South Australian waters that include Spencer Gulf, Gulf St Vincent and the Coorong (Rogers and Ward 2007, Froese and Pauly 2021). Diet of sandy sprat was based on the amalgamation of frequency of occurrence data from 190 gut samples from Murray Estuary and North Lagoon sites (Hossain et al. 2017), and numerical data from 60 gut samples from Murray Estuary sites (Bice et al. 2016a), in the Coorong. Diet of sandy sprat is dominated by small pelagic and benthic crustaceans such as harpacticoid copepods, ostracods, amphipods and cladocerans (Bice et al. 2016a, Hossain et al. 2017).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	12.6	1.89	0.07
SL	1.0	-	12.6	1.89	0.95

*Estimated by *Ecopath*

Small-Medium Marine Pelagic Zooplanktivores



Small-Medium Marine Pelagic Zooplanktivores consist of four species in the North Coorong. Australian anchovy (*Engraulis australis*), Australian pilchard (*Sardinops sagax*) and blue sprat (*Spratelloides robustus*) are the three species that occasionally venture from the Southern Ocean, through the Murray Mouth, and into the North Coorong. In comparison, yellowtail scad (*Trachurus novaezelandiae*) are rarely found in the Coorong. Small-Medium Marine Pelagic Zooplanktivores have not historically been recorded in the South Lagoon and were not included in that model domain. None of the species in the Small-Medium Marine Pelagic Zoolpanktivores are targeted by commercial and recreational fishing in the Coorong.

Biomass data were estimated by the *Ecopath* model. P/B and Q/B estimates of 1.05 and 14.53 were based on the median values of Australian anchovy, Australian pilchard and blue sprat, with recalculations for Blue Sprat using total length values from South Australian Gulf St Vincent and Spencer Gulf populations (Rogers et al. 2003, Froese and Pauly 2021, Goldsworthy et al. 2017). Diet data (biomass) for the Small-Medium Marine Pelagic Zooplanktivores group were based on the analyses of stomach contents from 218 Australian

Pilchard, 15 Australian Anchovy and 17 Blue Sprat from the Great Australian Bight in southern Australia (Daly 2007). Diet composition data for this group were calculated as 0.5:0.25:025 Australian anchovy:Australian pilchard:blue sprat as this was estimated to be the biomass ratio of the major species within this trophic group. Diet of this group mainly consists of pelagic crustaceans (e.g. zooplankton).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	14.53	1.05	0.95
SL	N/A	N/A	N/A	N/A	N/A

*Estimated by *Ecopath*

Small Freshwater Pelagic Zooplanktivores/Insectivores

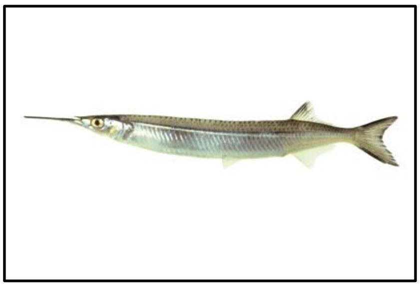
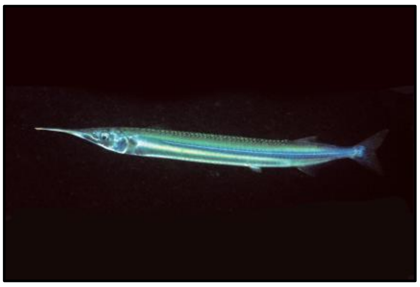
Small Freshwater Pelagic Zooplanktivores/Insectivores consist of eight species in the Coorong: Australian smelt, *Retropinna semoni*; common galaxias, *Galaxias maculatus*; mountain galaxias, *Galaxias olidus*; climbing galaxias, *Galaxias brevipinnis*; Murray hardyhead, *Craterocephalus fluviatilus*; un-specked hardyhead, *Craterocephalus stercusmuscarum fulvus*; Eastern gambusia, *Gambusia holbrooki*; carp gudgeon spp., *Hypseleotris* spp.;. Australian smelt and common galaxias are the two most common members of this trophic group in North Coorong waters and have not historically been recorded in the South lagoon, thus they were removed from that model domain (Ye et al. 2012). None of the species in the Small Freshwater Pelagic Zooplanktivores/Insectivores are commercially or recreationally targeted in the Coorong. The diets of Australian smelt and common galaxias are dominated (>65 % by volume) by aquatic insects (King 2005, Becker and Laurenson 2007).

P/B and Q/B estimates of 1.37 and 30 were based on the median values of Australian smelt and common galaxias, with recalculations using available asymptotic growth parameters for common galaxias from a riverine Western Australian population ($L\infty$91 mm, K = 1.08; Chapman et al. 2006, Froese and Pauly 2021). Volumetric data were sourced from temperate estuaries and rivers in southern Australia and based on stomach analysis of 508 common galaxias from the Surrey River estuary (Becker and Laurenson 2007) and 123 Australian smelt from the Broken River (King 2005). Biomass data were estimated by the *Ecopath* model. Diet composition data for this group were calculated as 0.7:0.3 common galaxias:Australian smelt as this was estimated to be the biomass ratio of the two major species within this trophic group.

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	30	1.37	0.95
SL	N/A	N/A	N/A	N/A	N/A

*Values in brackets estimated by the *Ecopath* model

Garfish

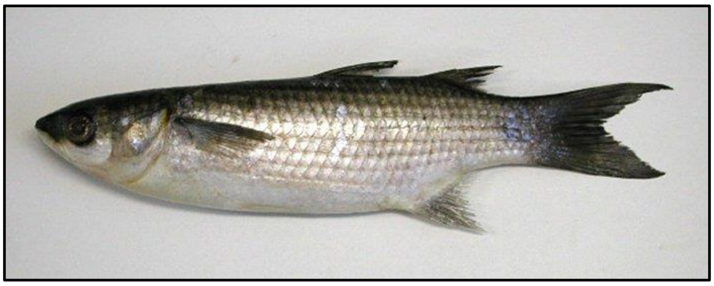
River garfish (*Hyporhamphus regularis*) that occur in the Coorong are a freshwater-brackish species that are commonly found in southern Australian estuaries (Gillanders et al. 2008). In comparison, the Southern garfish (*Hyporhampus melanochir*) is less common in the Coorong. Both River and Southern garfish species are within the Hemiramphidae family that are known for an herbivorous/omnivorous diet (Carseldine and Tibbetts 2005, Earl et al. 2011). Neither species of Hemiramphidae found in the Coorong are commercially targeted by the Lakes and Coorong Fishery (LCF) and recreational catch estimates are unknown (Earl 2015).

No biomass data were available for Garfish with parameters estimated by the *Ecopath* model. PB and Q/B estimates of 0.89 and 18.3 for garfish were based on the more commonly targeted Southern garfish in other South Australian fisheries outside of the LCF (Jones 1990, Froese and Pauly 2009). Diet for this group was based on diet of river garfish as this is the most frequently occurring member of this trophic group in the Coorong. There are no published diet data for river garfish in South Australia or the Coorong region, so data (250 gut samples, frequency of occurrence) were sourced and limited to a tropical bay; Stradbroke Island, Queensland (Tibbets and Carseldine 2005). The diet of this species is primarily composed of seagrass and algae, but also includes insects and small crustaceans (e.g. copepods).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	18.3	0.89	0.95
SL	1.0	-	18.3	0.89	0.95

*Values in brackets estimated by the *Ecopath* model

Other mugilids (mullets)




Other mugilids that occur in the Coorong include the goldspot mullet (*Liza argentea*) and sea mullet (*Mugil cephalus*). The species are not target by commercial fishers in the Coorong and recreational catch data is unknown.

No biomass data were available for Other mugilids with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 0.6 and 16.7 for Other mugilids was based on the median obtained from FishBase for the two species (Christensen and Pauly 1992). No biomass data were available for these species with parameters estimated by the model. There are no published data on the diet of goldspot and sea mullets from the Coorong region. Volumetric diet data were sourced from the analysis of gut samples from 110 goldspot mullet from Moreton Bay, Queensland (Morton et al. 1987), and from 46 sea mullet from the Wilson Inlet, Western Australia (Platell et al. 2006). Diet composition data for this group were calculated as 0.7:0.3 goldspot mullet:sea mullet as this was estimated to be the biomass ratio of the two major species within this trophic group. The diets of goldspot and sea mullet are predominantly algae (including diatoms), detritus and microcrustaceans (Morton et al. 1987, Platell et al. 2006).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	16.7	0.6	0.95
SL	1.0	-	16.7	0.6	0.95

*Estimated by *Ecopath*

Bony herring

Bony herring (*Nematolosa erebi*) are omnivorous generalists that are native to the Murray-Darling Basin and are commonly found in the Coorong due to outflows through the Barrages (Balcombe et al. 2005, Balcombe et al. 2012) The species is commonly captured by commercial fishers in the Coorong using many gear types, but has been below the annual CPUE of 600 tonnes since 1998-99, compared to much higher annual CPUE up to 1100 tonnes in the late 1980s/early 1990s (Earl 2015). No estimates are currently available for recreational catches of bony herring in the Coorong (Earl 2020).

No biomass data were available for bony herring with parameters estimated by the *Ecopath* model. P/B and Q/B estimates of 0.8 and 4.9 for bony herring were based on total Length (TL) of 37.9 cm recorded from lower River Murray populations (Puckridge and Walker 1990, Stocks et al. 2019) and correction for water temperature of 17.5°C (median for Coorong waters) (Froese and Pauly 2021). Diet of bony herring were based on 98 gut samples from freshwater sites in the lower River Murray, South Australia (Atkins 1984). To get a more comprehensive summary, frequency of occurrence data were averaged across fish size groups. The diet of bony herring is mostly detritus, algae and microcrustaceans (Atkins 1984).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	4.9	0.8	0.95
SL	1.0	-	4.9	0.8	0.95

*Estimated by *Ecopath*

Medium omnivores/herbivores

The medium omnivores/herbivores found in the Coorong consists of six species: Western striped grunter, *Helotes octolineatus*, prev. *Pelates octolineatus*; zebrafish, *Girella zebra*; luderick, *Girella tricuspidata*; sea sweep, *Scorpis aequipinnis*; spangled perch, *Leiopotherapon unicolor* and silver perch, *Bidyanus bidyanus*. None of the species are found in high abundances, and the Western striped grunter is the only species that has been captured across some annual monitoring surveys in the North Coorong only, thus the group was removed from the South lagoon model domain (Ye et al. 2012). No species in this group are targeted by commercial fisheries in the Coorong. Recreational fishing for species in this group is currently unknown for the Coorong.

P/B and Q/B estimates of 1.06 and 17.2 were calculated using asymptotic growth model estimates of $L\infty$ = 21.5 cm for the species in its western tropical range (Veale et al. 2015, Christensen and Pauly 1992). Biomass data were estimated by the *Ecopath* model with a value at 0.03 t/km^2 for the North Coorong. Diet for this group was based on diet of Western striped grunter as this is the most frequently occurring member of this trophic group in the Coorong. Diet was based on volumetric data from 6 stomach samples from marine waters in Spencer Gulf, South Australia (Currie and Sorokin 2010). The diet of this group is primarily composed of algae, annelids and crustaceans.

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	17.2	1.06	0.95
SL	N/A	N/A	N/A	N/A	N/A

*Estimated by *Ecopath*

Macroinvertebrates

Macroinvertebrates found in the Coorong ecosystem were separated into nine trophic groups. The divisions consisted of five benthos specific macroinvertebrate groups (i.e. Benthic decapods, Benthic Annelids, Benthic Deposit-feeding Annelids, Benthic Micro-molluscs, Subtidal Benthic Molluscs), Bentho-pelagic Crustaceans, Insect Larvae/Pupae, Zooplankton and the habitat-forming tubeworm *Ficopomatus enigmaticus*. Macroinvertebrate group production/biomass (P/B) estimates were calculated from Coorong macroinvertebrate survey data obtained every four weeks during August 2020 to December 2021. Trophic levels and consumption/biomass (Q/B) estimates for macroinvertebrates were calculated using *Ecopath* or obtained from literature of other food web studies undertaken in estuaries globally (Pauly and Christensen 1992).

Benthic Decapods

Benthic Decapods in the Coorong consist of five species with common shore crab (*Paragrapsus gaimardii*) being the most common and three shrimp taxa occurring occasionally (Panaeidae, Palaemonidae, Caridea) in the North Coorong. The freshwater yabby (*Cherax destructor*) is rarely recorded in the North Coorong. No historical records of Benthic Decapod occurrences exist from the South Lagoon and thus were removed from that model domain. No historic Benthic Decapod biomass estimates are available, and they were not sampled in North Coorong in 2020-21 by Dittmann et al. (2022). The P/B value estimate of 3.28 was based on Coorong survey production-biomass data in 2020-21 and the median consumption-biomass (Q/B) value of 13.0 was estimated from similar Benthic Decapod species in the food web model of Gulf St Vincent and trophic assessment of Port Phillip Bay (Robertson 1984; Goldsworthy et al. 2017). Diet of Benthic Decapods is omnivorous and consists of other invertebrates and carrion (Poore 2004).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	13	3.28	0.95
SL	N/A	N/A	N/A	N/A	N/A

* Estimated by the *Ecopath* model

Benthic Annelids


Benthic Annelids in the Coorong consist of five species and are all mainly found in the North Coorong: Arenicolidae; Nereididae, *Australonereis ehlersi*, *Simplisetia aequisetis*; Phyllodocidae, *Phyllodoce novaehollandiae*; Spionidae, *Boccardiella limnicola*. Biomass estimates for Benthic Annelids were based on monthly survey data from the Coorong in 2020-21 at 17.7 t/km^2 for the North Coorong. They were not sampled in South Lagoon in 2020-21 by Dittmann et al. (2022). P/B and Q/B value estimates of 6.11 and 20.90 were based on Coorong monthly survey production-biomass data in 2020/21 and median consumption-biomass values of similar Benthic Annelids from food web models in the: Labrador Sea, Canada (Bundy 2001); Venice lagoon, Italy (Pranovi et al. 2003); Mondego Estuary, Portugal (Patricio and Marques 2006); Alvarado coastal lagoon, Mexico (Cruz-Escalona et al. 2007); Catalan Sea, Spain (Coll et al. 2009); East China Sea, China (Li et al. 2009) and; Tyrrhenian and Balearic Seas, Corsica (Albouy et al. 2010). Diet of Benthic Annelids is broad, species dependant and largely omnivorous ranging from other annelids to crustaceans, molluscs, organic matter and detritus (Beesley et al. 2000).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	17.72290	20.9	6.11	-
SL	1.0	0.000000	20.9	6.11	-

*Estimated by *Ecopath*

Benthic Deposit-feeding Annelids

Benthic Deposit-feeding Annelids in the Coorong consist of capitellids (Capitellidae) and oligochaetes (Oligochaeta) that are found through both North Coorong and South Lagoon, but in much lower abundances in the southern Coorong (Dittmann et al. 2015). Biomass estimates were calculated from capitellids and oligochaetes obtained in monthly surveys during 2020-21 at 6.5 t/km^2 and 0.00069t/km^2 for the North Coorong and South Lagoon, respectively (Dittmann et al. 2022). P/B and Q/B estimates of 7.98 and 13.0 were based on Coorong monthly survey production-biomass data in 2020-21 and median consumption-biomass values of capitellids from the food web model in Mondego Estuary, Portugal (Patricio and Marques 2006). Diet of Benthic Deposit-feeding Annelids is mostly organic matter, algae, bacteria and detritus (Beesley 2000; Giere 2006).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	6.53513	13	7.98	-
SL	1.0	0.00069	13	7.98	-

*Estimated by *Ecopath*

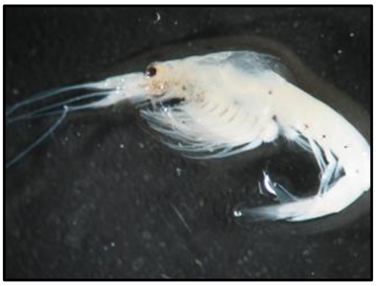
Tubeworm

The Tubeworm *Ficopomatus enigmaticus* is an annelid that lives in colonies of large calcium-carbonate structures as reefs in bare sediments of the Coorong (Dittmann et al. 2009). Biomass estimates were based on Coorong surveys in 2020-21 with values at 0.1782 t/km^2 and 0t/km^2 (absent) in the North Coorong and South Lagoon, respectively (Dittmann et al. 2022). P/B and Q/B value estimates of 6.11 and 20.90 were based on Coorong monthly survey production-biomass data in 2020-21 and median consumption-biomass values of benthic annelids from food web models in the: Labrador Sea, Canada (Bundy 2001); Venice lagoon, Italy (Pranovi et al. 2003); Mondego Estuary, Portugal (Patricio and Marques 2006); Alvarado coastal lagoon, Mexico (Cruz-Escalona et al. 2007); Catalan Sea, Spain (Coll et al. 2009); East China Sea, China (Li et al. 2009) and; Tyrrhenian and Balearic Seas, Corsica (Albouy et al. 2010). The Tubeworms sit in the water column and filter-feed in suspension while capturing small food particles such as plankton, organic matter and detritus (Davies et al. 1989).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	0.17822	20.9	6.11	-
SL	1.0	0.00000	20.9	6.11	-

*Estimated by *Ecopath*

Bentho-pelagic Crustaceans

Bentho-pelagic crustaceans in the Coorong consist of three taxa; amphipods (Amphipoda) and ostracods (Ostracoda) shrimps that are found throughout both North and South Lagoons and mysids (Mysida) that are restricted to the North Coorong (Dittmann et al. 2018). Biomass estimates were calculated by the *Ecopath* model for amphipods as they are the most abundant Bentho-pelagic Crustacean taxa in the Coorong (Dittmann et al. 2015). Biomass values were estimated at 15.31086 t/km^2 and 0.00595t/km^2 in the North Coorong and South Lagoon, respectively (Dittmann et al. 2022). P/B and Q/B estimates of 8.55 and 12.0 were based on Coorong monthly survey production-biomass data in 2020-21 and median consumption-biomass values of amphipods from the food web models in the; Venice lagoon, Italy (Pranovi et al. 2003); Mondego Estuary, Portugal (Patricio and Marques 2006) and Tyrrhenian and Balearic Seas, Corsica (Albouy et al. 2010). Diet of Bentho-pelagic Crustaceans consists of algae, detritus and fine organic matter (Fenton 1986, Rysgaard et al. 1995).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	15.31086	20.5	8.61	-
SL	1.0	0.00595	12.0	8.55	-

*Estimated by *Ecopath*

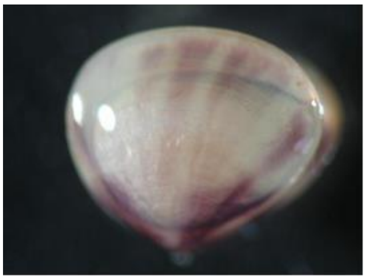
Insect Larvae/Pupae


Insect Larvae/Pupae in the Coorong consist of three main taxa (non biting midges, Chironimidae; true bugs, Hemiptera and; true flies, Diptera) and a range of other occasional insect larvae and nymphs (Dittmann et al. 2015, Dittmann et al. 2018). Biomass estimates were calculated by the *Ecopath* model with values at 1.42545 t/km^2 and 1.32959 t/km^2 in the North Coorong and South Lagoon, respectively (Dittmann et al. 2022). P/B estimates of 8.52 (NC) and 8.38 (SL), and Q/B estimates of 12.0 (both NC and SL) were based on Coorong monthly survey production-biomass data in 2020-21. Median consumption-biomass (Q/B) values of Insect Larvae/Pupae were obtained from another food web model in Laguna de Bay, Philippines (Reyes and Martens 1994). Diet of Insect Larvae/Pupae consists of other insect larvae/pupae and benthic annelids for predatory species or life stages, and filamentous algae, phytoplankton and detritus (Mullen and Hriber 1988, LaSalle and Bishop 1990, Gooderham and Tsyrlin 2003).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	1.42545	20.0	8.52	-
SL	1.0	1.32959	20.0	8.38	-

*Estimated by *Ecopath*

Benthic Micro-molluscs

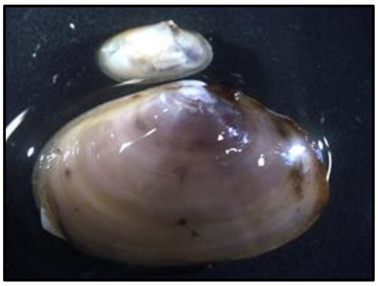


Benthic Micro-molluscs consist of three taxa that are found in the Coorong; micro-bivalve, *Arthritica semen*; air-breathing snail, *Salinator fragilis* and estuarine snail, Hydrobidae (Dittmann et al. 2015, Dittmann et al. 2018). Biomass estimates were based on Benthic Micro-molluscs collected in monthly surveys during 2019-20 with values at 50.02911 t/km^2 and 0.00050 t/km^2 in the North Coorong and South Lagoon, respectively (Dittmann et al. 2022). P/B estimates of 6.16 (NC) and 5.95 (SL), and Q/B estimates of 10.26 (both NC and SL) were based on Coorong monthly survey production-biomass data in 2020-21. Median consumption-biomass (Q/B) values of of Benthic Micro-molluscs were obtained from other food web models in the; Venice lagoon, Italy (Pranovi et al. 2003); Mondego Estuary, Portugal (Patricio and Marques 2006) and Tyrrhenian and Balearic Seas, Corsica (Albouy et al. 2010). Diet of Benthic Micro-molluscs consists of phytoplankton and detritus (Wells and Threlfall 1982, Roach and Lim 2000, Ponder et al. 1991).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE*
NC	1.0	50.02911	10.26	6.16	-
SL	1.0	6.52581	10.26	5.95	-

*Estimated by *Ecopath*

Subtidal Benthic Molluscs

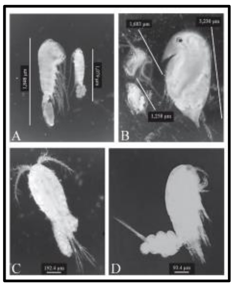


Subtidal Benthic Molluscs consist of three taxa that are found in the Coorong; white sunset shell, *Hiatula alba*; triangular cockle, *Spisula trigonella* and tellins, Tellinidae. (Dittmann et al. 2015, Dittmann et al. 2018). Biomass estimates were based on Subtidal Benthic Molluscs collected in monthly surveys during 2019-20 with values at 7.0673t/km^2 and 0 t/km^2 (absent) in the North Coorong and South Lagoon, respectively (Dittmann et al. 2022). P/B estimates of 6 (NC) and 2.85 (SL), and Q/B estimates of 10.6 (both NC and SL) were based on Coorong monthly survey production-biomass data in 2020-21. Median consumption-biomass (Q/B) values of Subtidal Benthic Molluscs were obtained from other food web models in the; Venice lagoon, Italy (Pranovi et al. 2003); Mondego Estuary, Portugal (Patricio and Marques 2006) and Tyrrhenian and Balearic Seas, Corsica (Albouy et al. 2010). Diet of micro-molluscs consists of phytoplankton and detritus (Murwaski and Serchuk 1982, Lamprell and Whitehead 1992, Matthews and Fairweather 2003).

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE
NC	1.0	7.06730	10.6	6	(0.24)
SL	1.0	0.00000	10.6	2.85	0.95

*Values in brackets estimated by the *Ecopath* model

Zooplankton



Zooplankton in the Coorong consist of multiple taxa (e.g. amphipods, copepods, ostracods, rotifers, crab zoea and megalopa) (Shiel and Aldridge 2011, Shiel and Tan 2013, Leterme et al. 2018). Biomass estimates were calculated by the *Ecopath* model. Median P/B and Q/B estimates of 160 and 20 were obtained from other food web models in the: Mondego Estuary, Portugal (Patricio and Marques 2006); Catalan Sea, Mediterranean (Coll et al. 2006, Coll et al. 2009) Gulf of Mexico, Baja California (Cruz-Escalona et al. 2007); Peruvian upwelling system, Peru (Guenette et al. 2008) and Rio da Aveiro, Portugal (Bueno-Pardo et al. 2018). Diet of zooplankton mainly consists of phytoplankton and detritus (Richardson et al. 2019).

REGION	HABITAT FRACTION	B IN HABITAT AREA*	Q/B	P/B	EE
NC	1.0	-	160	20	0.95
SL	1.0	-	160	20	0.95

*Estimated by *Ecopath*

Primary Producers

Primary Producers in the Coorong ecosystem consisted of three separate groups; two macro-organisms (Macrophytes and Filamentous Algae) and one group of micro-organisms (Phytoplankton). Filamentous Algae and Macrophyte biomass values were obtained from the researchers of 'Component 2 - Investigating the drivers and control of filamentous algae and restoration of aquatic plants in the Coorong' group for the Healthy Coorong, Healthy Basin – Trials and Investigations project.

REGION	FILAMENTOUS ALGAE T KM^{-2}	MACROPHYTES T KM^{-2}
Central	830.709	47.3067
North	601.575	43.9247
South	160.360	50.5149

Macrophytes

The Macrophytes in the Coorong considered for the food web model included only one seagrass Genera as the major contributor to the ecosystem (*Ruppia* spp.) (Asanopolous and Waycott 2020). Biomass estimates were calculated from samples obtained during 2021 by the University of Adelaide research team of Component 2 of the HCHB project. Those biomass values were 47.31 t/km^2 and 5 t/km^2 in the North Coorong and South Lagoon, respectively. Median P/B estimates of 7.08 (NC) and 117.52 (SL) were obtained from another food web model in the Gulf of Mexico, Baja California (Cruz-Escalona et al. 2007) and adjusted during balancing of the *Ecopath* model in this study.

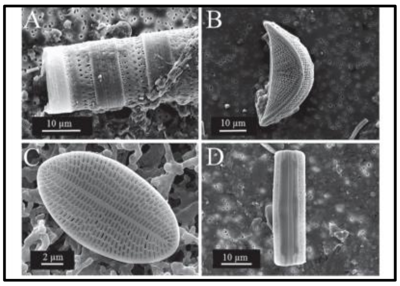
REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE
NC	1.0	47.30670	-	7.08	0.66
SL	1.0	5.0	-	117.52	0.25

Filamentous Algae

Filamentous Algae in the Coorong consists of two taxa; Cladophora and Ulva (Asanopolous and Waycott 2020). Biomass estimates were calculated from samples obtained during 2021 by the University of Adelaide research team of Component 2 of the HCHB project. Those biomass values were 100 t/km^2 and 5 t/km^2 in the North Coorong and South Lagoon, respectively. Median P/B estimates of 3.57 (NC) and 52.29 (SL) were obtained from another food web model along the Chilean Coast, Chile (Ortiz 2010) and adjusted during balancing of the *Ecopath* model in this study.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE
NC	1.0	100.00	-	3.57	0.88
SL	1.0	5.00	-	52.29	0.88

Phytoplankton (Diatoms)



Phytoplankton in the Coorong include diatoms and dinoflagellates (Leterme et al. 2018). Biomass estimates were unknown for each model domain. Based on similar ecosystems we applied a values of 15 t/km^2 for both the North Coorong and South Lagoon as the starting biomass. Median P/B estimates of 884.98 (NC) and 172.46 (SL) were obtained from another food web model in the Mondego Estuary, Portugal (Baeta et al. 2011) and adjusted during balancing of the *Ecopath* model in this study.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE
NC	1.0	15.00	-	884.982	0.55
SL	1.0	15.00	-	172.46	0.45

Detritus

For the Coorong ecosystem, two types of detritus were considered in the *Ecopath* model; Benthic Detritus within sediments and fishery discards.

Benthic Detritus

Benthic detritus biomass estimates for the Coorong ecosystem are unknown and were calculated by the *Ecopath* model. Those biomass values were 300 t/km^2 and 200 t/km^2 in the North Coorong and South Lagoon, respectively.

REGION	HABITAT FRACTION	B IN HABITAT AREA	Q/B	P/B	EE
NC	1.0	300.00	-	-	0.29
SL	1.0	200.00	-	-	0.43

Discards

Discards values were based on annual Lower Lakes Coorong fishery data records from 1984 to 2021.

Appendix B – Diet Matrix - North Coorong ecosystem model

No.	Group name	LN fur seal	Raptors	Aust pelican	Cormorants & grebes	Terns	Gulls	Egrets & herons	Ibis	Spoonbills	Migratory shorebirds (M-L bill)	Migratory shorebirds (S bill)	L non-migratory waders	S non-migratory shorebirds	Oystercatchers	Diving ducks	Dabbling ducks	Filter feeding ducks	Coots	Swans	Sharks	Rays & skates	Medium zoobenthivore/piscivore	Mulloway	M marine demersal piscivore	S demersal zoobenthivore/piscivore	L zoobenthivore/piscivore	Aust Salmon	Black bream	Syngnathids	Flounder	Yelloweye mullet
1	Long-nosed fur seal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Raptors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Aust pelican	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Cormorants & grebes	0	0.0274	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Terns	0	0.123301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Gulls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Egrets & herons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Ibis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Spoonbills	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Migratory shorebirds (M-L bill)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Migratory shorebirds (S bill)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	L non-migratory waders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	S non-migratory shorebirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Oystercatchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Diving ducks	0	0.0137	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Dabbling ducks	0	0.0548	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Filter feeding ducks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Coots	0	0.0137	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Swans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Sharks	0	0	0	0	0.000398	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Rays & skates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.052547	0	0	0	0	0	0	0	0	0	0	0
22	Medium zoobenthivore/piscivore	0	0	0	0	0.000523	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.022512	0	0	0	0	0	0.036159	0	0	0	0	0
23	Mulloway	0.002047	0	0.153751	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0049	0	0	0.03434	0	0	0	0	0	0	0	0
24	M marine demersal piscivore	0	0	0	0.000166	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.146627	0	0	0	0.05	0	0	0	0	0	0	0
25	S demersal zoobenthivore/piscivore	0	0	0	0.009289	0	0	0.041724	0.017982	0.028042	0	0	0	0	0	0	5.4E-06	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0.00283	0
26	L zoobenthivore/piscivore	0	0	0.005014	0	0.023949	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.065283	0	0	0	0	0	0.008708	0	0	0	0	0
27	Aust Salmon	0	0.066666	0	0	0.01044	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001597	0	0	0.014801	0	0	0	0	0
28	Black bream	0	0	0.011506	0	0	0	0	0	0	0	0	0	0	0	0	0.005432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	Syngnathids	0	0	0	0.000505	0.000584	0	0.006391	0	0	0	0	0	0	0	0	0	0	0	0	0.010218	0	0	0	0	0	0.007588	0	0	0	0	0
30	Flounder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004379	0	0	0.001781	0.06609	0	0	0	0	0	0	0
31	Yelloweye mullet	0.013306	0.066666	0.244066	0.260284	0.072614	0	0	0	0	0	0	0	0	0	0	1.42E-05	0	0	0	0.006541	0	0	0.642555	0.165225	0	0.000174	0.048255	0	0	0	0
32	Smallmouth hardyhead	0	0	0	0.106577	0.001146	0	0	0	0	0.035162	0	0.240826	0	0	0	0.003983	0	0	0	0	0	0.010798	0.012205	0	0.060398	0	0.397558	0	0	0	0.019675
33	Medium zoobenthivore	0	0	0.005917	0.067888	0.40797	0.283568	0	0	0	0	0	0	0	0	0.002463	0	0	0	0	0.020176	0.015991	0	0	0	0	0.032791	0	0	0	0	0
34	Toadfishes & leatherjackets	0	0	0	0.002518	0.054954	0	0.019173	0	0	0	0	0	0	0	0	0	0	0	0	0.156129	0	0	0	0	0	0.023566	0	0	0	0	0
35	S demersal omnivore/zoobenthivore	0	0	0	0.012921	0	0	0	0.0999	0.224334	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001553	0.033045	0.12227	0	0.03297	0	0	0	0
36	S demersal zoobenthivore	0.082907	0	0.026232	0.014476	0.000349	0	0.086737	0.04995	0	0	0	0	0	0	0	0	0	0	0	0	0	0.072889	0.108164	0.300341	0	0	0.193516	0.090909	0	0	0
37	Sandy sprat	0	0	0	0	0.031633	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000907	0	0	0.005793	0.033045	0	0.001586	0.188463	0	0	0	0
38	S-M marine pelagic zooplanktivore	0	0.133332	0	0.242281	0.233002	0.707707	0	0	0	0	0	0	0	0	0	0	0	0	0	0.291304	0.015991	0.253761	0.00223	0.033045	0	0.037092	0	0	0	0	0
39	S freshwater pelagic zooplankt/insectivore	0	0	0.325789	0.001202	0	0	0.041806	0	0	0	0	0	0	0	0.011613	0.00193	0	0.024385	0	0	0	0	2.44E-05	0	0	0	0.046919	0	0	0	0
40	Garfish	0	0	0	0	0.020477	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.010913	0	0	0	0	0	0.003707	0	0	0	0	0
41	Other muglids	0	0	0	0.003595	0.126626	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Bony herring	0.197544	0	0.000576	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.053754	0	0	0	0.009629	0	0	0	0
43	Medium omnivore/herbivore	0	0	0	0	0.011358	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012992	0	0	0	0	0	0.004073	0	0	0	0	0
44	Benthic decapods	0	0	0	0.247264	0.003978	0	0.745079	0.822178	0.742767	0.038885	0.000266	0	0	0.000239	0.067434	0.001516	0	0	0	0.192912	0.189008	0.475309	0.122573	0.292811	0.255053	0.66584	0.000559	0.545455	0.152097	0.03273	0.001618
45	Benthic annelids	0	0	0	0	0	0	0	0	0	0.142716	0.004733	0	0.569892	0	0	0.002044	0	0.034245	0	0.001107	0.188913	0.097737	0.000244	0.015411	0.016368	0	0.003652	0.151515	0	0.362719	0.013934
46	Benthic deposit-feeding annelids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.38E-05	0	0	0	0	0.055224	0.001029	0	0.001896	0	0	0	0.075758	0	0.004795	0.029786
47	Ficopomatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.83E-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003397	0
48	Bentho-pelagic crustaceans	0	0	0	0.00018	0	0	0.005478	0.00999	0.004857	0.020697	0.020215	0	0	0.013315	0.00227	0.007136	0.110328	0	0	0	0.121226	0.079218	0.002319	0.009092	0.20595	0.008076	0.041612	0	0.646119	0.389367	0.139255
49	Insect larvae/pupae	0	0	0	0.012046	0	0	0	0	0	0.044793	0.332223	0.032685	0	0.931118	0.028399	0.017888	0.019963	0	0.001	0	0	0.001029	0	0	0.088264	0	1.59E-05	0	0	0.023386	0.01455
50	Benthic micro-molluscs	0	0	0	0.001129	0	0	0.020104	0	0	0.115678	0.000126	0.277522	0	0.000212	0.091317	0.001635	0.34707	0.024385	0	0.000553	0.303838	0	0	0	0.122122	0.000838	6.38E-05	0.045455	0	0.000832	0.035745
51	Subtidal benthic molluscs	0	0	0	0	0	0	0	0	0	0.000422	0	0	0.430108	0	0.091371	0.000137	0.055917	0.024385	0	0	0.089552	0.001029	0	0	0	0.037757	0.03473	0	0	0.154122	0.001618
52	Zooplankton	0	0	0	0	0	0.008725	0	0	0	0	0.000294	0	0	0.000395	0.002972	9.97E-05	0	0	0	0	0	0	0	0	0.066644	0	0.001882	0	0.178027	0.023317	0.231842
53	Filamentous algae	0	0	0	0.002792	0	0	0	0	0	0	0.000137	0	0	0.00057	0.015233	0.012454	0	0.000954	0.35555	0	0	0	0.005494	0	0.001254	6.19E-05	0	0.045455	0.023757	0.002504	0.145912
54	Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.045455	0	0	0.12307
55	Macrophytes	0	0	0	0.001396	0	0	0	0	0	0.101647	0.142008	0.448967	0	0.054151	0.686928	0.658053	0.466721	0.891645	0.64345	0	0.020256	0.007202	0	0	0.000459	0.117183	0.000175	0	0	0	0
56	Detritus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.011218	0	0	0	0	0	0.242995
57	Import diet	0.704197	0.500435	0.227149	0.013492	0	0	0.033507	0	0	0.5	0.5	0	0	0	0	0.2876	0	0	0	0	0	0	0.005374	0	0	0	0	0	0	0	0
	Total	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

No.	Group name	Smallmouth hardyhead	Medium zoobenthivore	Toadfishes & leatherjackets	S demersal omnivore/zoobenthivore	S demersal zoobenthivore	Sandy sprat	S-M marine pelagic zooplanktivore	S freshwater pelagic zooplankt/insectivore	Garfish	Other muglids	Bony herring	Medium omnivore/herbivore	Benthic decapods	Benthic annelids	Benthic deposit-feeding annelids	Ficopomatus	Bentho-pelagic crustaceans	Insect larvae/pupae	Benthic micro-molluscs	Subtidal benthic molluscs	Zooplankton
1	Long-nosed fur seal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Raptors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Aust pelican	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Cormorants & grebes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Terns	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Gulls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Egrets & herons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Ibis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Spoonbills	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Migratory shorebirds (M-L bill)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Migratory shorebirds (S bill)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	L non-migratory waders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	S non-migratory shorebirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Oystercatchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Diving ducks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Dabbling ducks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Filter feeding ducks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Coots	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Swans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Sharks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Rays & skates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Medium zoobenthivore/piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	Mulloway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	M marine demersal piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	S demersal zoobenthivore/piscivore	0	0	0	0	0	0	0	0.002535	0	0	0	0	0	0	0	0	0	0	0	0	0
26	L zoobenthivore/piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Aust Salmon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	Black bream	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	Syngnathids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	Flounder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	Yelloweye mullet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	Smallmouth hardyhead	1.28E-05	0	0	0	0.034339	0	0	0.02267	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Medium zoobenthivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Toadfishes & leatherjackets	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	S demersal omnivore/zoobenthivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	S demersal zoobenthivore	0	0	0	0	0.052515	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Sandy sprat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	S-M marine pelagic zooplanktivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	S freshwater pelagic zooplankt/insectivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	Garfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	Other muglids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Bony herring	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	Medium omnivore/herbivore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Benthic decapods	0	0.12965	0.280187	0.000424	0.017072	0	0.001831	0.103377	0	0.006358	0	0.041981	0.02	0	0	0	0	0	0	0	0
45	Benthic annelids	0.004515	0.479524	0.023363	0.204032	0.112529	0	1.54E-08	0.003543	0.001812	0	0	0.101184	0.02	0	0	0	0	0	0	0	0
46	Benthic deposit-feeding annelids	0.004359	0	0	0	0.011365	0	0	0	0	0	0	0	0.02	0.04	0	0	0	0.1	0	0	0
47	Ficopomatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	Bentho-pelagic crustaceans	0.166096	0.301308	0.493997	0.16412	0.234629	0.310496	0.827827	0.113191	0.006643	0	0.017485	0.041981	0.07	0.08	0	0	0.01	0	0	0	0
49	Insect larvae/pupae	0.003278	0	0	0.020108	0.007179	0	0	0.105512	0	0	0	0	0.02	0.02	0	0	0	0.1	0	0	0
50	Benthic micro-molluscs	0	0	0.079565	0.009143	0.002004	0	9.7E-06	0.035194	0.003019	0.008483	0	0	0.06	0.02	0	0	0	0	0	0	0
51	Subtidal benthic molluscs	0	0.014386	0.066166	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0
52	Zooplankton	0.821738	0.075133	0	0.014305	0.527966	0.689504	0.041416	0.508742	0.108092	0.415382	0.224608	0	0.02	0.01	0	0	0	0	0	0	0
53	Filamentous algae	0	0	0.008029	0.384654	0.000127	0	0.128912	0.018178	0.224034	0.270782	0.378954	0.803014	0	0	0	0	0.16	0.1	0	0	0
54	Phytoplankton	0	0	0	0	0	0	0	0	0.059179	0.005184	0	0	0	0.53	0.33	1	0.31	0.1	0.6	0.6	0.8
55	Macrophytes	0	0	0.005957	0	0.000274	0	4.54E-06	0	0.597222	0	0	0.011841	0.2	0	0	0	0.15	0	0	0	0
56	Detritus	0	0	0.042736	0.203214	0	0	0	0.087057	0	0.29381	0.378954	0	0.51	0.3	0.67	0	0.37	0.6	0.4	0.4	0.2
57	Import diet	0	0	0	0	0	0	0	0	0	0	0	0									
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

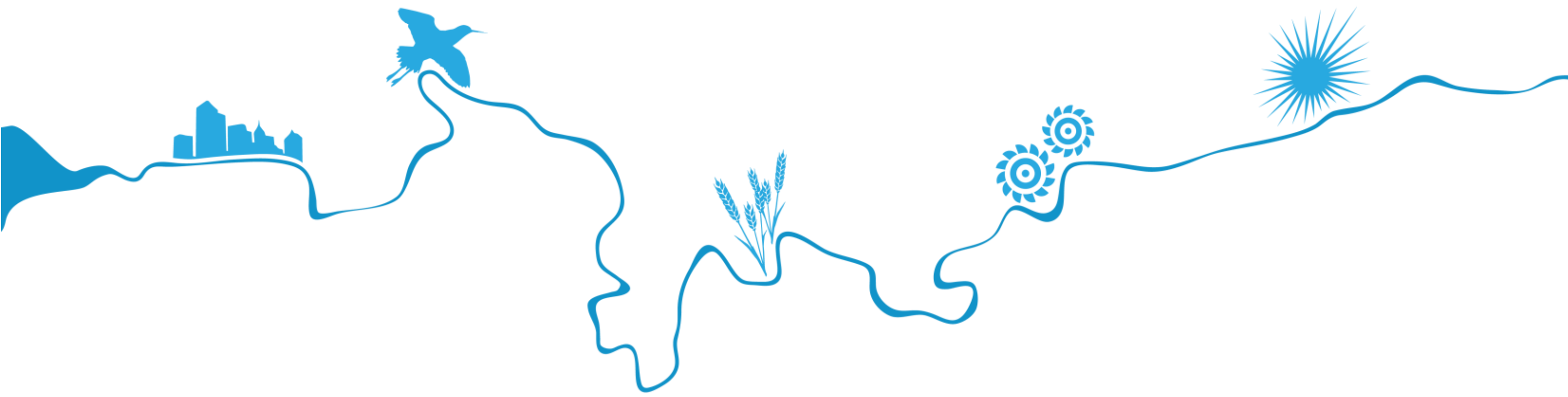
Appendix C – Diet Matrix – South Lagoon ecosystem model

No.	Group name	Raptors	Australian pelican	Cormorants & grebes	Terns	Gulls	Egrets & herons	Ibis	Spoonbills	Migratory shorebirds (M-L bill)	Migratory shorebirds (S bill)	L non-migratory waders	S non-migratory shorebirds	Oystercatchers	Diving ducks	Dabbling ducks	Filter feeding ducks	Coots	Swans	Sharks	Rays & skates	Medium zoobenthivore/piscivore	Mulloway	M marine demersal piscivore	S demersal zoobenthivore/piscivore	L zoobenthivore/piscivore	Pelagic mesopredator	Black bream	Flounder	Yelloweye mullet	Smallmouth hardyhead	S demersal omnivore/zoobenthivore
1	Raptors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Australian pelican	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Cormorants & grebes	0.027275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Terns	0.122735	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Gulls	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Egrets & herons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Ibis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Spoonbills	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Migratory shorebirds (M-L bill)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Migratory shorebirds (S bill)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	L non-migratory waders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	S non-migratory shorebirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Oystercatchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Diving ducks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Dabbling ducks	0.078186	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Filter feeding ducks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Coots	0.003637	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Swans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Sharks	0	0	0	0.000868	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Rays & skates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.052547	0	0	0	0	0	0	0	0	0	0	0	0
21	Medium zoobenthivore/piscivore	0	0	0	0.00499	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06162	0	0	0	0	0	0.088948	0	0	0	0	0	0
22	Mulloway	0	0.348527	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.013413	0	0	0.034644	0	0	0	0	0	0	0	0	0
23	M marine demersal piscivore	0	0	0.000676	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.401349	0	0	0	0.05	0	0	0	0	0	0	0	0
24	S demersal zoobenthivore/piscivore	0	0	0.045151	0	0	0.020782	0.017982	0.028042	0	0	0	0	0	0	1.19E-05	0	0	0	0	0	0	0	0	0.112397	0	0	0	0.002975	0	0	0
25	L zoobenthivore/piscivore	0	0.011367	0	0.228689	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.178693	0	0	0	0	0	0.021421	0	0	0	0	0	0
26	Pelagic mesopredator	0.198549	0	0	0.099691	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001611	0	0	0.036408	0	0	0	0	0	0
27	Black bream	0	0.026082	0	0	0	0	0	0	0	0	0	0	0	0	0.011938	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	Flounder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.011987	0	0	0.001797	0.06609	0	0	0	0	0	0	0	0
29	Yelloweye mullet	0.198549	0.583254	0.041584	0.051029	0.009913	0	0	0	0	0	0	0	0	0	3.12E-05	0	0	0	0.017905	0	0	0.698243	0.099135	0	0.000427	0.200857	0	0	0	0	0
30	Smallmouth hardyhead	0	0	0.183357	0.010945	0.971449	0	0	0	0.035162	0	0.300783	0	0	0	0.008753	0	0	0	0	0	0.193542	0.067313	0.099135	0.039767	0	0.418989	0	0	0.019675	1.28E-05	0
31	S demersal omnivore/zoobenthivore	0	0	0.016264	0	0	0	0.0999	0.224334	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001567	0.06609	0.002004	0	0.014747	0	0	0	0	0
32	S demersal zoobenthivore	0	0.009464	0.01307	0.003333	0	0.140951	0.04995	0	0	0	0	0	0	0	0	0	0	0	0	0	0.143907	0.004121	0.300341	0	0	0.003947	0.010909	0	0	0	0
33	Sandy sprat	0	0	0	0.30206	0.009913	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002484	0	0	0.005844	0	0	0.003903	0.198623	0	0	0	0	0
34	Garfish	0	0	0	0.195529	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02987	0	0	0	0	0	0.009119	0	0.08	0	0	0	0
35	Other muglids	0	0	0.005911	0.099795	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.035561	0	0	0	0	0	0.010019	0.05	0	0	0	0	0
36	Bony herring	0	0.021305	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05423	0	0	0	0.010148	0	0	0	0	0
37	Benthic annelids	0	0	0	0	0	0	0	0	0.142716	0.003874	0	0.569892	0	0	0.003748	0	0.034245	0	0.001107	0.188913	0.097737	0.000244	0.015411	0.016368	0	0.003652	0.151515	0.3775	0.093934	0.034515	0.241294
38	Benthic deposit-feeding annelids	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.85E-05	0	0	0	0	0.055224	0.001029	0	0.001896	0	0	0	0.075758	0.00504	0.109786	0.029359	0
39	Ficopomatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.79E-05	0	0	0	0	0	0	0	0	0	0	0	0	0.003571	0	0	0
40	Bentho-pelagic crustaceans	0	0	0.170539	0.00307	0	0.834962	0.832168	0.747624	0.059582	0.01679	0	0	0.013554	0.129758	0.015785	0.063377	0	0	0.192912	0.310235	0.554527	0.124892	0.301903	0.539503	0.673916	0.062171	0.545455	0.396403	0.140873	0.666096	0.158375
41	Insect larvae/pupae	0	0	0.340678	0	0	0	0	0	0.044793	0.327957	0.227543	0	0.931118	0.094961	0.032635	0.363022	0	0.001	0	0	0.001029	0	0	0.088264	0	1.59E-05	0	0.02458	0.01455	0.128278	0
42	Benthic micro-molluscs	0	0	0.170874	0	0	0.003305	0	0	0.115678	0.000109	0.097652	0	0.000212	0.105079	0.002982	0.05085	0.024385	0	0.000553	0.303838	0	0	0	0.122122	0.000838	6.38E-05	0.045455	0.0008	0.035745	0	0
43	Subtidal benthic molluscs	0	0	0	0	0	0	0	0	0.000422	0	0	0.430108	0	0.055513	0.000249	0.008193	0.024385	0	0	0.089552	0.001029	0	0	0	0.037757	0.03473	0	0.161992	0.001618	0	0
44	Zooplankton	0	0	0	0	0.008725	0	0	0	0	0.00024	0	0	0.000395	0.009304	0.000182	0	0	0	0	0	0	0	0	0.066644	0	0.001882	0	0.024507	0.071842	0.141738	0
45	Filamentous algae	0	0	0.007931	0	0	0	0	0	0	0.000124	0	0	0.00057	0.008557	0.02272	0	0.000954	0.35555	0	0	0	0.005494	0	0.001254	6.19E-05	0	0.045455	0.002632	0.145912	0	0.445274
46	Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.045455	0	0.12307	0	0
47	Macrophytes	0	0	0.003965	0	0	0	0	0	0.101647	0.150907	0.374022	0	0.054151	0.569146	0.900849	0.514558	0.891645	0.64345	0	0.020256	0.007202	0	0	0.000459	0.117183	0.000175	0	0	0	0	0
48	Detritus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.011218	0	0	0	0	0.242995	0	0.155058
49	Import	0.371067	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0.027681	0	0	0.024385	0	0	0.031983	0	0	0	0	0	0	0	0	0	0	0
	Total	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

No.	Group name	S demersal zoobenthivore	Sandy sprat	Garfish	Other muglids	Bony herring	Benthic annelids	Benthic deposit-feeding annelids	Ficopomatus	Bentho-pelagic crustaceans	Insect larvae/pupae	Benthic micro-molluscs	Subtidal benthic molluscs	Zooplankton
1	Raptors	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Australian pelican	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Cormorants & grebes	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Terns	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Gulls	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Egrets & herons	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Ibis	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Spoonbills	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Migratory shorebirds (M-L bill)	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Migratory shorebirds (S bill)	0	0	0	0	0	0	0	0	0	0	0	0	0
11	L non-migratory waders	0	0	0	0	0	0	0	0	0	0	0	0	0
12	S non-migratory shorebirds	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Oystercatchers	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Diving ducks	0	0	0	0	0	0	0	0	0	0	0	0	0
15	Dabbling ducks	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Filter feeding ducks	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Coots	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Swans	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Sharks	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Rays & skates	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Medium zoobenthivore/piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0
22	Mulloway	0	0	0	0	0	0	0	0	0	0	0	0	0
23	M marine demersal piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0
24	S demersal zoobenthivore/piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0
25	L zoobenthivore/piscivore	0	0	0	0	0	0	0	0	0	0	0	0	0
26	Pelagic mesopredator	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Black bream	0	0	0	0	0	0	0	0	0	0	0	0	0
28	Flounder	0	0	0	0	0	0	0	0	0	0	0	0	0
29	Yelloweye mullet	0	0	0	0	0	0	0	0	0	0	0	0	0
30	Smallmouth hardyhead	0.10586	0	0	0	0	0	0	0	0	0	0	0	0
31	S demersal omnivore/zoobenthivore	0	0	0	0	0	0	0	0	0	0	0	0	0
32	S demersal zoobenthivore	0.00977	0	0	0	0	0	0	0	0	0	0	0	0
33	Sandy sprat	0.03	0	0	0	0	0	0	0	0	0	0	0	0
34	Garfish	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Other muglids	0.02	0	0	0	0	0	0	0	0	0	0	0	0
36	Bony herring	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Benthic annelids	0.34826	0	0.001812	0	0	0.1	0	0	0	0	0	0	0
38	Benthic deposit-feeding annelids	0.021334	0	0	0	0	0.1	0	0	0	0.1	0	0	0
39	Ficopomatus	0	0	0	0	0	0	0	0	0	0	0	0	0
40	Bentho-pelagic crustaceans	0.459382	0.310496	0.006643	0.006358	0.017485	0.08	0	0	0.01	0	0	0	0
41	Insect larvae/pupae	0.000162	0	0	0	0	0.02	0	0	0	0.1	0	0	0
42	Benthic micro-molluscs	0.003097	0	0.003019	0.008483	0	0.02	0	0	0	0	0	0	0
43	Subtidal benthic molluscs	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Zooplankton	0.001367	0.689504	0.108092	0.415382	0.224608	0.01	0	0	0	0	0	0	0
45	Filamentous algae	0.000243	0	0.224034	0.270782	0.378954	0	0	0	0.16	0.1	0	0	0
46	Phytoplankton	0	0	0.059179	0.005184	0	0.37	0.33	1	0.31	0.1	0.6	0.6	0.8
47	Macrophytes	0.000526	0	0.597222	0	0	0	0	0	0.15	0	0	0	0
48	Detritus	0	0	0	0.29381	0.378954	0.3	0.67	0	0.37	0.6	0.4	0.4	0.2
49	Import	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	1	1	1	1	1	1	1	1	1	1	1	1	1

Appendix D – Time-series applied to the *Ecosim* models

NO.	NORTH COORONG	SOUTH LAGOON	DATA TYPE
1	C Sharks	C Sharks	Catch
2	C Rays & skates		Catch
3	C Mulloway	C Mulloway	Catch
4	C marine demersal piscivore		Catch
5	C A salmon		Catch
6	C B bream	C B bream	Catch
7	C Flounder		Catch
8	C YE mullet	C YE Mullet	Catch
9	C Medium zoobenthivore	C S demersal zoobenthivore	Catch
10	C Toadfishes & leatherjackets		Catch
11	C S demersal zoobenthivore		Catch
12	C S-M marine pelagic zooplanktivore		Catch
13	C Garfish		Catch
14	C Other mugilids		Catch
15	C B herring		Catch
16	C M omnivore/herbivore		Catch
17	C Benthic decapods		Catch
18	E Mulloway LMG	E Mulloway LMG	Effort by gear
19	E Mulloway SMG		Effort by gear
20	E A salmon LMG		Effort by gear
21	E A salmon SMG		Effort by gear
22	E B bream LMG	E B bream LMG	Effort by gear
23	E B bream SMG		Effort by gear
24	E Flounder LMG		Effort by gear
25	E Flounder SMG		Effort by gear
26	E Yelloweye mullet LMG		Effort by gear
27	E YE mullet SMG	E YE mullet SMG	Effort by gear
28	E YE mullet Other		Effort by gear
29	E B herring LMG		Effort by gear
30	E B herring SMG		Effort by gear
31	CPUE Mulloway LMG	CPUE Mulloway LMG	Relative biomass
32	CPUE B bream LMG	CPUE B bream LMG	Relative biomass
33	CPUE Flounder LMG		Relative biomass
34	CPUE YE mullet SMG	CPUE YE mullet SMG	Relative biomass
35	CPUE B herring LMG		Relative biomass
36	B LNFS		Absolute biomass
37	B Pelican	B Pelican	Absolute biomass
38	B Cormorants & grebes	B Cormorants & grebes	Absolute biomass
39	B Terns	B Terns	Absolute biomass
40	BGulls	BGulls	Absolute biomass
41	B Egrets & herons	B Egrets & herons	Absolute biomass
42	B Ibis	B Ibis	Absolute biomass
43	B Spoonbill	B Spoonbill	Absolute biomass
44	B MS (M-L bill)	B MS (M-L bill)	Absolute biomass
45	B MS (S bill)	B MS (S bill)	Absolute biomass
46	B LN-M waders	B LN-M waders	Absolute biomass
47	B SN-M shorebirds	B SN-M shorebirds	Absolute biomass
48	B Oystercathcers	B Oystercathcers	Absolute biomass
49	B Diving D	B Diving D	Absolute biomass
50	B Dabbling D	B Dabbling D	Absolute biomass
51	B FF ducks	B FF ducks	Absolute biomass
52	B Coots	B Coots	Absolute biomass
53	B Black swan	B Black swan	Absolute biomass
54	B S demersal zoobenth/pisc		Absolute biomass
55	B S fwater pelagic zooplankt/insectivore		Absolute biomass
56	B Smallmouth hardyhead	B Smallmouth hardyhead	Absolute biomass
57	B S demersal omni/zoobenthivore	B S demersal omni/zoobenthivore	Absolute biomass
58	B S demersal zoobenthivore	B S demersal zoobenthivore	Absolute biomass
59	B Sandy sprat	B Sandy sprat	Absolute biomass
60	B Medium zoobenthivore/piscivore		Absolute biomass
61	B Australian salmon		Absolute biomass



The Goyder Institute for Water Research is a research alliance between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.