Inland Waters &
Catchment Ecology

Coorong Fish Condition Monitoring 2008–2021: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouth hardyhead (*Atherinosoma microstoma*) populations

Qifeng Ye, Luciana Bucater and David Short

SARDI Publication No. F2011/000471-9
SARDI Research Report Series No. 1129

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

May 2022

Government of South Australia
Department of Primary Industries and Regions

Government of South Australia
Department for Environment and Water

Australian Government

MURRAY–DARLING BASIN AUTHORITY

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Coorong Fish Condition Monitoring 2008–2021: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouth hardyhead (*Atherinosoma microstoma*) populations

Qifeng Ye, Luciana Bucater and David Short

SARDI Publication No. F2011/000471-9
SARDI Research Report Series No. 1129

May 2022

This publication may be cited as:
Ye, Q., Bucater, L. and Short, D. A. (2022). Coorong fish condition monitoring 2008–2021: 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. F2011/000471-9. SARDI Research Report Series No. 1129. 77pp.

Author(s):	Qifeng Ye, Luciana Bucater and David Short
Reviewer(s):	Kate Frahn (SARDI), Kirsty Wedge and Luke Vial (DEW), Joné Wright (MDBA)
Approved by:	Professor Xiaoxu Li Subprogram Leader – Shellfish & Finfish Aquaculture Program
Signed:	
Date:	26 May 2022
Distribution:	DEW, MDBA, SARDI Aquatic Sciences, Parliamentary Library, State Library and National Library
Circulation:	OFFICIAL

ALL ENQUIRIES
South Australian Research and Development Institute - SARDI Aquatic Sciences
2 Hamra Avenue West Beach SA 5024, PO Box 120 Henley Beach SA 5022
P: (08) 8207 5400 **F:** (08) 8207 5415 **E:** pirsa.sardiaquatics@sa.gov.au
W: http://www.pir.sa.gov.au/research

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This project was funded by The Living Murray initiative of the Murray–Darling Basin Authority (MDBA). The Living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian, Australian Capital Territory and Commonwealth Governments, coordinated by the MDBA. In 2015/16 and 2016/17, additional funding was provided by the MDBA Joint Venture Monitoring and Evaluation Program to support additional field sampling. Also, the 2014/15 data were collected through the fish intervention monitoring project as part of the former Coorong, Lower Lakes and Murray Mouth (CLLMM) Recovery Project, which was a key component of South Australia's $610 million Murray Futures program, funded by the Australian Government. Furthermore, the data collected during December 2020 was funded via the Healthy Coorong Healthy Basin Trials and Investigations Project – Component 3 Food Web Research. Sampling during 2020/21 was conducted under an exemption (No. ME9903055) of section 115 of the *Fisheries Management Act 2007*.

The authors would like to thank the Coorong commercial fishers, Garry Hera-Singh, Darren Hoad, Matt Hoad, Rod Ayres, Rod "Dingles" Dennis, Glen Hill, Raymond Modra, Tim Hoad and many others for supplying fish samples. SARDI staff Neil Wellman (*in memory*), David Fleer, Kate Frahn, David Schmarr, George Giatas, Jason Earl, and Hannah Wang provided assistance with fieldwork, laboratory analyses or data entry. Also thanks to the Ngarrindjeri Regional Authority (NRA) who provided assistance with fieldwork in previous years, through funding received from The Living Murray's Indigenous Partnerships Program. Thanks to Peta Hansen (DEW) who provided the Salt Creek flow and salinity data. Thanks to Adrienne Rumbelow and Kirsty Wedge (DEW) for excellent support and management of this project. Thanks to Kirsty Wedge, Luke Vial (DEW), Kate Frahn (SARDI) and Joné Wright (MDBA) for reviewing this report and providing constructive comments; and to Professor Xiaoxu Li and Annie Sterns for managing the SARDI review process.

EXECUTIVE SUMMARY

The Lower Lakes, Coorong and Murray Mouth (LLCMM) region is a wetland of international importance under the Ramsar Convention, and an 'icon site' under The Living Murray (TLM) initiative. During the Millennium Drought (2001–2010) in the Murray–Darling Basin (MDB), the Coorong ecosystem was severely degraded due to diminished freshwater inflows and substantial increases in salinity. To restore and enhance the environmental values of the LLCMM region, an Environmental Water Management Plan (2014) was developed, which included ecological fish targets for the Coorong. Fish condition monitoring commenced in 2008/09 to evaluate the ecological targets, guided by the TLM Condition Monitoring Plan (revised, 2017). This report presents the findings of 13 years' monitoring (2008/09–2020/21) for smallmouth hardyhead (*Atherinosoma microstoma*), black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) in the Murray Estuary, North Lagoon and South Lagoon of the Coorong.

During the study period, there were variable hydrological conditions, including extreme drought (2008/09 and 2009/10, no flow), low flows (e.g. 2013–2016, 2017–2021, <1,300 GL y^{-1}) and flood/high flows (2010–2012 and 2016/17, >6,000 GL y^{-1}), which allowed investigation of biological responses to flow variability and population recovery over time. This monitoring involved evaluation of two fish ecological objectives: (1) Maintain abundant self-sustaining populations of smallmouth hardyhead in the North Lagoon and South Lagoon of the Coorong (F-3); and (2) Restore resilient populations of black bream and greenback flounder in the Coorong (F-4).

The monitoring indicated that the ecological objective F-3 for smallmouth hardyhead was achieved in 2020/21, despite this being a low flow year. The 'good' population condition was reflected by a broad distribution of both adults and new recruits throughout the North and South lagoons; and higher abundance of adults and new recruits (476 fish.UE^{-1} and 1,628 fish.UE^{-1}, respectively) compared to the ecological targets (>120 fish.UE^{-1} and >800 fish.UE^{-1}), but the extent of recruitment in the Coorong fell just below the target (>75% of sites). Smallmouth hardyhead plays an important role in the trophic ecology of the region. As a small-bodied, solely estuarine species, it is highly responsive to river flows to the Coorong, showing rapid increases in abundance, recruitment and distribution post high flows. This was corroborated by significant improvement and 'good/very good' population conditions in 2011/12, 2012/13 and 2016/17, following flood/high flows, as well as the 'extremely poor' population condition that occurred in 2008/09 and 2009/10 during the latter part of the Millennium Drought. The smallmouth hardyhead population condition declined to 'moderate' during 2017/18–2019/20, with reduced inflows and

increased salinities in the Coorong. In 2020/21, the population condition improved to 'good' following a slight increase in flow (1,260 GL y^{-1}), generally reduced salinities across the region and enhanced *Ruppia* abundance in the South Lagoon. This study supports the importance of freshwater flows to the population ecology of smallmouth hardyhead in the Coorong, and the flow related biological responses observed demonstrated its population resilience in this region.

The results of black bream monitoring suggest that the ecological objective F-4, to restore resilient populations of this species in the Coorong, has not been achieved over the last 13 years, whereas for greenback flounder, the ecological objective was not achieved in the first 12 years of the study, but it was achieved in 2020/21. For black bream, the population condition remained 'extremely poor' to 'poor' in the Coorong till 2016/17, but it improved to 'moderate' in recent years (2017/18, 2019/20 and 2020/21). The 'moderate' condition in 2020/21 was characterised by:

- An increasing 4-year catch trend (meeting the target about a positive trend) despite a low relative abundance (annual commercial catch of 3.2 t vs the target: ≥8 t);
- Increased distribution of the commercial catches (73% from the southern Coorong, meeting the target: >50%);
- The presence of two strong cohorts with both ≤5 years (meeting the target) despite only 9.7% of the catches >10 years of age (vs the target: >20%);
- No detection of YOY (vs the target CPUE: >0.77 fish.net $night^{-1}$);

For greenback flounder, the population condition improved from 'extremely poor' during the late drought (2008/09 and 2009/10) to 'moderate' during the three post-drought years (2011/12–2013/14). It then declined to 'poor' in 2014/15 and 2015/16, with low river inflows (<1,300 GL y^{-1}). In 2016/17, the population condition improved to 'moderate' following high flows to the Coorong although it declined again with flow reductions in the subsequent three years. Nevertheless, in 2020/21, the population condition improved to 'good' with elevated flows and a general reduction in salinity particularly in the Murray Estuary and North Lagoon. For this year, the 'good' population condition was characterised by:

- A broad distribution of commercial catches (>89% from the southern Coorong, meeting the target: >70%).
- An increasing 4-year trend in catches (meeting the target) despite a low relative abundance (annual commercial catch 4.5 t vs the target: >24 t)
- The presence of a very strong cohort (82% 1 year olds, meeting the target: >60%);

- Increased recruitment with a high YOY CPUE (1.3 fish.seine net^{-1} vs the target: >1.04 fish.seine net^{-1}) and a broad distribution (present at 56% sites vs the target: >50% sites)

Freshwater flow is important in facilitating successful recruitment of black bream and greenback flounder, through maintaining/restoring estuarine habitats (providing a favourable salinity gradient and suitable environmental conditions) and increasing productivity in the Coorong. As a marine-estuarine opportunist and relatively fast growing species with a moderate life-span (~10 years), greenback flounder seem to be more responsive to river flow increases and environmental improvements in the Coorong than black bream, which is a slower growing, solely estuarine long-lived fish. The current greenback flounder population reached 'good' condition in 2020/21. For black bream, although periodic recruitment occurred over the monitoring years and there were some improvements in the population condition to 'moderate' in recent years, the population recovery will take a longer time given the low spawning biomass and truncated age structure of the current population in the Coorong.

This study suggests that river inflows and allocations of water for the environment are critical to improve estuarine fish habitats (salinities, connectivity and productivity), enhance fish recruitment and abundance, and improve population resilience in the Coorong. Importantly, flow management should consider inter-annual and intra-annual flow regimes, including small to moderate freshwater releases that may meet different environmental or life-history process requirements of different species (e.g. low to moderate flows, as per the releases in 2017/18 associated with stronger black bream recruitment). Further investigations are needed to support management including to: (1) understand the influence of freshwater flows on population dynamics and recruitment of medium and large-bodied estuarine species; (2) evaluate the benefit/impact of various flow scenarios (both natural and managed flows including water for the environment) for these populations; and (3) assess population recovery (abundance and demographics). Furthermore, to support the recovery of the solely estuarine black bream, fishery management should continue to seek to protect the remnant spawning biomass and maximise the survival of new recruits to rebuild population abundance and age structure to improve resilience. Overall, the results of this study form an important basis to inform the adaptive management of barrage flows and the delivery of water for the environment to ensure the ecological sustainability of iconic estuarine fish species in the LLCMM region.

Keywords: Coorong, freshwater flow, salinity, recruitment, estuary.

1. INTRODUCTION

1.1. Background

The Lower Lakes, Coorong and Murray Mouth (LLCMM) is located at the end of the Murray–Darling Basin (MDB). It is a Ramsar Wetland, recognised internationally as an important breeding and feeding ground for waterbirds and for supporting significant populations of fishes and invertebrates (Phillips and Muller 2006; Mosely *et al.* 2018). The region is an 'icon site' under The Living Murray (TLM) initiative, based on its unique ecological qualities, hydrological significance, and economic and cultural values (Murray–Darling Basin Commission 2006).

The Coorong is a long (about 110 km) and narrow (<4 km) estuarine lagoon system with a strong north–south salinity gradient, generally ranging from brackish/marine in the Murray Estuary near the Murray Mouth to hypersaline in the North and South lagoons (Geddes and Butler 1984; Geddes 1987). Salinities are spatio-temporally variable and highly dependent on freshwater flows from the River Murray, with a longitudinal gradient of increasing salinities from the north to south, supporting different ecological communities (Brookes *et al.* 2009). In addition, the southern end of the South Lagoon receives small volumes of fresh/brackish water (mean = 14.2 GL y^{-1} between 2000/01–2020/21) from a network of drains (the Upper South East Drainage Scheme) through to Salt Creek.

As the terminal system of the MDB, the Coorong region has been heavily impacted by river regulation and water extraction since European settlement. The mean annual flow at the Murray Mouth has declined by 61% since 1895 (from 12,333 GL y^{-1} to 4,733 GL y^{-1}; CSIRO 2008). The construction of five tidal barrages in the 1940s significantly reduced the original area of the estuary, establishing an abrupt physical and ecological barrier between the marine and freshwater systems. During the Millennium Drought (2001–2010) in the MDB, there were low or no annual flow releases through the barrages between 2002 and 2009 (DEW 2020). Further, the Murray Mouth closed in 2002 due to siltation and regular dredging was required to maintain its opening (DWLBC 2008). During the drought, the Coorong was transformed into a marine–extremely hypersaline environment (Brookes *et al.* 2009). Many native fish species that resided in the Coorong and depended on its habitat for breeding, nursery and feeding grounds were negatively affected (Noell *et al.* 2009; Ye *et al.* 2015a; 2016), and recruitment of diadromous fish failed due to a lack of connectivity between freshwater and marine environments (Zampatti *et al.* 2010).

Since late 2010, several years of high river flows (i.e. 2010–2013, 2016/17) and the delivery of water for the environment to this region, have contributed to increased barrage releases to the Coorong; and ensured the continuous connection between the freshwater and marine environments (with barrages and fishways opening) (Ye *et al.* 2020a; 2020b). Fish assemblages in the Coorong have shown significant responses to freshwater flows and changing environmental conditions, with a general increase in species richness and diversity, and enhanced abundance and recruitment of several estuarine and diadromous species (Ye *et al.* 2015a; 2016; Bice *et al.* 2018; 2019; Ye *et al.* 2019b; Bice *et al.* 2020; Ye *et al.* 2020b).

Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouth hardyhead (*Atherinosoma microstoma)* are target species in the LLCMM Environmental Water Management Plan (MDBA 2014). A scientifically robust monitoring program was designed in 2008/09 and has been implemented since then for these fish species in the Coorong (Maunsell Australia Pty Ltd. 2009). A review of the TLM Condition Monitoring Program was undertaken by Robinson (2015), when fish data collected from the Coorong between 2008/09 and 2013/14 were analysed and new quantitative targets were developed for black bream, greenback flounder and smallmouth hardyhead (Ye *et al.* 2014). The new ecological targets and objectives for these fish species are presented in Tables 1.1 and 1.2, which have been incorporated in the revised Condition Monitoring Plan (DEWNR 2017).

The current report presents the findings of fish condition monitoring from 2008–2021, with a focus on assessing whether the ecological targets and objectives have been achieved for the populations of the three fish species in the Coorong in 2020/21. The assessment builds on previous data collected from commercial fishery (fishery-dependent) and fishery-independent research sampling between 2008/09–2019/20 (Ye *et al.* 2021a).

Table 1.1. Ecological objectives and targets for black bream and greenback flounder (DEWNR 2017). (Samples from C = Commercial samples, R = Research samples, CR = Commercial and research samples combined).

Characteristic	Description
Ecological Objective	*Restore resilient populations of black bream and greenback flounder in the Coorong*
Ecological Targets	**Black bream**
	1. **Relative abundance *(based on the commercial fishery catch, t/year)*** – *Annual catch ≥8 t or positive trend over previous four years (linear regression) (C)*
	2. **Distribution** – *>50% of the catch from southern part of the Coorong (south of Mark Point) (C)*
	3. **Age structures** – *Need to meet at least 2 of the following 3 targets: >20% of fish above 10 years; at least one strong cohort over the last five years; ≥2 strong cohorts in the population (C).* *(Strong cohort is defined as a cohort representing ≥ 15% of the population)*
	4. **Recruitment** – *Catch per unit effort (CPUE) of young-of-the-year (YOY) >0.77 fish.net night^{-1} by fyke net (R)* *– YOY distribution in the Coorong: > 50% sites with black bream YOY present (R)*
	Greenback flounder
	1. **Relative abundance *(based on the commercial fishery catch, t/year)*** – *Annual catch ≥24 t or positive trend over previous four years (linear regression) (C)*
	2. **Distribution** – *>70% of the catch from southern part of the Coorong (south of Mark Point) (C)*
	3. **Age structure** – *Presence of a very strong cohort (>60%) or at least a strong cohort (>40%) in year 0–2 and >20% of fish >2 years (C)*
	4. **Recruitment** – *CPUE of YOY >1.04 fish.seine net^{-1}* *– YOY distribution in the Coorong: >50% sites with greenback flounder YOY present (R)*

Table 1.2. Revised ecological objective and targets for smallmouth hardyhead (DEWNR 2017).

Characteristic	Description
Ecological Objective	*Maintain abundant self-sustaining populations of smallmouth hardyhead in the North Lagoon and South Lagoon of the Coorong*
Ecological Targets	1. **Relative abundance** – *Mean CPUE of adult smallmouth hardyhead sampled in spring/early summer is >120 fish.UE^{-1}. UE: One unit of effort is defined by one standard (large) seine net shot and one small seine net shot, noting both gear types are used as complementary sampling method to cover whole population.*
	2. **Recruitment** – *Mean CPUE of juvenile (new recruit) smallmouth hardyhead is >800 fish.UE^{-1}.*
	3. **Extent of recruitment** – *At the entire icon site level >75% of sites having a proportional abundance of new recruits of >60%*
	4. **Distribution** – *Adult and new recruit smallmouth hardyhead are present at 7 out of the 8 sites*

1.2. Objectives

This project undertook condition monitoring for black bream, greenback flounder and smallmouth hardyhead in the Coorong in 2020/21, aiming to assess their recruitment and population status against specific quantitative targets (Tables 1.1 and 1.2) and to report on overall condition scores of these fish species. Specific monitoring objectives for each species were to:

- Determine relative abundance and distribution;
- Determine population size and/or age structures;
- Assess the level of recruitment in the Coorong.

2. BIOLOGY/ECOLOGY OF FISH SPECIES

2.1. Black bream

Black bream is a sparid, endemic to the estuaries and coasts of southern Australia (Haddy and Pankhurst 2000; Gomon *et al.* 2008). It is an important commercial and recreational fisheries species (Rowland and Snape 1994; Haddy and Pankhurst 1998; Sarre and Potter 2000) that has a reputation for hardiness due to its wide environmental tolerance with respect to temperature, salinity and dissolved oxygen concentration (Norriss *et al.* 2002; Partridge and Jenkins 2002). Even though the species shows a preference for brackish waters (Hindell *et al.* 2008), individuals can survive in aquaria in salinity as high as 88 psu (McNeil *et al.* 2013) and have been found in the Coorong at sites approximately 100 km from the Murray Mouth, in salinity up to approximately 70 psu (Ye *et al*. 2015a).

Black bream is a rare example of a large-bodied teleost species which can complete its entire lifecycle within its natal estuary (Sarre *et al.* 2000; Burridge *et al.* 2004), and is classified as a 'solely estuarine' species (Potter *et al.* 2015; Bice *et al.* 2018). It is a multiple batch spawner, with spawning often taking place in the upper reaches of the estuarine system near the interface between fresh and brackish waters (Walker and Neira 2001). Several studies have related recruitment success of black bream to freshwater flows and associated factors, i.e. establishment of a favourable salinity gradient, maintenance of dissolved oxygen levels and increased larval food supply (Newton 1996; Norriss *et al.* 2002; Nicholson and Gunthorpe 2008). Further, a study in the Gippsland Lakes, Victoria, identified salt wedge/haloclines (salinity stratification by depth) as important larval nursery habitat affecting recruitment of black bream (Williams *et al.* 2012). It is likely that under certain freshwater flow conditions, there is a coupling between the halocline, primary productivity, zooplankton and larval fishes (Kimmerer 2002; North *et al*. 2005), which promotes the survival and growth of larvae through high prey availability and reduced risk of starvation and predation (North and Houde 2003; Islam *et al*. 2006). Black bream is considered to be a periodic strategist (Winemiller and Rose 1992), with a life-history characterised by slow-growth (k=0.04–0.08), high longevity (29–32 years), an intermediate age of maturity (1.9–4.3 years) (Coutin *et al.* 1997; Morison *et al.* 1998; Norriss *et al.* 2002), and high fecundity (estimated up to 3 million eggs for a large female) (Butcher 1945; Dunstan 1963).

Given its ecological and economic importance, black bream is a key species that has been studied in the Coorong over the last decade. Cheshire *et al.* (2013) found that black bream in the Coorong, similar to that from Victorian estuaries, has a spring spawning season (Coutin *et al.* 1997; Norriss *et al.* 2002) with a peak in the gonadosomatic index (GSI) occurring in October and November. A more recent study suggested that spawning of this species can extend to late summer, based on back calculated spawning date of young-of-year black bream (Ye *et al.* 2019a). The study also demonstrated the presence of halocline conditions associated with releases of water for the environment to the Coorong, which supported successful recruitment of black bream in 2017/18 (Ye *et al.* 2019a).

Variability in freshwater flows has been identified as a key factor influencing recruitment of black bream in estuaries (Sarre and Potter 2000; Nicholson *et al.* 2008; Jenkins *et al*. 2010; Williams *et al*. 2012), with greatest recruitment success during years of intermediate river flows and poor recruitment following periods of extremely low or high flows (Jenkins *et al.* 2010). In the substantially modified estuary of the Coorong, recent studies suggest strong cohorts are associated with low to moderate river flows (e.g. up to 12,000 ML day^{-1} barrage discharge) (Ye *al.* 2019c; 2020c). As individuals generally complete their entire lifecycle within a single estuary (Sherwood and Blackhouse 1982; Elsdon and Gillanders 2006), population dynamics are strongly influenced by inflows to the estuary and fishing impact, and individual populations are more dependent on self-recruitment than from adjacent systems (Potter *et al.* 1996; Partridge and Jenkins 2002; Sakabe *et al*. 2011).

2.2. Greenback flounder

Greenback flounder is the most common pleuronectid (right-eyed flatfish) in southern Australian and New Zealand waters (Kurth 1957; Van den Enden *et al.* 2000), and supports commercial and recreational fisheries (Kailola *et al.* 1993; Froese and Pauly 2013; Earl 2014). It has a high salinity tolerance (up to 88 psu) (McNeil *et al*. 2013), and the preferred habitats for adult greenback flounder are sand, silt and mud substrate in sheltered bays, estuaries and inshore coastal waters to depths of 100 m, whereas juveniles tend to be more common in shallower water (<1 m deep) (Jenkins *et al.* 1997; Van den Enden *et al.* 2000; Gomon *et al.* 2008).

Greenback flounder is a ‘marine-estuarine opportunist’ species, which by definition, are marine fishes that enter estuaries regularly, in substantial numbers, often as juveniles, but also use marine waters to varying degrees as alternative nurseries (Potter *et al.* 2015; Bice *et al.* 2018). Greenback flounder is a ‘medium-bodied’ fast-growing species that can live to more than 10 years of age with early maturity and high fecundity at about one year of age (Crawford 1986; Sutton *et al.* 2010; Earl *et al.* 2014). These traits suggest a life history strategy that is intermediate between opportunist and periodic strategies (Ferguson *et al.* 2013). Regarded as a multiple batch spawner with asynchronous oocyte development (Kurth 1957; Barnett and Pankhurst 1999), this species has a protracted spawning season during autumn/winter/spring (Crawford 1984b; Earl 2014). Spawning is known to occur in the deeper areas of tidal rivers and estuaries, as well as offshore (Kurth 1957; Crawford 1984a; Earl 2014).

Within the Coorong, spawning of greenback flounder occurs from March to October, peaking between April and July (Earl 2014). The study determined that gonadal development commenced in autumn when temperatures were below 20°C and peaked in June when temperatures were approximately 12°C. The same study showed contrasting salinity regimes in the Murray Estuary and North Lagoon did not influence the level of spawning activity. This suggested that there could have been a mixing between fishes from these sub-regions or that differences in salinity did not affect the physiological processes involved in gonadal development and oocytes maturation. Females and males reach sexual maturity at approximately 200 mm (Cheshire *et al.* 2013; Earl 2014) and 211 mm total length (TL) (Earl 2014), respectively.

Spawning aggregations of female greenback flounder have been described in areas of deeper water and sex-related differences in habitat selection have also been documented (Kurth 1957; Crawford 1984a). An acoustic monitoring study in the Coorong found mature females used both shallow flats and deeper channels/holes during the spawning season (Earl *et al.* 2017). Furthermore, the virtual absence of male greenback flounder from both deep and shallow water habitats in the Coorong suggests that sex-related partitioning may be occurring on a much broader spatial scale (Ye *et al.* 2013).

In South Australia, almost all commercial catches of greenback flounder are taken from the Coorong by the Lakes and Coorong Fishery (LCF), which is a multi-species and multi-gear fishery (Earl 2014). Long-term statistics for this fishery indicate large inter-annual and spatial variation in population biomass and abundance of greenback flounder (Earl and Ye 2016; Ye *et al*. 2021a). Age structures of this species within the Coorong are truncated with a dominant class of 1 or 2 year olds, potentially resulting from removal of older individuals through commercial and recreational fishing (Ferguson 2012; Ye *et al*. 2021a). However, Earl *et al.* (2016) suggested that temporal and spatial variation of biomass and abundance could also be related to the migration of older individuals to the sea.

Given their ecological and commercial importance to the LCF, greenback flounder has been a key focus species in several research and monitoring projects in recent years (e.g. Earl 2014; Ye *et al.* 2013; Earl *et al.* 2017; Ye *et al.* 2021a). Individuals have been recorded in the Coorong up to 50 km from the Murray Mouth (salinity ~74 psu) during the drought (Noell *et al.* 2009) and 70 km from the Murray Mouth (~80 psu) after increased river flows post 2010/11 (Ye *et al.* 2015a). Nevertheless, this species shows a preference for brackish and near-marine salinities (Earl *et al.* 2017).

2.3. Smallmouth hardyhead

Smallmouth hardyhead is a member of the widespread Atherinidae family (Potter *et al*. 1983; 1986) and the genus *Atherinosoma*, which is endemic to southern Australia (Gomon *et al.* 2008). It is considered a euryhaline species (Lui 1969) and found in shallow and calm waters of estuaries, marine embayments and hypersaline lagoons from the mid-coast of New South Wales to Spencer Gulf, South Australia (McDowall 1980; Molsher *et al.* 1994).

Smallmouth hardyhead is one of the most salt-tolerant fish species in the world (Molsher *et al.* 1994). It has a wide salinity tolerance range from 3–108 psu in aquaria (Lui 1969) and an even greater tolerance range under natural conditions where individuals have been observed at approximately 130 psu in the Coorong (Noell *et al.* 2009). The tolerance of smallmouth hardyhead to such hypersaline conditions is likely to be advantageous by limiting potential predators and competitors, thus allowing them broader access to food, space and habitat (Colburn 1988; Vega-Cendejas and Hernández de Santillana 2004).

Smallmouth hardyhead is a 'solely estuarine' species, whose reproduction is confined to estuarine habitats (Potter *et al.* 2015; Bice *et al.* 2018). It may be the only recorded Australian atherinid to reproduce in hypersaline waters (Lenanton 1977). This species is a multiple batch spawner with a protracted spawning season of four months (September to December) (Molsher *et al.* 1994; Cheshire *et al.* 2013). During reproduction, only one ovary develops in smallmouth hardyhead with this ovary holding batches of asynchronous adherent eggs. This species dies after spawning, completing its life span in only one year (Molsher *et al.* 1994). It grows to a maximum TL of 100 mm (Ye *et al*. 2013) and reaches sexual maturity at 45 mm TL (Molsher *et al.* 1994).

In the Coorong, the diet of smallmouth hardyhead consists mainly of crustaceans, including amphipods and microcrustaceans (e.g. ostracods and copepods) (Geddes and Francis 2008; Deegan *et al.* 2010; Hossain *et al.* 2017). The importance of macrophytes to the recruitment of atherinids has also been well documented, as they provide a sessile medium to which eggs can adhere and be retained within the areas of favourable salinity, thus facilitating enhanced egg survival and subsequent recruitment (Molsher *et al.* 1994; Ivanstoff and Crowley 1996).

In the Coorong, smallmouth hardyhead demonstrated a rapid population recovery within two years of resumption of flows and reduced salinities following their extirpation from approximately 60% of their range during the Millennium Drought (Wedderburn *et al.* 2016). Nonetheless, maintaining and/or improving the abundance and distribution of smallmouth hardyhead is pivotal, since it is a critical component of the Coorong ecosystem, serving as a major prey item for piscivorous fishes and water birds (Paton 2010; Giatas *et al.* 2018; Ye *et a.* 2020c). The importance of smallmouth hardyhead in the Coorong was strongly supported by trophic dynamic and fish diet studies in the Coorong (e.g. Deegan *et al.* 2010; Giatas and Ye 2015).

3. METHODS

3.1. General approach

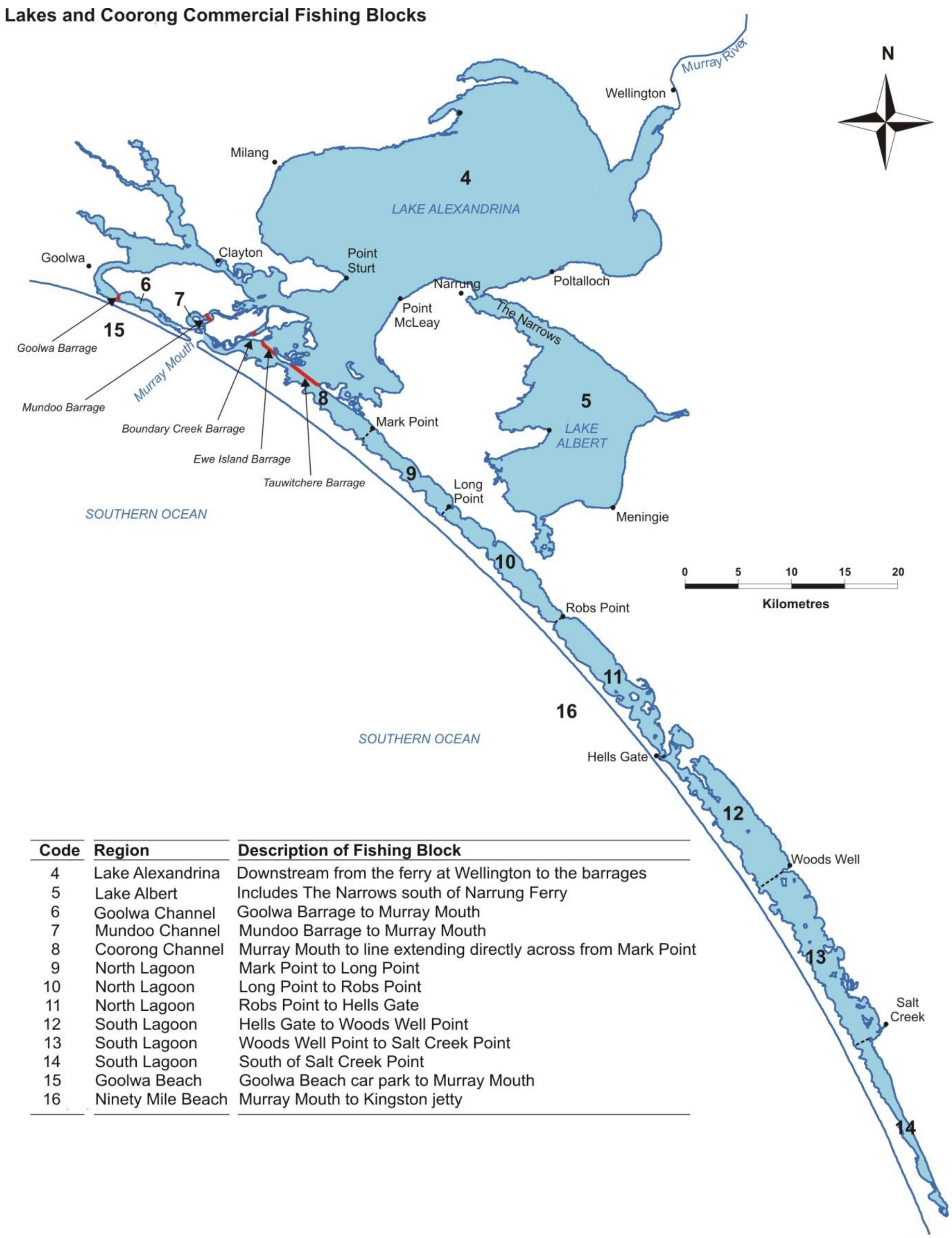
For black bream, greenback flounder and smallmouth hardyhead, four indicators were used to assess population condition in the Coorong (Ye *et al.* 2014), with each indicator having 1–2 quantitative targets (Tables 1.1 and 1.2). For the two large-bodied species (i.e. black bream and greenback flounder), three indicators, namely relative abundance (catch), adult fish distribution and age structure, were based on data/samples collected from the LCF. The fourth indicator (i.e. recruitment) was assessed based on fishery-independent sampling to collect data of relative abundance (catch per unit effort, CPUE) and spatial distribution of young-of-the-year (YOY) for both species. For smallmouth hardyhead, all four indicators (relative abundance, distribution, recruitment and extent of recruitment) were assessed using data collected through fishery-independent sampling. The multiple-lines-of-evidence approach was adopted to assess the overall population condition for each species in this region. When the population condition was classified as ‘good’ or ‘very good’, the ecological objective was deemed to have been achieved.

3.2. Fishery catch and freshwater flows

3.2.1. Data

Commercial fishery data (1984/85 to 2020/21) for black bream and greenback flounder from the LCF were obtained from the SARDI Information Services, including annual catch (kg) and spatial reporting of fishing blocks (Figure 3.1). The Coorong region encompasses fishing blocks 6 to 14.

Monthly freshwater discharge across the barrages was available for the period from July 1984 to June 2021, based on the estimates of the regression-based Murray hydrological model (MDM, BIGMOD, Murray–Darling Basin Authority, MDBA) and on daily discharge calculated by the Department for Environment and Water (DEW). In addition, daily salinity and freshwater discharge data from the Salt Creek inlet to the South Lagoon of the Coorong (Station A2390568) were obtained from the Water Data SA website of the DEW.



Code	Region	Description of Fishing Block
4	Lake Alexandrina	Downstream from the ferry at Wellington to the barrages
5	Lake Albert	Includes The Narrows south of Narrung Ferry
6	Goolwa Channel	Goolwa Barrage to Murray Mouth
7	Mundoo Channel	Mundoo Barrage to Murray Mouth
8	Coorong Channel	Murray Mouth to line extending directly across from Mark Point
9	North Lagoon	Mark Point to Long Point
10	North Lagoon	Long Point to Robs Point
11	North Lagoon	Robs Point to Hells Gate
12	South Lagoon	Hells Gate to Woods Well Point
13	South Lagoon	Woods Well Point to Salt Creek Point
14	South Lagoon	South of Salt Creek Point
15	Goolwa Beach	Goolwa Beach car park to Murray Mouth
16	Ninety Mile Beach	Murray Mouth to Kingston jetty

Figure 3.1. Spatial reporting blocks for the Lakes and Coorong Fishery.

3.2.2. Analysis

Annual fishery catches of black bream and greenback flounder, and barrage flows were plotted for each financial year for the period between July 1984 and June 2021. Temporal trends of catch were analysed to indicate the fluctuation in abundance of these species in the Coorong. The annual catch of each species was compared against the target values to determine whether the target has been met (Table 1.1). Additionally, linear regression analysis was performed on the annual catches of the last 4-year period to describe the trend of increase or decrease in population biomass over recent years. To assess fish distribution, proportional catch from the southern part of the Coorong (south of Mark Point) was calculated based on the catch from fishing blocks 9–14.

3.3. Age/size structures of fishery species

3.3.1. Samples

Sampling of black bream and greenback flounder from commercial catches was conducted in the Murray Estuary and North Lagoon of the Coorong from 2008/09–2020/21 to establish the age/size structures of fishery catches. In each year, adult black bream were collected from various sites (e.g. Goolwa Channel, Newells, Sugars Beach, Boundary Creek, Pelican Point, Long Point and Seven Mile) (Figure 3.2) mostly during spring–summer, and greenback flounder were collected from multiple sites (e.g. the Goolwa Channel, Mark Point, Long Point, Sam Island, Seven Mile and Needles) (Figure 3.3) mainly during winter.

3.3.2. Laboratory processing and analysis

To assess the presence/absence of strong year classes that recruit to the fishery, age structures were generated from estimates of age for individual fish, which was determined by counting annual increments in their sagittae (the largest pair of otoliths). Otoliths were extracted from black bream and greenback flounder in the laboratory. Transverse sections of otoliths from both species were prepared as described in Ye *et al.* (2002).

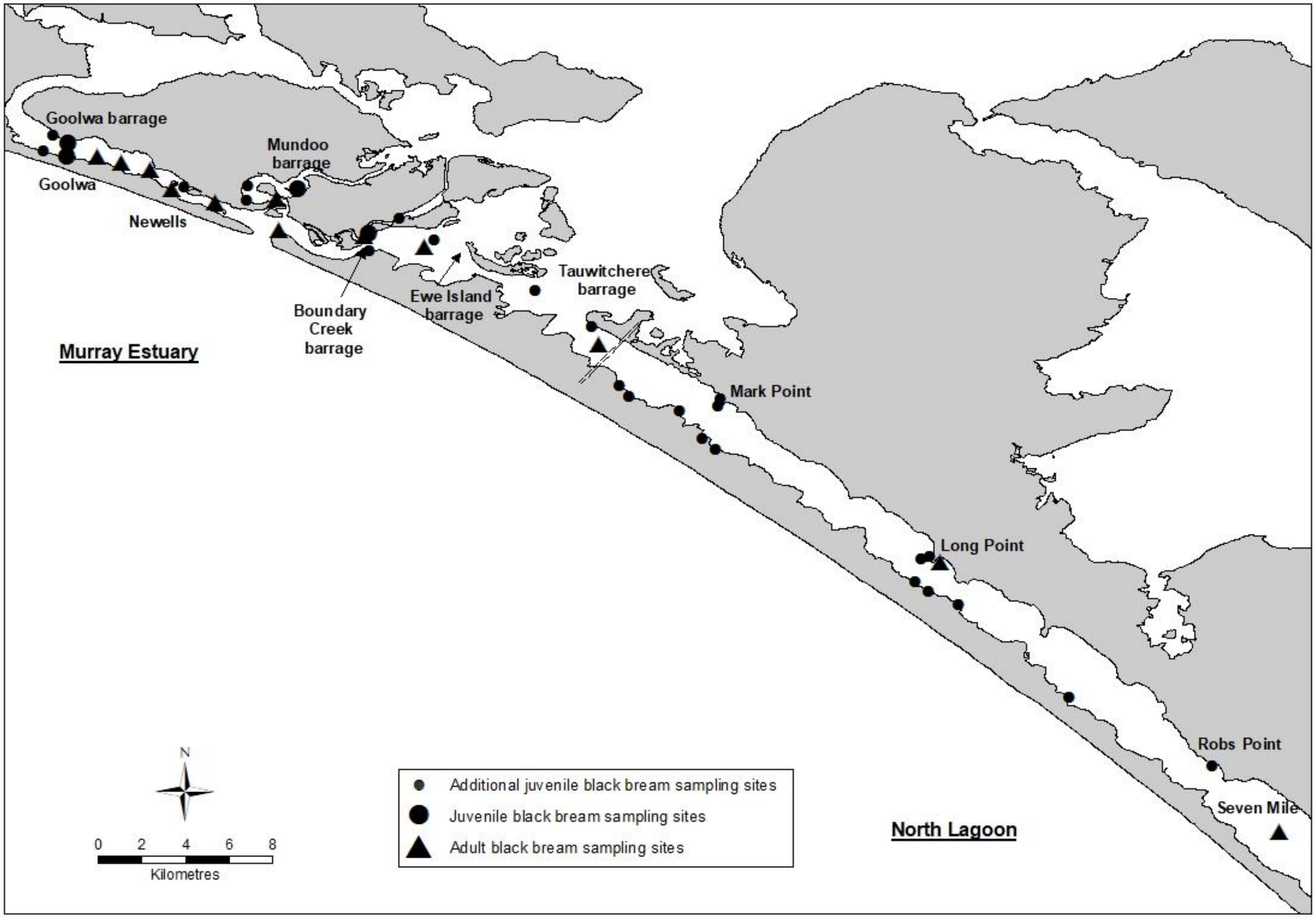


Figure 3.2. Condition monitoring sampling sites for adult and juvenile black bream at the Coorong. Adult black bream sampling sites represent commercial fishery sampling sites.

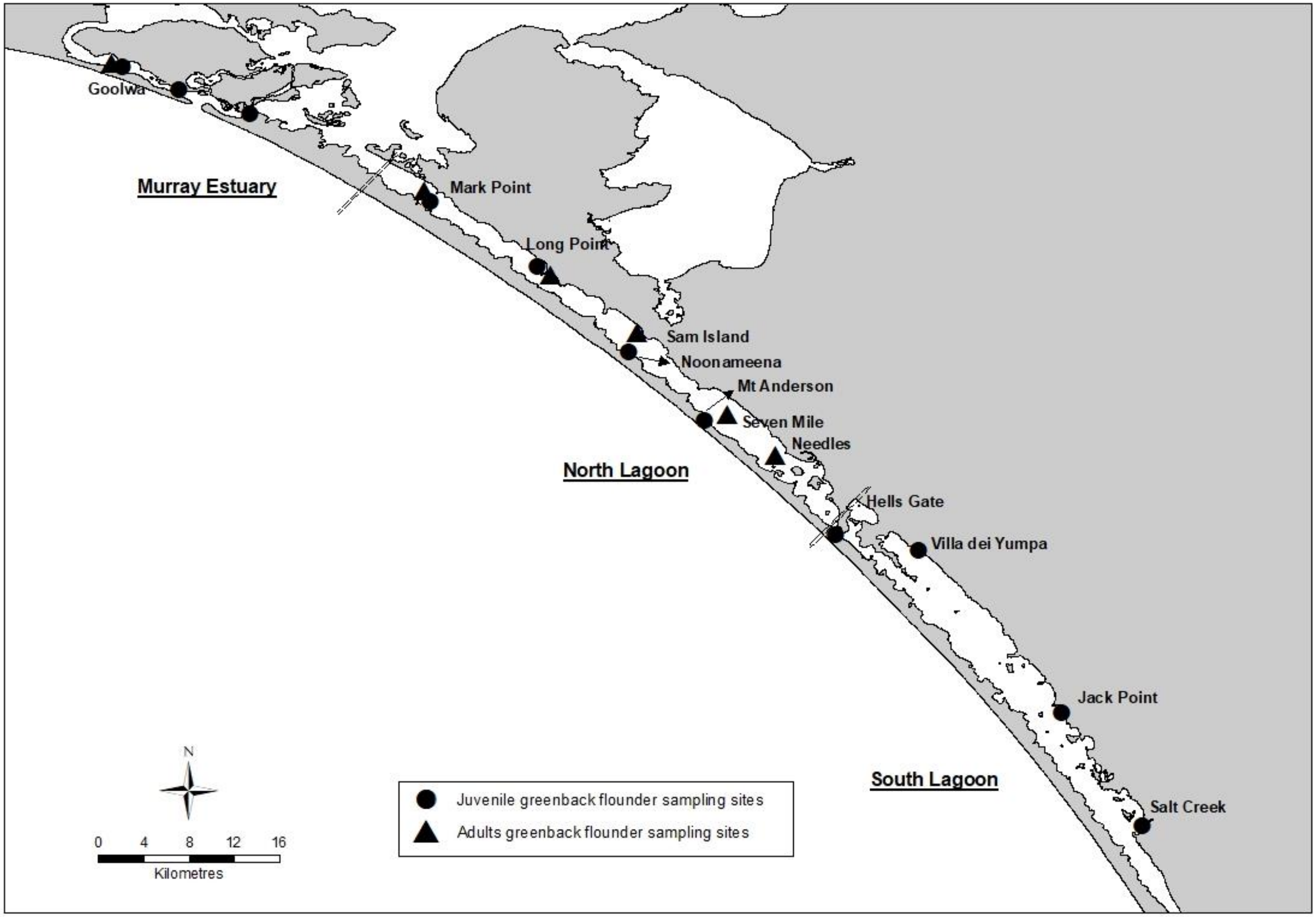


Figure 3.3. Condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong. Adult greenback flounder sampling sites represent commercial fishery sampling sites.

3.4. Recruitment

3.4.1. Sampling

Additional sampling was carried out to quantify the abundance of juvenile black bream and greenback flounder, to assess annual recruitment of YOY. In late summer/autumn (February–April) from 2008/09–2020/21, sampling was conducted to target YOY black bream at four regular sites (i.e. two below the Goolwa Barrage, one in Boundary Creek and one below Mundoo Barrage) using single-wing fyke nets (*n* = 1–3 trips per year) (Figure 3.2). In most years, exploratory sampling was also conducted at other sites (e.g. Beacon 19, Swan Point, Godfrey's Landing, Ewe Island, Cattle Point, Mark Point and Long Point) to determine the distribution of juveniles. The single-wing fyke nets were 8.6 m long (3 m wing plus 5.6 m funnel) with a mesh size of 8 mm and a hoop diameter of 0.6 m. On most sampling occasions, eight fyke nets were set overnight at each site. A summary of sampling effort for juvenile black bream is presented in Appendix A.

Greenback flounder juvenile sampling was conducted at 7–9 sites along the length of the Coorong (Figure 3.3). During spring–summer from 2008/09–2020/21, sampling was conducted using standard (large) seine net hauls/shots (*n* = 1–3 trips per year) (Figure 3.2). The seine net was 61 m long and consisted of two 29 m-long wings (22 mm mesh) and a 3 m-long bunt (8 mm mesh). It was deployed in a semi-circle, sampled to a maximum depth of 2 m and swept an area of about 592 m^2 per shot. A standardised sampling regime comprising three replicate shots was conducted at each site. A summary of sampling effort for juvenile greenback flounder is presented in Appendix B.

Standardised seine netting, as described above, was also used for quantitative sampling of smallmouth hardyhead at eight regular sites along the North and South lagoons of the Coorong. (Figure 3.4). Sampling was conducted at each site during spring–early autumn over 12 years (2008/09–2019/20) (*n* =1–4 trips per year), aiming to target the main spawning and recruitment season. However, no sampling was conducted in spring/early summer in 2015/16, 2018/19 and 2019/20 due to funding constraints, providing no data to evaluate the ecological target of adult abundance for this species. A small seine net was also used from December 2008 onwards as a complimentary method to more efficiently target new recruits (juveniles). The small seine net was 8 m long with a 2 m drop and a mesh size of 2 mm. It was hauled through water less than 0.5 m deep over a distance of 20 m by two people walking 5 m apart, thus sampling an area of about

100 m^2. Sampling was replicated (i.e. three standard shots) at each site for each seine net type. A summary of sampling effort for smallmouth hardyhead is presented in Appendix C.

At each site, the number of juvenile black bream, greenback flounder and smallmouth hardyhead from each net were counted and a random subsample of up to 50 individuals per species per net measured for TL (mm). During the first two years of monitoring, age (in days) was determined for a sub-sample of 20 juveniles per species for black bream and greenback flounder using otoliths, by counting daily increments to confirm whether fish collected were YOY (Ye *et al.* 2011a).

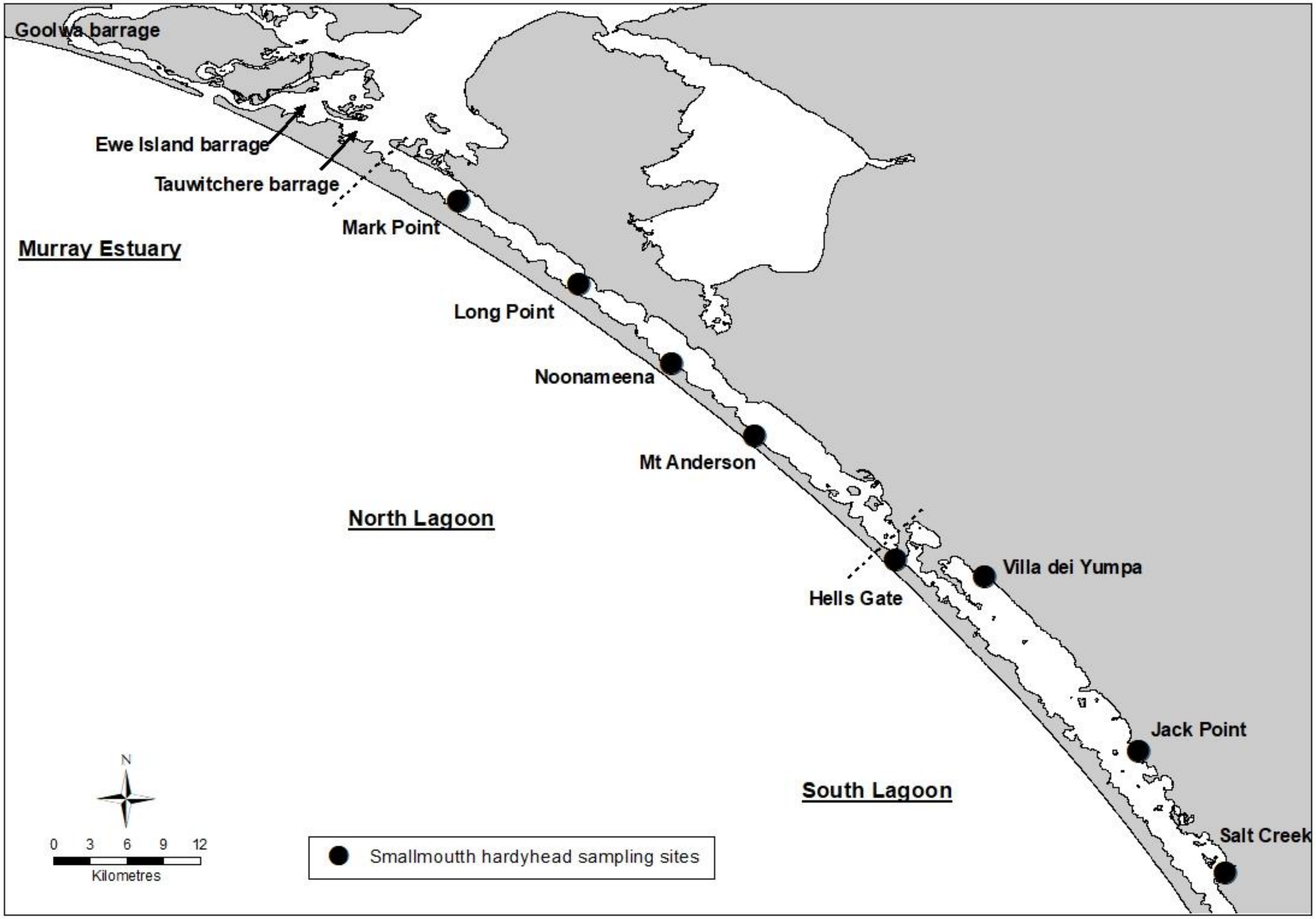


Figure 3.4. Condition monitoring sampling sites for smallmouth hardyhead in the Coorong.

Water quality parameters (i.e. salinity, temperature, pH) were recorded using a TPS water quality meter and water transparency was measured with the aid of a Secchi disc at each site on each fish sampling occasion. Salinity and water transparency were presented in results as these two parameters were most variable in response to barrage releases over the last 12 years of fish monitoring in the Coorong, and thus considered to be key parameters influencing population dynamics of the target species. See Table 3.1 for a summary list of sites, gear types used, and fish species targeted at each site.

Table 3.1. List of sampling sites, species targeted, and sampling gear used for fishery-independent sampling during the Coorong fish condition monitoring from 2008/09–2020/21. Both seine nets = large and small seine nets.

Sites*	Site code	Species targeted	Sampling gear
Murray Estuary			
Goolwa Barrage saltwater side Hindmarsh Island end	E1	Black bream	Fyke net
Goolwa Barrage saltwater side Sir Richard Peninsula end	E2	Black bream	Fyke net
Mundoo Barrage	E3	Black bream	Fyke net
Boundary Creek	E4	Black bream	Fyke net
Sugars Beach/Beacon 19**	E5	Greenback flounder	Large seine net
Godfrey's Landing	E6	Greenback flounder	Large seine net
North Lagoon			
Mark Point	N1	Greenback flounder/smallmouth hardyhead	Both seine nets
Long Point	N2	Greenback flounder/smallmouth hardyhead	Both seine nets
Noonameena	N3	Greenback flounder/smallmouth hardyhead	Both seine nets
Mt Anderson	N4	Greenback flounder/smallmouth hardyhead	Both seine nets
South Lagoon			
Hells Gate	S1	Greenback flounder/smallmouth hardyhead	Both seine nets
Villa dei Yumpa	S2	Greenback flounder/smallmouth hardyhead	Both seine nets
Jack Point	S3	Greenback flounder/smallmouth hardyhead	Both seine nets
Salt Creek	S4	Greenback flounder/smallmouth hardyhead	Both seine nets

Note: Exploratory sampling sites for black bream juveniles are not included; The Sugars Beach site was replaced by Beacon 19 after 2013/14.*

3.4.2. Analysis

Estimates of CPUE (fish.net night^{-1}) of YOY black bream were analysed to compare recruitment through time, using fyke net data collected at the four regular sites. To determine the distribution of YOY, data collected from exploratory sampling sites were also included. The reduced sampling effort, in 2014/15 and 2015/16, limited the capacity for assessing distribution. During this time, there was no/little additional sampling other than fyke netting at the regular sites (Appendix A).

Estimates of CPUE (fish.seine net^{-1}) of YOY greenback flounder were analysed to compare recruitment through time, using large seine net data collected at seven to nine regular sites. These data were also used to determine the distribution of YOY. It should be noted that the sampling effort was reduced in 2015/16, 2017/18, 2018/19 and 2019/20 due to funding constraints (Appendix B).

Both large and small seine net data were used to estimate CPUE (fish.UE^{-1}) of adults and new recruits of smallmouth hardyhead. Individuals ≥40 mm collected in spring/early summer were defined as adults, whereas those <40 mm collected in summer/early autumn were defined as new recruits (Ye *et al.* 2014). One unit of effort (UE) is the combined effort of one large seine net shot and one small seine net shot. In 2015/16, 2018/19 and 2019/20, sampling for smallmouth hardyhead was only conducted during summer/early autumn. The data were used to estimate adult abundances, which may not be reliable.

For black bream and greenback flounder, YOY abundance and distribution provided an indication of the level of recruitment in the sampling year. In addition, age structures of fishery catches were analysed to identify year class strength, suggesting strong recruitment in specific years, although it usually took 3–5 years for black bream and 1–2 years for greenback flounder to recruit to the Coorong fisheries (Ye *et al.* 2021a).

4. RESULTS

4.1. Freshwater flow

From 1984/85–2020/21, freshwater flow from the River Murray to the Coorong fluctuated substantially. Annual discharge was >4,000 GL in nine out of the 17 years between 1984/85 and 2000/01 (Figure 4.1). During the drought (2001–2010), the mean annual barrage discharge was 229 GL, with no freshwater released from 2007/08–2009/10. After September 2010, significant flow increases in the MDB led to substantial barrage releases, with an annual discharge of ~12,800 GL in 2010/11. Flow decreased in the subsequent five years, however, in 2016/17, flooding in the MDB resulted in a 10-fold increase in barrage discharge to ~6,500 GL compared to 2015/16. Over the last four years, annual barrage flows ranged between 337 and 1,260 GL, with 2020/21's being the highest. Daily discharge was highly variable with peaks occurring at different times (i.e. seasons) in different years. During 2020/21, daily flow was highest (20,600 ML day^{-1}) around late August 2020.

Similarly, freshwater flows from Salt Creek into the South Lagoon were highly variable among years from 2000/01 to 2020/21 (Figure 4.2). Annual discharges were generally low between 2000/01 and 2009/10 (mean 7.3 GL), and increased substantially thereafter (mean 20.5 GL), with the exception of 2015/16, 2019/20 and 2020/21 when annual discharges averaged 4.2 GL. Freshwater flows were highly seasonal in most years, with peak discharges occurring from July to October (winter–spring). Salinity in Salt Creek was also variable and seasonal, ranging between 0 and 30.4 psu from 2010 onwards.

For this 13-year study, based on the freshwater flows from the River Murray to the Coorong, 2008/09 and 2009/10 are defined as drought years, whereas 2010/11–2020/21 are defined as post-drought years. Within the post-drought period, 2010/11 was a flood year; 2011/12 and 2016/17 were high flow years; 2012/13 was a moderate flow year; and 2013/14–2015/16 and 2017/18–2020/21 were low flow years.

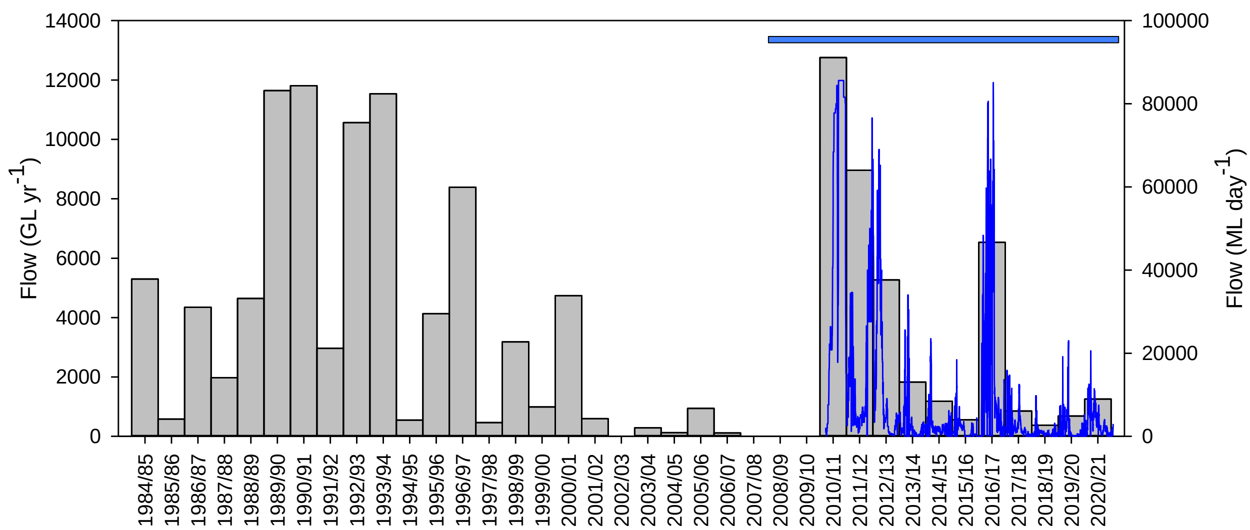


Figure 4.1. Annual (grey bar) and daily (blue line) freshwater flows across the barrages from July 1984 to June 2021 (sources: MDBA and DEW). 1984 refers to start of the 1984/85 financial year, i.e. 1st July 1984. Blue bar indicates the years when fish condition monitoring was conducted.

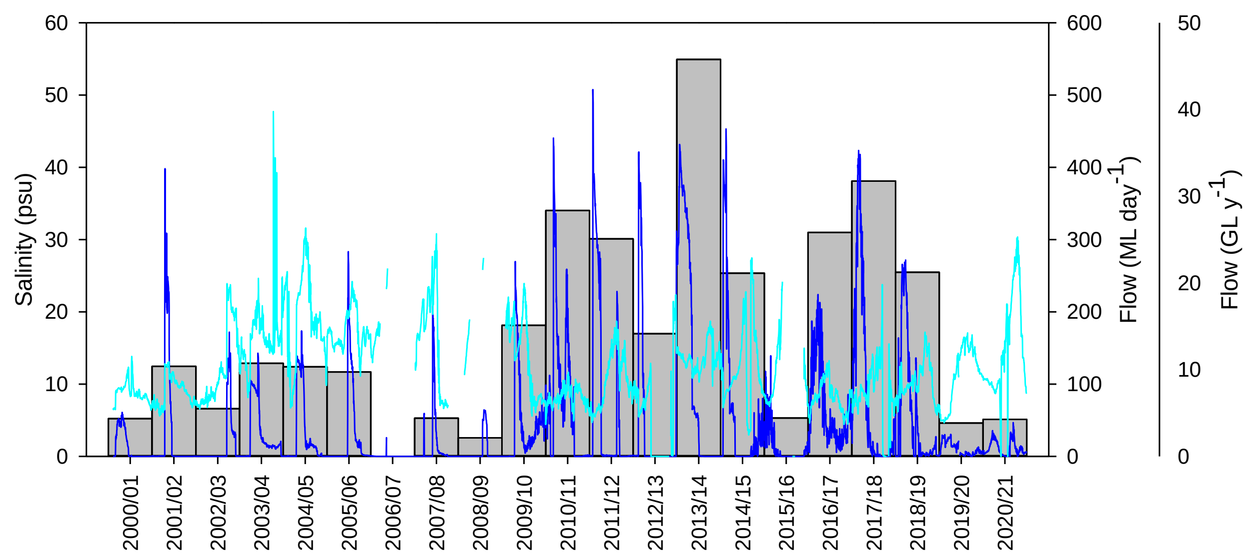


Figure 4.2. Annual (grey bar) and daily (blue line) discharge through the Salt Creek outlet, with salinity levels (cyan line) from July 2000 to June 2021 (DEW 2021, Water Data SA, Station A2390568).

4.2. Water quality

There has been a typical north-south gradient of increasing salinity in all years in the Coorong. Mean salinity over the 13-year monitoring period was 18, 42 and 97 psu in the Murray Estuary and North and South lagoons, respectively (Table 4.1 and Figure 4.3). Noticeable salinity reduction occurred at all sites/sub-regions in post-drought years from 2010/11 to 2014/15 and in 2016/17–2017/18. In the drought years (2008/09–2009/10), mean salinities were 41 psu in the Murray Estuary, 75 psu in the North Lagoon and 144 psu in the South Lagoon. Mean salinities during the flood/high flow years (2010/11, 2011/12 and 2016/17) were 5 psu in the Murray Estuary, 31 psu in the North Lagoon and 83 psu in the South Lagoon; whereas in the low flow years (2013/14–2015/16 and 2017/18–2020/21), they were 22 psu in the Murray Estuary, 43 psu in the North Lagoon and 94 psu in the South Lagoon.

Conversely, water transparency remained lowest and generally stable in the South Lagoon (Secchi disc depth mostly <0.8 m), compared to the Murray Estuary and North Lagoon in all years except for 2010/11 (Figure 4.3). In the Murray Estuary and North Lagoon, water transparency increased during the drought and low flow years and decreased considerably in flood and high flow years.

Table 4.1. Mean salinity across Coorong sub-regions during the last 13 years of monitoring (2008/09 – 2020/21). Highlighted cells show annual mean salinity ≤ long term mean for the sub-region.

	Murray Estuary	North Lagoon	South Lagoon	Mean across sub-regions
2008/09	41	70	147	**83** (± 31.7)
2009/10	40	80	140	**91** (± 29.0)
2010/11	1	36	85	**46** (± 24.3)
2011/12	6	24	88	**41** (± 24.9)
2012/13	18	33	86	**49** (± 20.4)
2013/14	18	51	84	**55** (± 19.0)
2014/15	15	41	92	**51** (± 22.7)
2015/16	34	46	102	**71** (± 20.8)
2016/17	7	33	77	**29** (± 20.4)
2017/18	16	33	83	**43** (± 19.8)
2018/19	20	42	87	**48** (± 19.5)
2019/20	35	50	108	**72** (± 22.3)
2020/21	19	36	106	**49** (± 26.5)
Mean among years	**18** (± 3.9)	**42** (± 4.7)	**96** (± 6.6)	

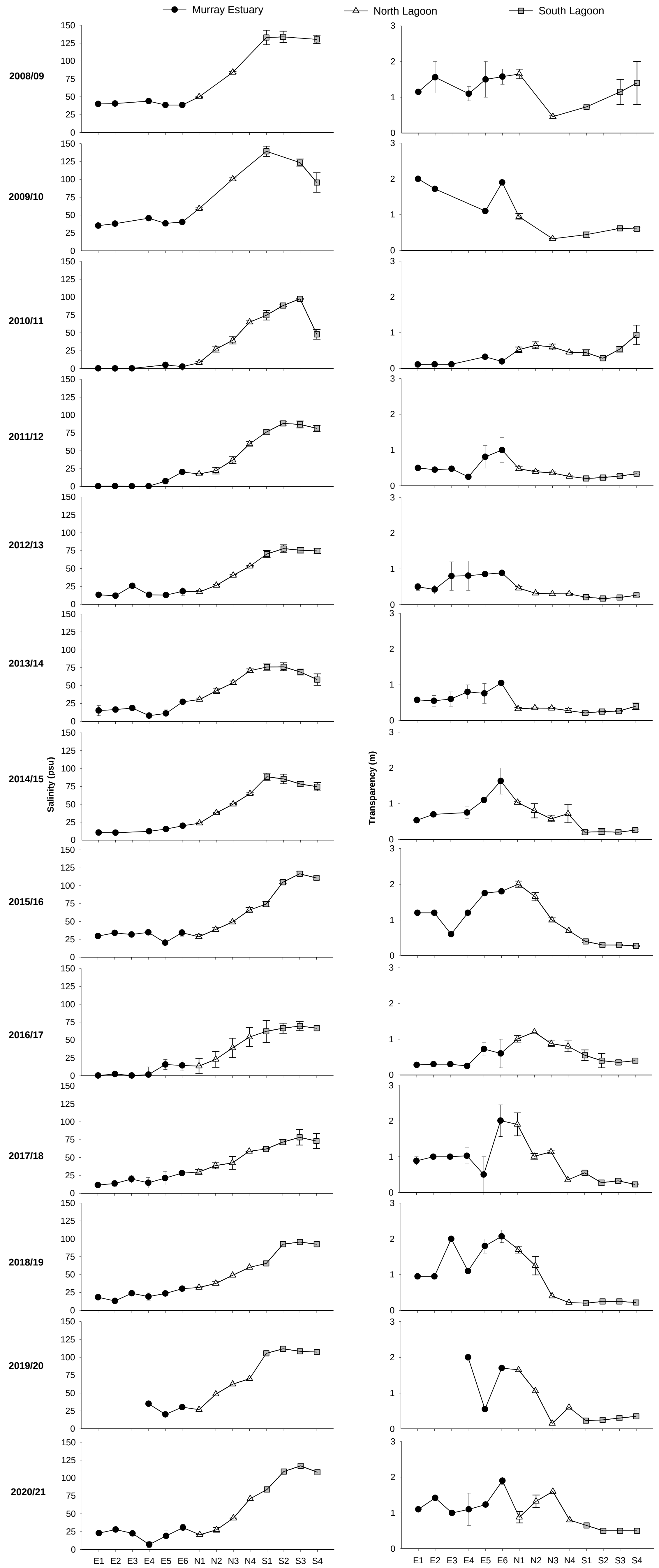


Figure 4.3. Mean values ± S.E. of salinity (psu) (left) and transparency (secchi disc depth, m) (right) over the core sampling period (January–March) at each sampling site (data from all sampling occasions pooled) in the Coorong between 2008/09 and 2020/21. See Table 3.1 for site code.

4.3. Black bream

4.3.1. Relative abundance (fishery catch)

The annual catch of black bream was less than 3.3 t in all years of this study (2008/09–2020/21) (Figure 4.4). The catch in 2020/21 was 3.2 t, which was nearly double the 2019/20 catch, however it remained considerably below the ecological target of 8 t (20%). The annual catch of the last 4-year period showed a positive trend, suggesting a general increase in the population abundance/biomass from 2017/18 to 2020/21 (Figure 4.5).

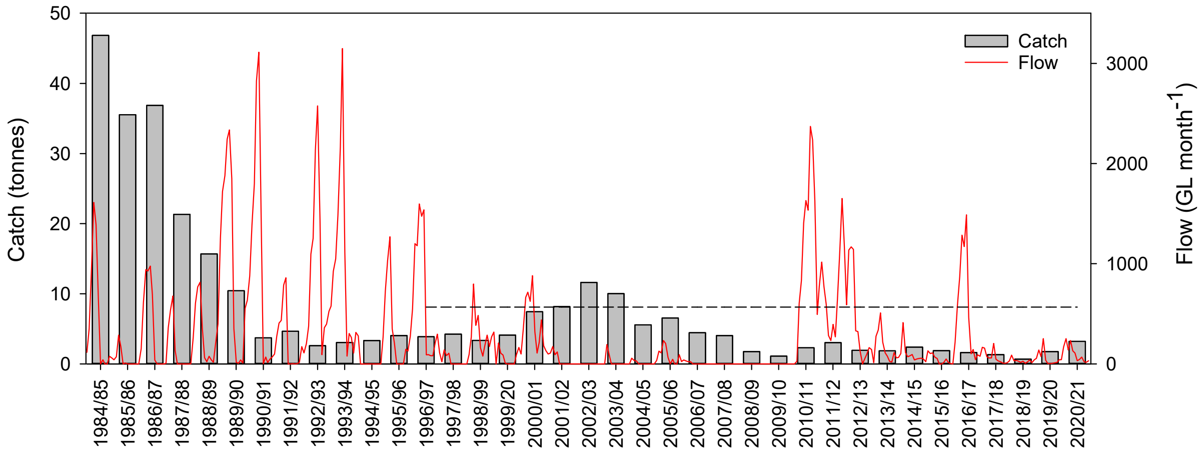


Figure 4.4. Annual commercial catch of black bream from the Coorong between 1984/85 and 2019/20. The redline represents modelled monthly flow discharge to the Coorong (GL month^{-1}) between July 1984 and June 2021 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (8 t) between 2000/01 and 2005/06.

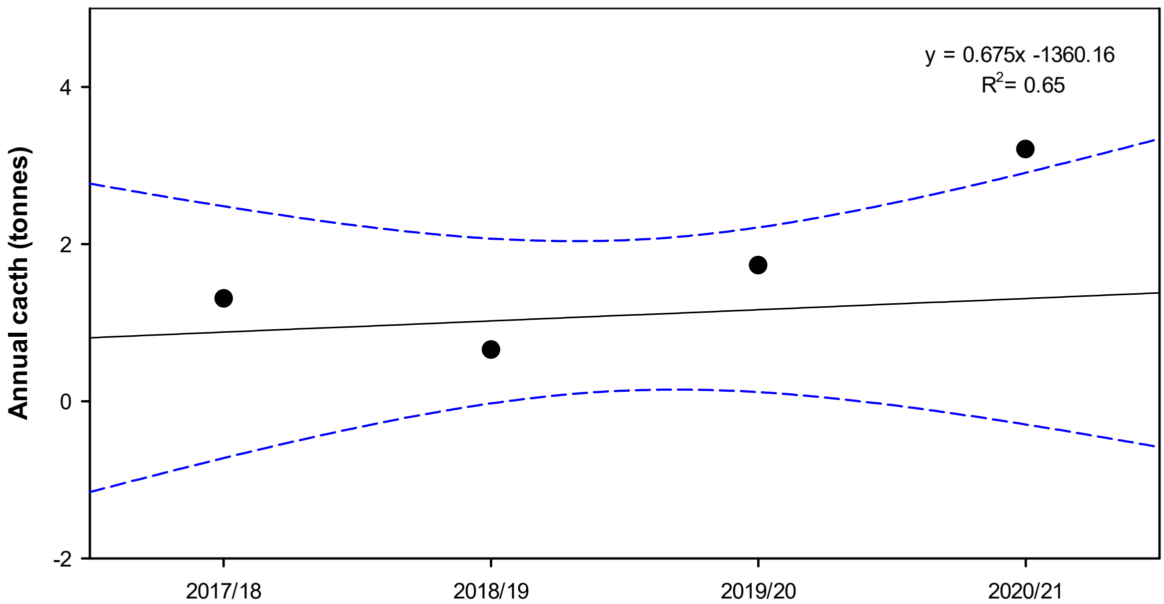


Figure 4.5. Trend in the black bream catches over four years (2017/18–2020/21). Blue dashed lines show 95% confidence intervals.

4.3.2. Distribution

The spatial distribution of commercial fishery catches of black bream varied across the Coorong over the last 37 years (Figure 4.6). Prior to the mid-1990s, the majority of black bream catches were from the southern Coorong (south of Mark Point), whereas during the Millennium Drought (2001–2010), >90% of the catch came from the Estuary (north of Mark Point). Following the substantially increased barrage flows from 2010/11–2012/13, the proportional catch from the southern Coorong gradually increased, reaching 54% in 2012/13. In the following eight years, this proportion was >50% only in 2017/18, 2019/20 and 2020/21 (e.g. 73% in 2020/21).

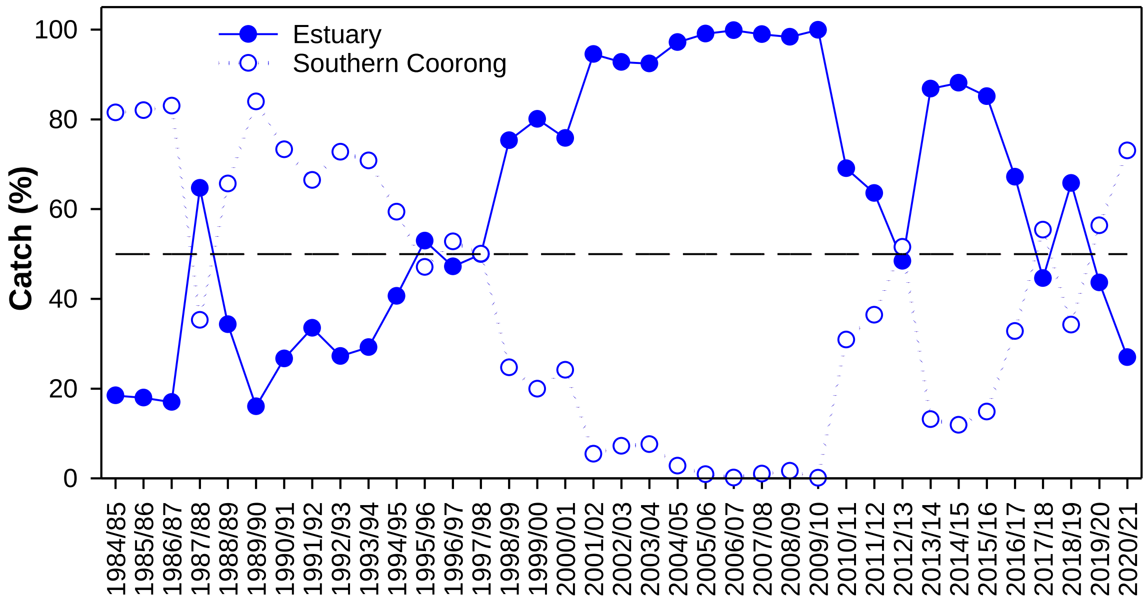


Figure 4.6. Black bream commercial fishery catches from different areas (proportional catches from the north (Estuary) vs the south of Mark Point in the Coorong (Southern Coorong)) between 1984/85 and 2020/21. Dashed black line indicates 50%.

4.3.3. Age structure

From 2008/09 to 2020/21, black bream sampled from commercial fishery catches ranged in age from 2 to 32 years, although most fish were <10 years old (Figure 4.7). In 2008/09 and 2009/10, there was a greater proportion of fish >10 years old (30% and 36%, respectively).

The time-series of annual age structures in the last 13 years indicated several relatively strong cohorts (i.e. ≥15% of the sampled population) of black bream present in the Coorong, mostly with one or two strong cohorts in each year. In the first three years, the strongest cohort was the 2003/04 year class. This cohort was present as 5 year olds in

2008/09, and persisted as 6 and 7 year olds in 2009/10 and 2010/11, respectively. The second strongest cohort, originated in 1997/98, persisted as 11 and 12 year olds in 2008/09 and 2009/10, respectively, but was not distinct in 2010/11.

In 2011/12, another strong cohort (i.e. 2006/07) of 5 year olds appeared, which remained the most dominant in the following five years. A moderate cohort (i.e. 2009/10) of 4 year olds was observed in 2013/14, which persisted in the following three years. In 2016/17, the 2012/13 cohort became distinct as 4 year olds in the age structure, along with the dominant 2006/07 cohort as 10 year old fish. The 2012/13 cohort dominated the age structure as 5 year olds in 2017/18, although this cohort was not apparent in later years.

In 2018/19, the age structure was evenly distributed with 73% of fish ranging between 3 and 6 year olds. In 2019/20, the black bream age structure was dominated by the 2016/17 and 2015/16 cohorts (3 and 4 year olds, respectively), whilst the 2006/07 cohort was still distinct in the age structure, as 13 year olds. In 2020/21, the 2016/17 cohort continued to be most dominant, representing 34% of the sampled population, whereas 2015/16 and 2006/07 cohorts became less distinct.

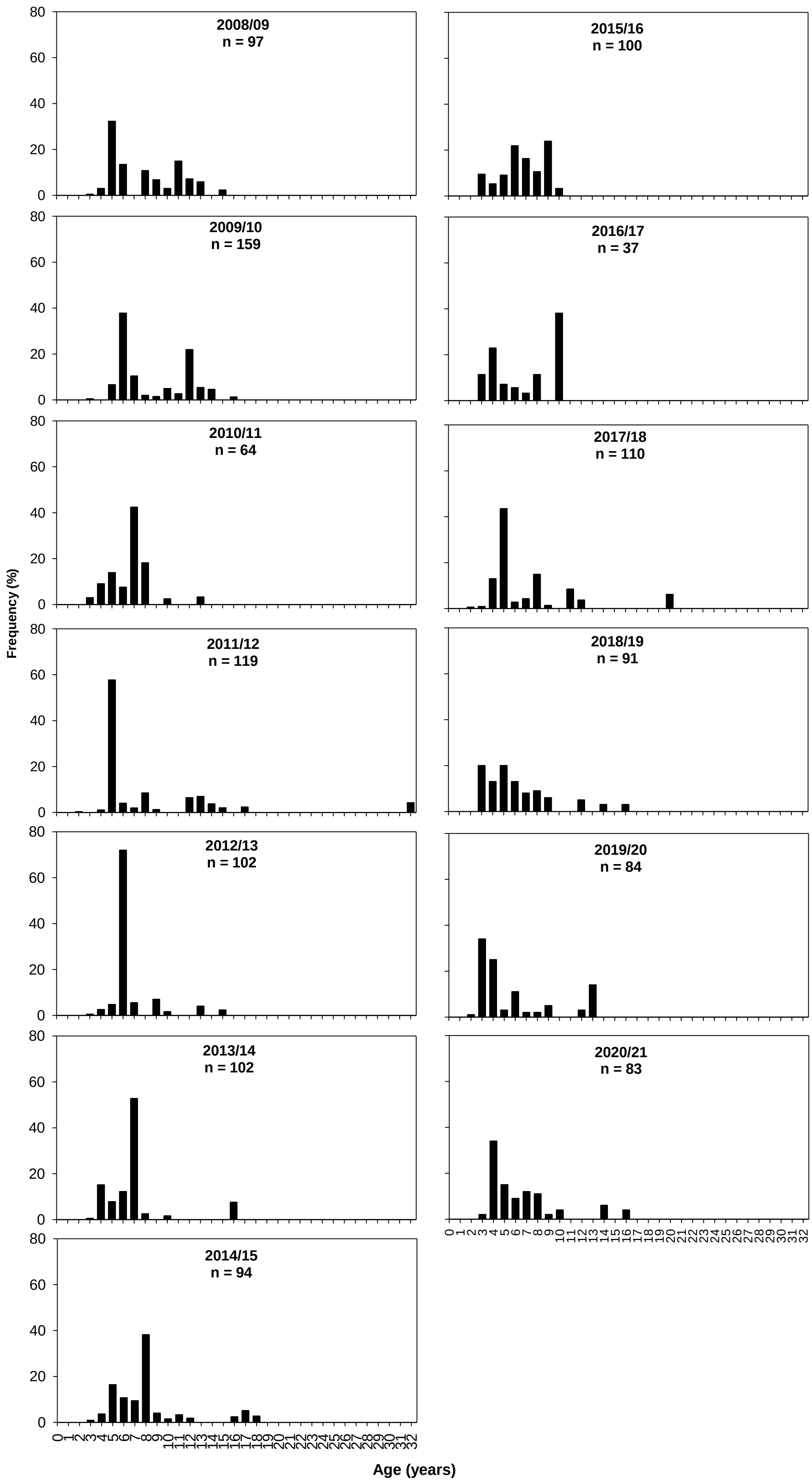


Figure 4.7. Age structure of black bream from the Coorong from 2008/09 to 2019/20 (commercial fishery samples).

4.3.4. Recruitment

Relative abundance (fyke net CPUE, fish.net night^{-1}) of black bream YOY generally remained low and varied across sampling sites in the Coorong over the last 13 years (2008/09–2020/21) (Table 4.1). Mean CPUE across the regular sites declined from 2.03 fish.net.night^{-1} in 2008/09 to 0.86 fish.net night^{-1} in 2012/13, and no YOY were caught in 2014/15, 2016/17, 2018/19, 2019/20 and 2020/21. Notably, in 2017/18 relative abundance of YOY was the highest of all years (2.06 fish.net night^{-1}). Black bream YOY were collected in >50% of the sites only in 2008/09 and 2017/18, although in the earlier year, sampling was generally restricted within the Murray Estuary.

4.3.5. Condition assessment

Based on the above analyses of indicators and indices against ecological targets (reference points), scores were assigned to each indicator and a total score of population condition was calculated for black bream in each year (Table 4.2). In 10 out of the 13 years, the black bream population condition in the Coorong, was ‘extremely poor’, ‘very poor’ or ‘poor’. In 2017/18 and 2019/20, the condition improved to ‘moderate’, due to the increased abundance and distribution of YOY and an increasing trend in commercial catch, respectively. In 2020/21, the population condition was also ‘moderate’, reflected by an increasing trend in population abundance/biomass, >50% of commercial catch from the southern Coorong and the presence of two strong, recently recruited cohorts (2016/17 and 2015/16).

Table 4.2. Relative abundance (CPUE, fish.net night[-1]) of young-of-year black bream for different sampling sites in the Coorong (SE= standard error). (HI = Hindmarsh Island, SRP = Sir Richard Peninsula, YHP = Young Husband Peninsula). NS = Not sampled.

CPUE (fish per net.night)	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19		2019/20		2020/21	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Goolwa Barrage saltwater side HI end	**4.00**	**1.95**	**0.42**	**0.16**	**0.00**	**0.00**	**0.00**	**0.00**	**0.92**	**0.32**	**0.00**	**0.00**	**NS**	**NS**	**0.19**	**0.14**	**0.00**	**0.00**	**2.25**	**2.25**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Goolwa Barrage saltwater side SRP end	**5.33**	**1.69**	**1.25**	**0.33**	**0.00**	**0.00**	**0.05**	**0.05**	**1.06**	**0.34**	**0.03**	**0.03**	**NS**	**NS**	**0.00**	**0.00**	**0.00**	**0.00**	**1.75**	**1.11**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Mundoo Barrage	**0.25**	**0.25**			**0.00**	**0.00**	**0.08**	**0.06**	**1.47**	**0.82**	**0.00**	**0.00**	**NS**	**NS**	**0.00**	**0.00**	**0.00**	**0.00**	**4.25**	**1.31**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Boundary Creek	**0.09**	**0.09**	**0.00**	**0.00**			**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**NS**	**NS**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Additional sites																										
Goolwa Barrage FW HI end	0.00	0.00																								
Goolwa Barrage FW SRP end	0.00	0.00	0.00	0.00																						
Beacon 19																					0.00	0.00	0.00	0.00	0.00	0.00
Swan Point							0.00	0.00													0.00	0.00	0.00	0.00	0.00	0.00
Mundoo Channel	0.00	0.00																								
Mundoo Channel in front of house							0.00	0.00																		
Boundary Creek Barrage	0.75	0.25													0.00	0.00										0.00
Boundary Creek Pole															0.00	0.00										
Boundary Creek Structure															0.00	0.00										
Godfrey's Landing							0.25	0.25													0.00	0.00	0.00	0.00	0.00	0.00
Ewe Island																			1.25	0.75	0.00	0.00	0.00	0.00	0.00	
Ewe Island Causeway	0.00	0.00	0.00	0.00																						
Opposite Tauwitchere Barrage	1.33	1.33	0.00	0.00																						
Pelican Point	0.00	0.00																								
Pelican Point YHP	0.13	0.13																								
Pelican Pt. YHP Opp. Rumbelow Shack							0.00	0.00																		
Cattle Point					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00	1.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
South Cattle Point							0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00								
Mark Point	0.13	0.13			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Mark Point beach							0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00								
Opp Mark Point YHP							0.00	0.00																		
Long Point					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00	4.00	1.35	0.00	0.00	0.00	0.00	0.00	0.00
Long Point beach							0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00								
Long Point corner																	0.00	0.00								
Long Point reef							0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00								
Long Point sand dune					0.00	0.00					0.00	0.00					0.00	0.00	2.00	1.68	0.00	0.00	0.00	0.00	0.00	0.00
Long Point YHP Side; opp. Jetty							0.00	0.00	0.00	0.00																
Robs Point					0.00	0.00																				
Noonameena					0.00	0.00																				
Average across regular sites	**2.80**	**1.33**	**0.56**	**0.37**	**0.00**	**0.00**	**0.04**	**0.02**	**0.86**	**0.31**	**0.01**	**0.01**			**0.06**	**0.05**	**0.00**	**0.00**	**2.06**	**0.87**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Average across sites	**1.63**	**0.40**	**0.42**	**0.10**	**0.00**	**0.00**	**0.03**	**0.01**	**0.68**	**0.20**	**0.01**	**0.01**			**0.05**	**0.03**	**0.00**	**0.00**	**2.09**	**0.47**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
# Sites sampled	13		6		9		17		12		12		0		7		13		9		12		12		12	
# Sites black bream YOY present	8		2		0		3		3		1				1		0		8		0		0		0	
% of site YOY present	62%		33%		0%		18%		25%		8%				14%		0%		89%		0%		0%		0%	

Table 4.3. Condition assessment for black bream populations in the Coorong from 2008/09 to 2020/21. Rule of scoring: each indicator receives 1 point if indices meet the following requirements: (1) Relative abundance – one of the indices meets the reference point; (2) Distribution – meet the reference point; (3) Age structure – at least two out of the three indices meet the reference points and (4) Recruitment – both indices meet the reference points. NS = Not sampled. Overall score – fish population condition: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor.

Population Indicator	Indices	Condition Assessment													Ecological Target (Reference Point)
		2008/09 Drought	**2009/10** Drought	**2010/11** Flood	**2011/12** High flow	**2012/13** Moderate flow	**2013/14** Low flow	**2014/15** Low flow	**2015/16** Low flow	**2016/17** High flow	**2017/18** Low flow	**2018/19** Low flow	**2019/20** Low flow	**2020/21** Low flow	
Relative abundance	Catch (t/year)	No	No	No	No	No	No	No	No	No	No	No	No	No	≥8 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Positive (slope)
	Score	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	1	**1**	
Distribution	Proportional catch	No	No	No	No	Yes	No	No	No	No	Yes	No	Yes	Yes	>50% from southern Coorong
	Score	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	
Age structure	% fish >10 years	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	No	>20% of fish >10 years
	Number of strong cohorts in first 5 years	Yes	No	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	At least one strong cohort (≥ 15%)
	Number of strong cohorts in population	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	≥2 strong cohorts
	Score	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	
Recruitment indices	YOY CPUE	Yes	No	No	No	Yes	No	NS	No	No	Yes	No	No	No	>0.77 YOY.net night^{-1}
	YOY distribution	---*	No	No	No	No	No	NS	No	No	Yes	No	No	No	>50% sites (detected)
	Score	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	0	0	
Icon site total score		**1**	**1**	**0**	**2**	**2**	**1**	**1**	**0**	**1**	**3**	**1**	**3**	**3**	
Black bream condition		**Very poor**	**Very poor**	**Extremely poor**	**Poor**	**Poor**	**Very poor**	**Very poor**	**Extremely poor**	**Very Poor**	**Moderate**	**Very poor**	**Moderate**	**Moderate**	

*Although YOY were present at >50% sites in 2008/09, this value should be treated with caution as the sampling sites were generally restricted to the Murray Estuary during that year. Therefore, this value should be disregarded.

4.4. Greenback flounder

4.4.1. Relative abundance (fishery catch)

The annual catch of greenback flounder was below the ecological target (≥24 t y^{-1}) in all study years, except 2011/12 (Figure 4.8). The high catch in 2011/12 (31 t) indicated an increase in relative abundance following high flows in 2010/11 and 2011/12. Catches, however, decreased drastically in the following three years. The catches remained ≤2.1 t y^{-1} since 2013/14, except for 2015/16 (3.5 t) and 2020/21 (4.5 t). Additionally, the annual catches of the last 4-year period showed a positive trend, suggesting a general increase in the population abundance/biomass from 2017/18 to 2020/21 (Figure 4.9).

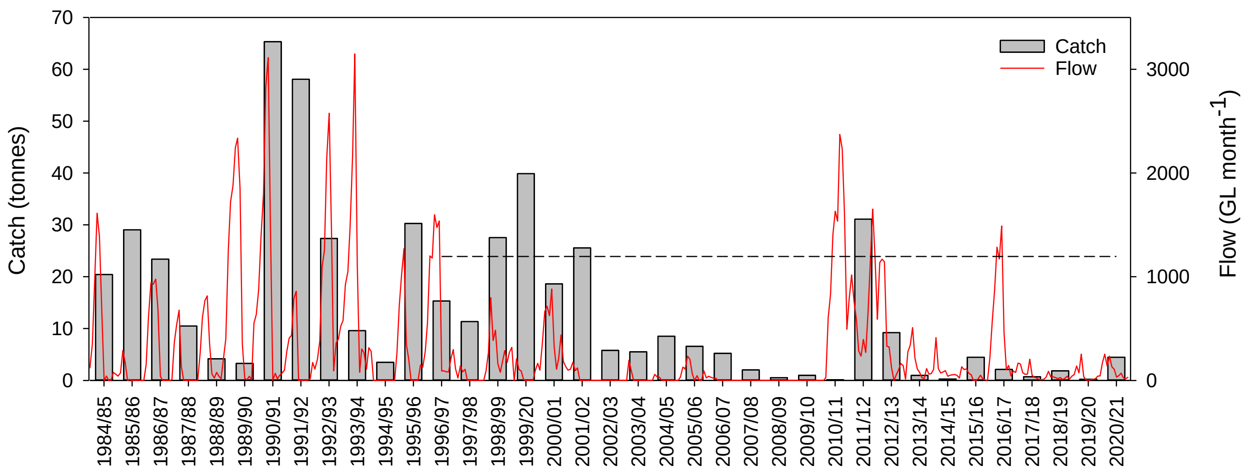


Figure 4.8. Annual commercial catch of greenback flounder from the Coorong between 1984/85 and 2020/21. The red line represents modelled monthly flow discharge to the Coorong (GL/month) between July 1984 and June 2021 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (24 t) between 1995/96 and 2001/02.

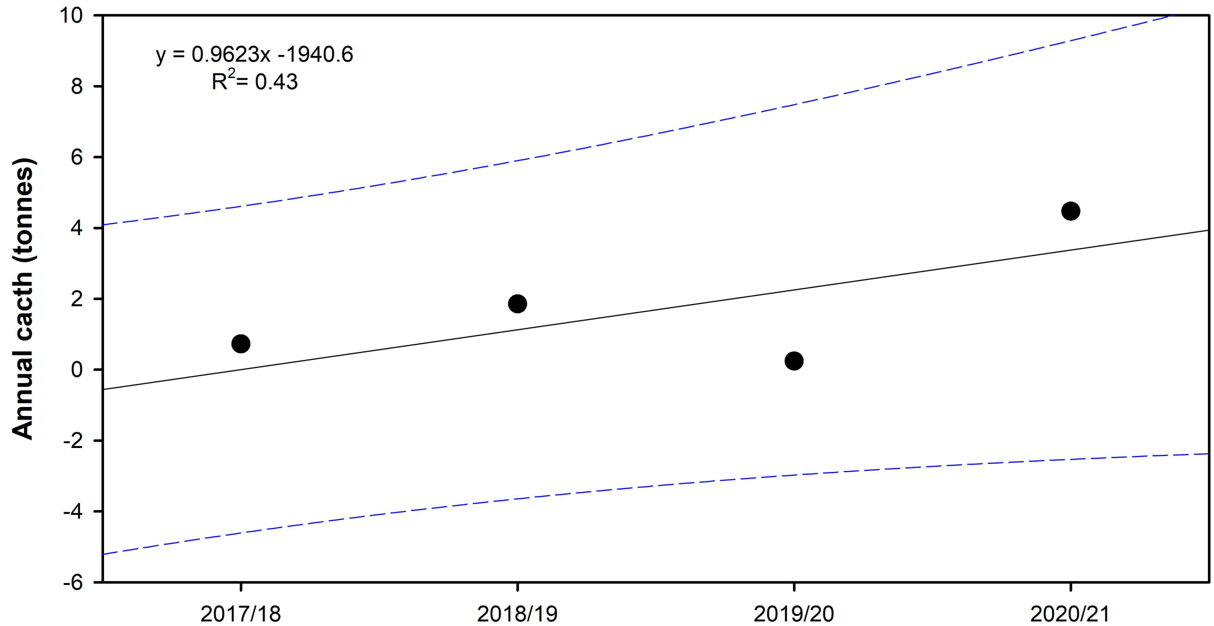


Figure 4.9. Trend in the greenback flounder catches over four years (2017/18–2020/21). Blue dashed lines show 95% confidence intervals.

4.4.2. Distribution

The spatial distribution of commercial fishery catches of greenback flounder varied across the Coorong over the last 37 years (Figure 4.10). Prior to 2001, most of the catches were from the southern Coorong. During 2000/01–2010/11, there was an increase in the proportional catch from the Murray Estuary such that in 2009/10 and 2010/11, 100% of catches were from this sub-region. Following high flows from 20010/11–2011/12, fish from the southern Coorong again dominated the catch, whereas the proportional catches from the Murray Estuary increased in 2013/14 and 2014/15, associated with reduced flows. From 2015/16 onwards, the majority (~75–99%) of the catch was from the southern Coorong, thus meeting the ecological target (>70%).

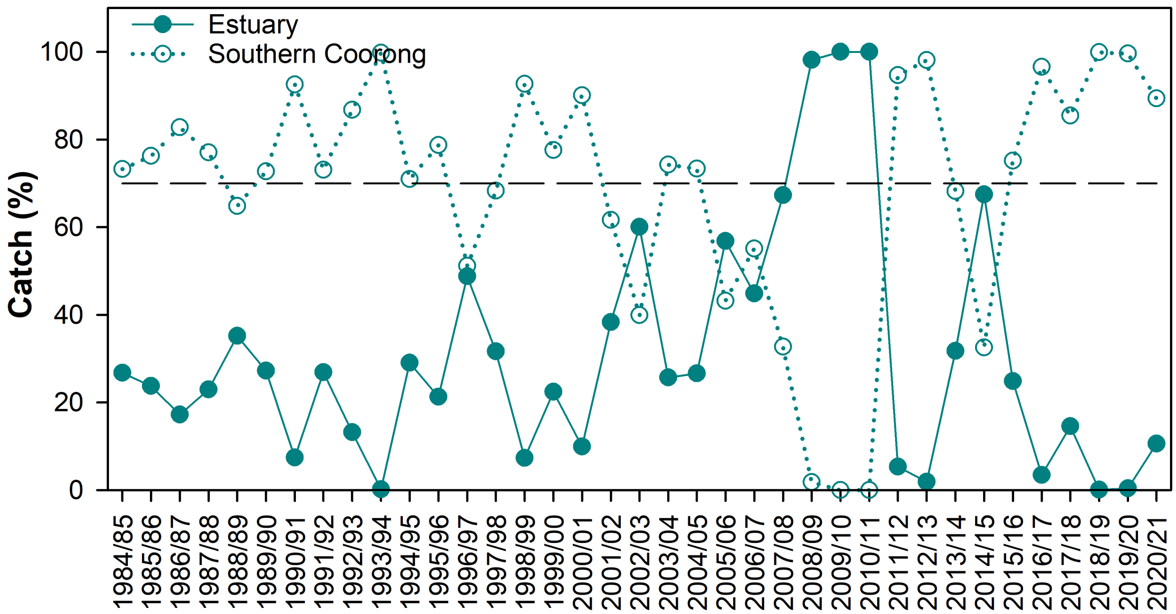


Figure 4.10. Greenback flounder commercial fishery catches from different areas (proportional catches from the north (Estuary) vs the south of Mark Point (southern Coorong)) in the Coorong between 1984/85 and 2020/21. Dashed black line indicates 70%.

4.4.3. Age structure

Greenback flounder, sampled from the commercial fishery between 2009–2021, ranged in age from 0 to 5 years, and most individuals caught in the Coorong were 1–3 years old (Figure 4.11). In most years, the age structure was dominated by 1 or 2 year olds.

In 2011, the age structure comprised a very strong cohort (i.e. >60% of samples) of 1 year olds, that originated in 2010 and recruited to the Coorong following high flows. This year class persisted as a dominant (66%) cohort of 2 year olds in 2012, and remained present as 3 year olds in 2013.

Similarly, in 2015, the age structure was dominated by 1 year olds (i.e. 2014 cohort), which persisted as 2 and 3 years olds in 2016 and 2017, respectively, although the sample size was very low in 2016 (n = 8). In 2020 and 2021, a very strong cohort (> 80%) of 1 year olds was present. In all years, there was at least one cohort of age 0–2 years representing >40% in the fishery age structure, although only in 2014, 2017 and 2018 were there >20% of fish older than 2 years.

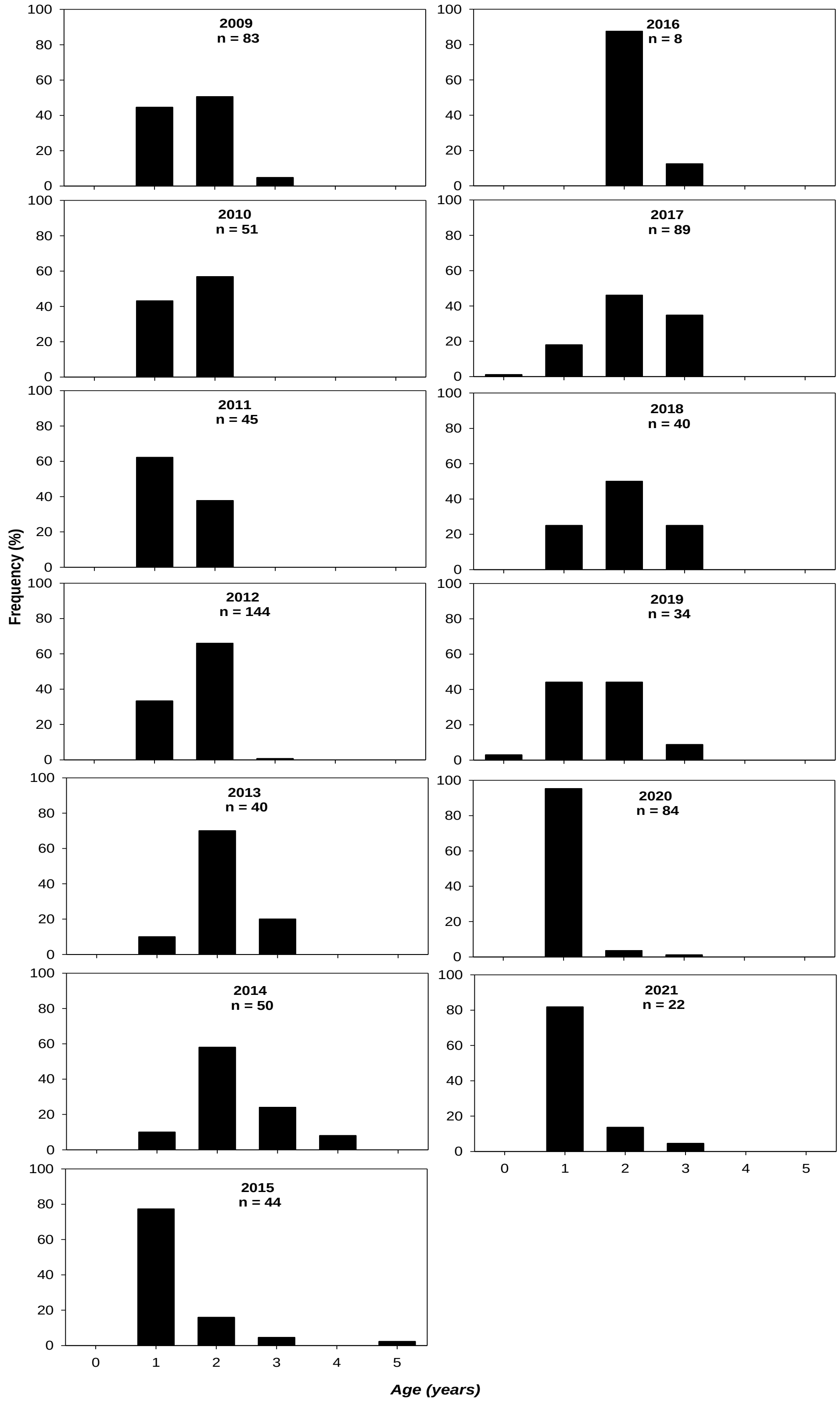


Figure 4.11. Age structure of greenback flounder from the Coorong from 2009 to 2021 (commercial fishery samples).

4.4.4. Recruitment

Relative abundance (CPUE, fish.seine net^{-1}) of greenback flounder YOY varied across sampling sites in the Coorong over the last 12 years (2008/09–2019/20) (Table 4.4). Whilst CPUE of YOY appeared high during the drought years (2008/09–2009/10), the distribution of YOY was largely confined to the Murray Estuary. From 2010/11 to 2014/15 (post-drought years), the distribution of YOY expanded considerably into the South Lagoon, and mean CPUE showed an increasing trend from 2011/12 to 2014/15. However, in 2015/16, both abundance and distribution declined compared to previous years. Since then, mean CPUE across sampling sites has remained <1 fish.seine net^{-1}, although the distribution appeared broader in 2016/17 and 2017/18 than the other two years. In 2020/21, the CPUE of YOY was 1.3 fish.seine net^{-1}, which was 25% higher than the target value (1.04 fish.seine net^{-1}), and they were present at five out of the nine sites sampled (56% of the sites).

4.4.5. Condition assessment

Based on the above analyses of indicators and indices against ecological targets (reference points), scores were assigned to each indicator and a total score of population condition was calculated for greenback flounder in each year (Table 4.5). The population condition of this species in the Coorong was ‘extremely poor’ in 2008/09 and 2009/10. Following high flows, it improved to ‘moderate’ during 2011/12–2013/14, but then declined to ‘poor’ in 2014/15 and 2015/16 with reduced flow to the Coorong. In 2016/17, the population condition improved to ‘moderate’ with substantially higher flow, whereas the condition declined to ‘poor’ or ‘very poor’ in 2017/18, 2018/19 and 2019/20, coinciding with continued reduced flows. In 2020/21, the population condition improved substantially to ‘good’ condition, showing an increased abundance and distribution of YOY, an increasing trend of commercial catch with >50% from the southern Coorong, and the presence of a very strong cohort of 1 year olds.

Table 4.4. Relative abundance (CPUE, fish.seine net^{-1}) of young-of-year greenback flounder at sampling sites within the Coorong from 2008/09 to 2020/21.

CPUE (fish per seine net)	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19		2019/20		2020/21	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Sugars Beach	10.8	3.1	27.7	8.8	0.7	0.4	2.9	1.1	0.4	0.2	6.1	2.4														
Beacon 19													1.1	0.0	0.0	0.0	0.8	0.6	1.3	1	0.0	0.0	0.3	0	7.0	5.9
Godfrey's Landing	17.4	3.2	4.3	1.1	5.3	2.0	0.8	0.5	1.1	0.4	3.5	2.0	1.9	0.8	1.3	0.8	0.3	0.2	1.5	0.8	2.3	1.9	2.0	1.0	1.0	0.7
Mark Point	0.9	0.4	0.8	0.3	2.1	0.6	2.0	1.1	6.5	2.0	2.8	0.6	1.3	0.4	1.3	0.8	0.2	0.2	2.0	1.8	1.7	0.9	0.0	0.0	0.6	0.3
Noonameena	0.0	0.0	0.0	0.0	0.3	0.3	0.7	0.4	1.1	0.6	0.7	0.3	14.3	3.0	2.2	0.9	0.1	0.1	2.8	1.1	0.0	0.0	0.3	0.3	1.7	0.7
Mt Anderson					2.0	0.9	0.1	0.1	0.1	0.1	0.5	0.2	0.4	0.2	0.2	0.2	0.2	0.1	0.7	0.7	0.3	0.3	0.0	0.0	1.1	0.5
Hells Gate	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.2	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Villa dei Yumpa					0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jack Point	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salt Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Mean across sites	**4.2**	**2.7**	**4.7**	**3.9**	**1.2**	**0.6**	**0.7**	**0.3**	**1.0**	**0.7**	**1.5**	**0.7**	**2.1**	**1.5**	**0.6**	**0.3**	**0.2**	**0.1**	**1.0**	**0.3**	**0.5**	**0.3**	**0.3**	**0.2**	**1.3**	**0.7**
# Sites sampled	**7**		**7**		**9**		**9**		**9**		**9**		**9**		**9**		**9**		**9**		**9**		**9**		**9**	
# Sites greenback flounder YOY present	**3**		**3**		**5**		**5**		**6**		**6**		**6**		**4**		**6**		**7**		**3**		**3**		**5**	
% of site YOY present	**43%**		**43%**		**56%**		**56%**		**67%**		**67%**		**67%**		**44%**		**67%**		**78%**		**33%**		**33%**		**56%**	

Table 4.5. Condition assessment for greenback flounder population in the Coorong from 2008/09 to 2020/21. Please note, age composition was based on calendar year. Rule of scoring: each indicator receives 1 point if indices meet the following requirements: (1) Relative abundance – one of the indices meets the reference point; (2) Distribution – meet the reference point; (3) Age structure – one of the indices meets the reference point and (4) Recruitment – both indices meet the reference points. Overall score – fish population condition: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor.

Population Indicator	Indices	Condition Assessment													Ecological Target
		2008/09 Drought	2009/10 Drought	2010/11 Flood	2011/12 High flow	2012/13 Moderate flow	2013/14 Low flow	2014/15 Low flow	2015/16 Low flow	2016/17 High flow	2017/18 Low flow	2018/19 Low flow	2019/20 Low flow	2020/21 Low flow	(Reference Point)
Relative abundance	Annual catch	No	No	No	Yes	No	No	No	No	No	No	No	No	No	≥24 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Positive (slope)
	Score	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	
Distribution	% catch	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	>70% from southern part
	Score	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	
Age structure	A very strong cohort	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes	Presence of a very strong cohort (>60%)
	A recent strong cohort and % fish >2 years	No	No	No	No	No	Yes	No	No	Yes	Yes	No	No	No	≥1 strong cohort (>40%) in year 0–2 and >20% >2 years
	Score	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	
Recruitment	YOY CPUE	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	Yes	>1.04 fish.seine net^{-1}
	YOY distribution	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	>50% sites
	Score	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	
Icon site total score		**0**	**0**	**2**	**3**	**3**	**3**	**2**	**2**	**3**	**2**	**1**	**2**	**4**	
Greenback flounder condition		**Extremely poor**	**Extremely poor**	**Poor**	**Moderate**	**Moderate**	**Moderate**	**Poor**	**Poor**	**Moderate**	**Poor**	**Very Poor**	**Poor**	**Good**	

4.5. Smallmouth hardyhead

4.5.1. Relative abundance

Relative abundance of adult smallmouth hardyhead in the Coorong varied over the last 13 years (Figure 4.12). The mean CPUE was above the ecological target value (120 fish.UE^{-1}) in six of the 13 years, including 2020/21. However, the results of 2015/16, 2018/19 and 2019/20 should be interpreted with caution because no spring–early summer sampling occurred in these years, and instead, data collected in late summer/early autumn (February/March) were used, which may have resulted in an over-estimate of adult abundance. See Appendix D for more detailed information on adult CPUE by sampling site.

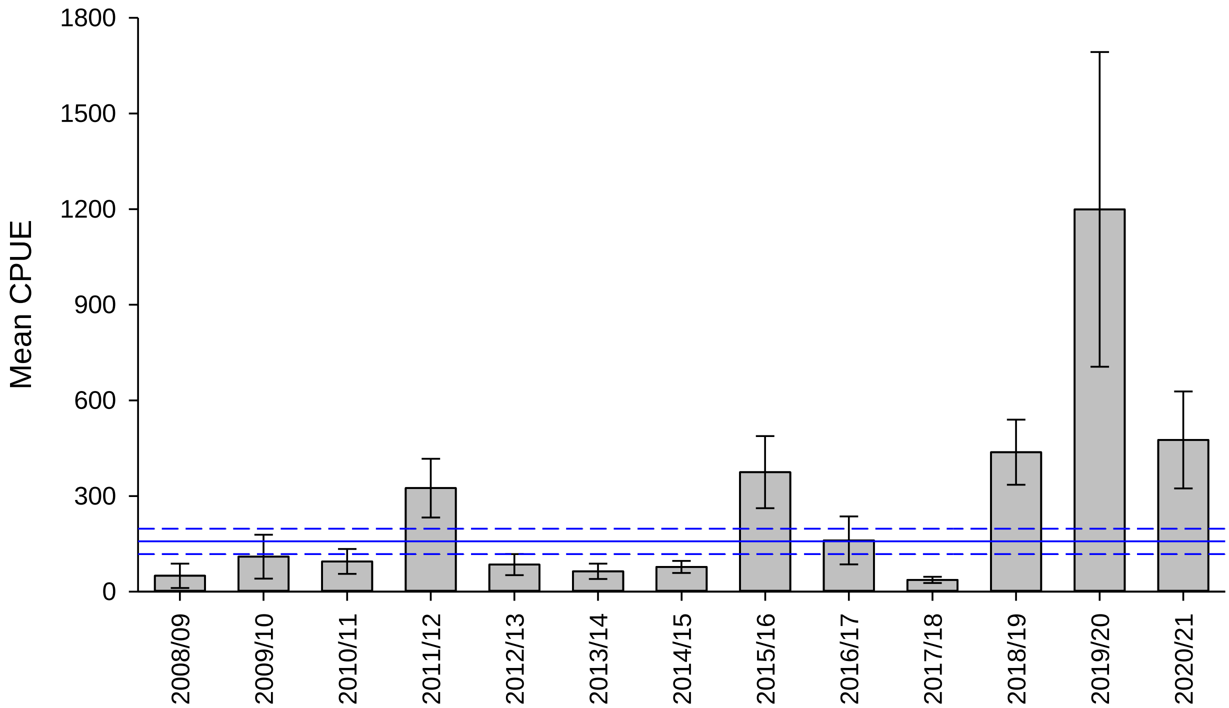


Figure 4.12. Mean seine net catch per unit effort (CPUE) ± SE of smallmouth hardyhead adults (spring/early summer; ≥40 mm TL) in the Coorong from 2008/09 to 2020/21. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are ± 25% (dashed blue lines, with the lower line set as the ecological target >120 fish.UE^{-1}). 2014/15 value is based on large seine net data only; sampling in 2015/16, 2018/19 and 2019/20 was conducted in late summer/autumn.

4.5.2. Recruitment

Relative abundance of new recruits (smallmouth hardyhead <40 mm TL) showed a rapid response to the 2010/11 flood, with significant increases in January/February 2011 and 2012 (Figure 4.13). Abundance declined over the next three years from 817 fish.UE^{-1} in 2012/13 to 195 fish.UE^{-1} in 2014/15. However, it should be noted that the 2014/15 value may have been under-estimated because only large seine net data were available from intervention monitoring (Murray Futures CLLMM Recovery Program) in this year, whereas the small seine net has been more effective in sampling new recruits. Abundance of new recruits increased over the next two years to 1,162 fish.UE^{-1} in 2016/17. Following a decrease in 2017/18, it increased again in 2018/19–2020/21 (>1,300 fish.UE^{-1}) to above the ecological target (800 fish.UE^{-1}). More detailed information on new recruit CPUE by sampling site is presented in Appendix E.

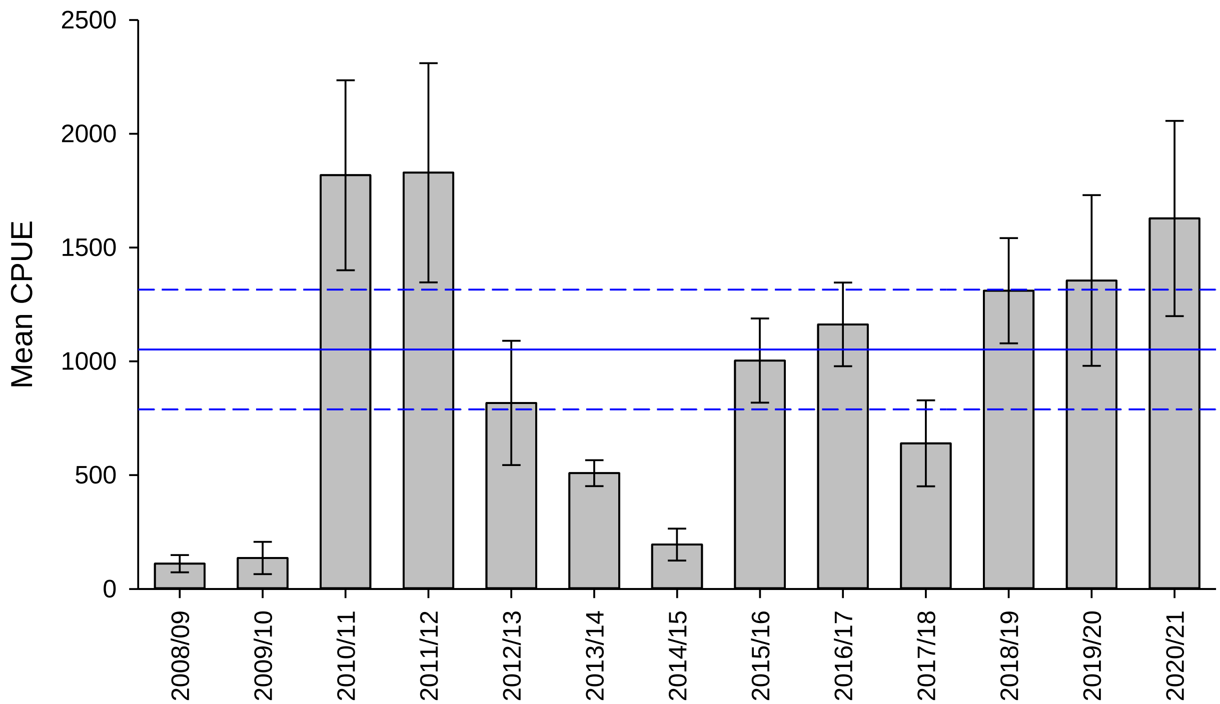


Figure 4.13. Mean seine net catch per unit effort (CPUE) ± SE of smallmouth hardyhead new recruits (late summer/autumn; <40 mm TL) in the Coorong from 2008/09 to 2020/21. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are ± 25% (dashed blue lines with the lower line set as the ecological target >800 fish.UE^{-1}). 2014/15 value is based on large seine net data only.

4.5.3. Extent of recruitment

In 2008/09 and 2009/10, only 20% of sites showed significant recruitment (i.e. having >60% of fish being new recruits) (Table 4.5). In contrast, the proportion of sites showing significant recruitment substantially increased in the post-drought years (i.e. since 20210/11), and the ecological target (of >75% of sites with significant recruitment) was met in six of these years (i.e. 2010/11–2013/14 and 2016/17–2017/18), which all followed high flows. In 2018/19, 2019/20 and 2020/21 with lower flows, only 63%–75% of the sites had significant recruitment. However, it is important to note that the results of 2018/19 and 2019/20, as well as 2014/15 and 2015/16 should be interpreted with caution. As previously indicated, only large seine net data were available in 2014/15, which may have resulted in the underestimation of recruit abundance, whereas data from February/March instead of November/December that was used in 2015/16, 2018/19 and 2019/20 may have over-estimated adult abundance, thus leading to the potential under-estimation of the extent of recruitment.

4.5.4. Distribution

The presence of smallmouth hardyhead adults and new recruits across sampling sites was used as an indication of their distribution across the Coorong from 2008/09 to 2020/21(Table 4.6). In 2008/09 and 2009/10, new recruits and adults were present in no more than 80% of the sites, which failed to meet the ecological target for distribution (>87% sites). Since 2010/11, new recruits have been present across all sampling sites (100%) and adults at most sites (88%–100%) (except for 2010/11), meeting the ecological target.

Table 4.6. Proportional abundance (CPUE) of new recruit smallmouth hardyhead in relation to total abundance across eight sites in the North and South lagoons of the Coorong from 2008/09 to 2020/21. Note: 2014/15 values are based on large seine net data only; 2015/16, 2018/19 and 2019/20 adult fish data are based on sampling conducted in late summer/autumn. Note: * denotes significant recruitment.

Year	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Site	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**
Abundance of juvenile													
Mark Point (N1)	73	357	699	233	99	254	48	582	620	230	683	353	927
Long Point (N2)			3352	499	161	345	23	523	561	319	1148	521	767
Noonameena (N3)	149	242	2447	4707	378	626	26	385	810	1716	1069	1152	403
Mt Anderson (N4)			2863	2248	423	562	9	641	1101	160	454	1534	1322
Hells Gate (S1)		0	2123	1654	1740	578	527	1658	1806	1103	1808	856	1988
Villa de Yumpa (S2)			2337	1470	373	688	364	1264	1974	363	1009	2003	1171
Jack Point (S3)		0	141	1699	2098	646	333	1618	1336	460	2180	3622	2206
Salt Creek (S4)		80	583	2120	1269	371	231	1351	1090	765	2129	797	4239
Total abudance (juvenile + adults)													
Mark Point (N1)	73	698	790	463	100	263	55	848	761	230	1587	2337	942
Long Point (N2)			3504	750	175	367	120	999	654	335	1470	4488	1387
Noonameena (N3)	396	439	2701	5578	387	849	84	653	936	1746	1492	3360	641
Mt Anderson (N4)			2863	2527	491	621	60	1103	1128	169	797	2143	1981
Hells Gate (S1)	1	0	2194	2185	2028	616	632	2740	1999	1173	2253	1114	3376
Villa de Yumpa (S2)			2337	1539	471	754	421	1348	2636	415	1123	2121	1310
Jack Point (S3)	0	1	143	1814	2170	721	525	1724	1377	506	3000	4017	2540
Salt Creek (S4)	1	94	584	2373	1402	391	292	1602	1093	837	2260	850	4654
Proportional abundance of juvenile (%)													
Mark Point (N1)	100	51	88	50	99	97	88	69	81	100	43	15	98
Long Point (N2)			96	67	92	94	19	52	86	95	78	12	55
Noonameena (N3)	38	55	91	84	98	74	31	59	87	98	72	34	63
Mt Anderson (N4)			100	89	86	90	15	58	98	95	57	72	67
Hells Gate (S1)	0	0	97	76	86	94	83	61	90	94	80	77	59
Villa de Yumpa (S2)			100	96	79	91	86	94	75	87	90	94	89
Jack Point (S3)	-	0	99	94	97	90	63	94	97	91	73	90	87
Salt Creek (S4)	0	85	100	89	91	95	79	84	100	91	94	94	91
% of sites with significant recruitment	**20**	**20**	**100***	**88***	**100***	**100***	**63**	**63**	**100***	**100***	**75**	**63**	**75**

Table 4.7. Distribution of smallmouth hardyhead adults and new recruits from 2008/09 to 2020/21 in the North and South lagoons of the Coorong. Note: 2014/15 values are based on large seine net data only. Thereafter sampling consisted of a combination of small and large seine nets; however, timing and number of sampling occasions varied due to funding constrains.

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
# Sites sampled	5	5	8	8	8	8	8	8	8	8	8	8	8
# Sites smallmouth hardyhead YOY present	2	3	8	8	8	8	8	8	8	8	8	8	8
# Sites adults smallmouth hardyhead present	3	4	6	8	8	8	8	8	8	7	8	8	8
% of site YOY present	**40%**	**60%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
% of site adults present	**60%**	**80%**	**75%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**88%**	**100%**	**100%**	**100%**

4.5.5. Condition assessment

Based on the above analyses of indicators and indices against ecological targets (reference points), scores were assigned to each indicator and a total score of population condition was calculated for smallmouth hardyhead in each year (Table 4.8). The population condition of this species was strongly influenced by river inflows to the Coorong and was ‘extremely poor’ in the North and South lagoons of the Coorong during drought years (2008/09 and 2009/10). In 2010/11–2012/13, with substantially increased flows, the condition improved, ranging from ‘moderate’ to ‘very good’. From 2013/14 to 2019/20, the population condition has remained ‘moderate’, except for 2014/15 when the condition was ‘poor’ and 2016/17 when the condition improved to ‘very good’ with high flows. In 2020/21, the population condition was ‘good’, reflected by the greater abundances and distributions of adults and juveniles compared to the ecological targets although the geographical extent of recruitment was 75%, just missed the target of >75% of sites.

Table 4.8. Condition assessment for smallmouth hardyhead populations in the Coorong from 2008/09 to 2020/21. Scoring system: each index receives 1 point if it is 'yes'. Icon site score: 0 = Extremely Poor, 1 = Very Poor, 2 = Poor, 3 = Moderate, 4 = Good and 5 = Very Good.

Population Indicator & Indices	**Condition Assessment**													**Ecological Targets (Reference point)**
	2008/09 Drought	**2009/10** Drought	**2010/11** Flood	**2011/12** High flow	**2012/13** Moderate flow	**2013/14** Low flow	**2014/15** Low flow	**2015/16** Low flow	**2016/17** High flow	**2017/18** Low flow	**2018/19** Low flow	**2019/20** Low flow	**2020/21** Low flow	
Relative abundance CPUE of adults	No	No	No	Yes	No	No	No	*	Yes	No	*	*	Yes	CPUE >120 $fish.UE^{-1}$
Recruitment CPUE of juveniles	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	CPUE >800 $fish.UE^{-1}$
Extent of recruitment	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	>75% sites with >60% juveniles
Distribution Adults	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	>87% sites (i.e. 7 out of 8 sites)
Juveniles	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Icon site score	**0**	**0**	**3**	**5**	**4**	**3**	**2**	**3**	**5**	**3**	**3**	**3**	**4**	
Smallmouth hardyhead condition	**Extremely Poor**	**Extremely Poor**	**Moderate**	**Very Good**	**Good**	**Moderate**	**Poor**	**Moderate**	**Very Good**	**Moderate**	**Moderate**	**Moderate**	**Good**	

*Note: In 2015/16, 2018/19 and 2019/20, no spring/early summer sampling was conducted for adults; the summer/early autumn data were evaluated but deemed not comparable.

5. DISCUSSION

5.1. Freshwater flow

Freshwater flow from the River Murray is a key driver of ecological processes and biological responses in the Coorong. Inflow affects fish mainly through changes in the following critical factors: (1) connectivity within, and between, marine, estuarine and lake environments; (2) salinity; and (3) productivity by transporting carbon, nutrients and microbiota from upstream (Ye *et al.* 2016; Bice *et al.* 2018).

Over the last 13 years of monitoring, barrage flows were highly variable, including two years (2008/09 and 2009/10) of drought, followed by moderate–high flows in 2010/11–2012/13, and subsequent low flows until 2020/21, except for a high flow year in 2016/17. During low flow years, water for the environment plays a significant role in maintaining barrage flows and connectivity, increasing salt export out of the MDB, reducing salt import to the Coorong, and thus maintaining estuarine habitat and biodiversity in the Coorong (Ye *et al.* 2020a). In 2018/19 and 2019/20, barrage flows were 377 GL and 685 GL, respectively, entirely (100%) comprised of Commonwealth environmental water (Ye *et al.* 2021b), whereas in 2020/21, due to unregulated flows in winter, the flow increased to 1,260 GL with 71% comprised of water for the environment. Monthly inflows were highly variable over the last 13 years, with peaks occurring at different seasons. In 2020/21, there was elevated winter flows peaking in late August (up to ~20,600 ML d^{-1}) and a spring flow pulse peaking around mid-October (up to ~11,500 ML d^{-1}), whereas barrage flows were <8,000 ML d^{-1} from November onward for the rest of 2020/21.

Salt Creek flows into the South Lagoon were also highly variable in the last 13 years, ranging between 2–46 GL y^{-1}, with salinities ranging between 0–30.4 psu. Peak flows usually occurred during winter–spring. Inflows have shown to affect local salinities in the South Lagoon (e.g. Ye *et al.* 2011b; 2020b). In 2020/21, annual inflow (4.3 GL) was the third lowest among all monitoring years.

5.2. Water quality

Salinity has been highly variable in the Coorong, mainly influenced by inflows from the barrages and interplay with tides, driven by oceanic water-level fluctuations, and winds (Gibbs *et al.* 2018). The hydrology and geomorphology of the Coorong, however, also produces a salinity gradient, with salinity increasing from the Murray Estuary southeast to the South Lagoon, irrespective of freshwater inflow (Gibbs *et al.* 2018). During the drought (2008/09 and 2009/10), the lack of freshwater inflows led to a general increase in salinity throughout the Coorong, which ultimately resulted in contraction and loss of a salinity gradient from brackish to marine; and salinity in the South Lagoon increased to greater than four times that of seawater. Connectivity between estuarine and freshwater habitats was substantially reduced or lost due to barrage closure (e.g. 2007–early 2010) and continuous dredging was required to maintain opening of the Murray Mouth (i.e. estuarine–marine connectivity) (DEWNR 2015). Increased salinities and reduced connectivity had a pronounced impact on fish assemblages in the Coorong with generally reduced abundance and species diversity (Noell *et al.* 2009; Zampatti *et al.* 2010; Ye *et al.* 2012; 2016; Bice *et al.* 2018).

Post 2010, increased flows including delivery of water for the environment, reduced salinity substantially throughout the Coorong. The salinity gradient (freshwater–brackish–marine) was restored in the Murray Estuary and northern part of the North Lagoon and mean salinity was predominantly (eight out of 11 years) <100 psu in the South Lagoon. There were some increases in salinity during low flow years (e.g. 2015/16, 2019/20), but the levels were much lower across the system than during the drought years (2008/09 and 2009/10). Importantly, connectivity between freshwater, estuarine and marine environments was restored and has been maintained since late 2010. As a result, fish assemblages in the Coorong showed a general increase in species diversity, abundance and distribution, particularly for estuarine and diadromous species (Ye *et al.* 2012; 2016; 2020b; Bice *et al.* 2020). Similar fish responses were observed in 1983/84 when high flows post-drought reduced salinities to brackish (<30 psu) in the North Lagoon and moderately hypersaline (55–70 psu) in the South Lagoon (Geddes 1987).

The other important water quality parameter that significantly changed in response to freshwater inflows to the Coorong was transparency. During the years of drought, water transparency was relatively high but was reduced considerably during flood and high flow years, particularly in the Murray Estuary and North Lagoon. Transparency was generally low (<0.6 m) in the South Lagoon during all monitoring years. Water transparency may affect individual species behaviour, predator/prey interactions, as well as habitat quality and water column productivity, which may influence fish communities (Whitfield 1994).

5.3. Black bream

As a solely estuarine species, black bream can complete its entire life-cycle within the Coorong estuary. Overall, the abundance, as indicated by commercial fishery catches, has declined substantially in the Coorong since 1984/85. The annual catches during the 13 years of this study (2008/09–2020/21) were no more than 3.2 t, compared to the peak in 1984/85 (46.7 t), suggesting a low biomass indicated by the catches of legal size fish ≥30 cm TL. The most recent fishery assessment classified the Coorong population as depleted (Earl and Bailleul 2021). In 2020/21, the catch (3.2 t) was the highest since 2008/09, although it remained at 40% of the ecological target (8 t) for the Coorong population. It should be noted that since 2009, commercial fishing has been impacted by the interference of long-nosed fur seals (*Arctocephalus forsteri*), which have entered the Lower Lakes and Coorong in substantial numbers (Mackay *et al.* 2016; Goldsworthy and Boyle 2019). Additionally, there was a seasonal closure of black bream fishing in the Murray Estuary during the spawning season (September to November) in 2018 and 2019. Nevertheless, the current low catch was of a similar magnitude to those in years prior to the introduction of long-nosed fur seals or before the implementation of the seasonal closure.

Despite the low abundance, there was a trend of a slight increase in catches over the last four years, and in three of these years (including 2020/21), >50% of the catch came from the southern Coorong. The positive trajectory in catch and increased distribution may be attributed to habitat improvement across the Coorong following 2016/17 high inflows, and additional support of water for the environment particularly in subsequent dry years (2017/18 to 2020/21) (Ye *et al*. 2022). Freshwater flow plays a pivotal role in maintaining suitable salinities and extending favourable estuarine habitat for black bream in the Coorong. This was well demonstrated by the contraction of fishing area to the Murray Estuary sub-region during the Millennium Drought (2001/02 to 2009/10) when there was a lack of freshwater inflow and substantially increased salinities in the Coorong, and the expansion of fishery catch in the southern Coorong during high flow periods (e.g. 1989/90 to 1992/93). An acoustic tagging study, examining the movement and habitat use of black bream in the Coorong, also showed an increased distributional range of this species during 2011/12 (high flow) compared to 2009/10 (drought) (SARDI unpublished data). The fish intervention monitoring in the Coorong also found an increased distribution of black bream into the South Lagoon during 2011/12–2013/14 (Ye *et al.* 2015a).

The age structures of black bream sampled from the commercial catches between 2008/09 and 2020/21 indicated episodic recruitment of this species in the Coorong. Several moderate to strong cohorts were identified, mostly corresponding to fish originating from spawning in low to moderate flow years (e.g. 1997/98, 2003/04, 2006/07, 2012/13 and 2015/16). The 2012/13 and 2015/16 cohorts were also detected as YOY during the new recruit sampling in this study (see Section 4.3.4). The results suggest that the recruitment of black bream may be benefited by small-scale barrage releases in this modified Coorong estuary, post river regulation. Indeed, this was further supported by the strong recruitment of black bream YOY in 2017/18 (a hydrologically dry year), facilitated by low to moderate barrage flows (up to 12,000 ML d^{-1}) made up predominantly of water for the environment to the Coorong during spring−summer (Ye *et al.* 2019a). Such inflows during the months prior to and during the spawning season of black bream (spring to summer) may have benefited recruitment by: (1) attracting spawning aggregations of black bream, which could be important given the low biomass in this region; and (2) providing favourable habitat by influencing salinity gradients (i.e. salt wedge conditions) and increasing biological productivity (i.e. food availability) in the Coorong, which could increase survival and growth in the early life stages (eggs, larvae and juveniles) and ultimately lead to recruitment success.

The importance of freshwater inflow to black bream recruitment has been indicated in many studies (Sarre and Potter 2000; Nicholson *et al.* 2008; Jenkins *et al.* 2010; Williams *et al.* 2012), however, the flow effects on salinity profile, and consequent recruitment, are unique to each estuary based on characteristics of catchment, channel topography and connection to the sea (Jenkins *et al.* 2010). For example, the greatest recruitment of black bream often occurred in years of moderate river flows in the Gippsland Lakes, whereas the timing of strong and weak year classes varied between other Victorian estuaries (Jenkins *et al.* 2010). In the Coorong, there has been concerted effort in recent years to deliver environmental flows to maintain end-of-system connectivity and improve estuarine fish habitat. This includes promoting black bream recruitment under suitable hydrological conditions (i.e. during low to moderate flow years). Several investigations have been conducted to understand what specific flow regime (magnitude, timing, duration and release location) is required to create and maintain salt wedge conditions in order to provide favourable larval nursery habitat to facilitate black bream recruitment in the Coorong (Ye *et al.* 2015b; 2019a; 2019b; SARDI unpublished data 2021).

Interestingly, in 2019/20 and 2020/21, the age structure of the commercial catches of black bream showed a new distinct cohort generated from 2016/17, which was a high flow year. During this year, no black bream YOY were detected in the Coorong, suggesting that the 2016/17 cohort could have originated from spawning in other estuaries and migrated into the Coorong in later years. Although black bream typically complete their lifecycle within estuaries, and many studies suggest little emigration from estuaries or large-scale movements (e.g. Butcher and Ling 1962; Lenanton 1977; Hall 1984; Hoeksema *et al.* 2006; Hindell *et al.* 2008), inter-estuarine movements may occur particularly after flood/high flows (Hall 1984). Currently, a PhD project (University of Adelaide) is studying the population structure and connectivity of black bream across southern

Australia, which will improve our understanding of the spatial scale that populations operate within and interactions between populations, including that of the Coorong.

Black bream is a slow-growing, long-lived estuarine species (Norriss *et al.* 2002). The maximum age reported from the Coorong population in this study was 32 years. Nevertheless, few individuals (generally no more than 10%) greater than 13 years old were present from 2008/09 to 2020/21, and the ecological target of >20% of fish being older than 10 years was only met in three of the 13 years. Given that black bream typically confine their lifecycle within estuaries (e.g. Lenanton 1977; Hall 1984; Hindell *et al.* 2008), the truncated age structures were probably caused by the removal of larger and older individuals by fishing (Hilborn and Walters 1992; Planque *et al.* 2010; Walsh *et al.* 2010; Ferguson *et al.* 2013; Earl *et al.* 2016). Nevertheless, processes occurring over broader spatial scales (e.g. inter-estuarine movements) may also influence population dynamics of black bream (Hall 1984; Gillanders *et al.* 2015). A study using otolith chemistry identified different contingents of black bream population in the Coorong with 63% of fish categorised as residents and the remainder as migratory (Gillanders *et al.* 2015), although it is unknown if the movements of migratory fish were between the estuarine and marine environment or between areas of contrasting salinities within the LLCMM region.

Rebuilding and maintaining a diverse age structure is important for population recovery and improving resilience of this long-lived species. Such populations depend on infrequent strong year classes that originate when environmental conditions are favourable (Ferguson *et al.* 2013). This is particularly critical for the population in the Coorong where river regulation has substantially modified and reduced the extent of estuarine habitats (Harvey 1996) and the ecosystem is still recovering from the severe impact of the Millennium Drought (2001–2010). Since 2010/11, with a number of years of high flows (e.g. 2010/11−2012/13, 2016/17) and the delivery of water for the environment, freshwater−estuarine connectivity and estuarine habitat has improved in the Coorong (Ye *et al.* 2020a; 2021). Indeed, the population condition of black bream showed an improvement to ‘moderate’ in the Coorong in recent years (2017/18, 2019/20 and 2020/21). The presence of new strong cohorts (e.g. 2016/17 and 2017/18) in the Coorong would help improve population resilience. Nevertheless, the extent of their contribution to population recovery in the Coorong remains uncertain given the low abundance of remnant population and substantially reduced spawning biomass (Earl *et al.* 2016; Earl and Bailleul 2021). Furthermore, there is a risk of further flow reduction in the MDB and to the Coorong in the future with impacts of climate change (Hughes 2003). A long-term strategy will be required for environmental flow and barrage management to restore favourable environmental conditions and habitats to promote more frequent recruitment success and improve population abundance of black bream in the Coorong. This can be informed by improved understanding of the influence of barrage releases on salt wedge dynamics (halocline conditions), food resource availability and black bream recruitment in the Coorong (Ye *et al.* 2019a; 2019b). Concurrently, fishery management should continue to seek to protect the remnant spawning biomass and maximise the survival of new recruits to rebuild population abundance and resilience in this region.

5.4. Greenback flounder

As a marine-estuarine opportunist species, greenback flounder regularly enter the Coorong estuary in substantial numbers, using it as a nursery ground (Bice *et al.* 2018). Their population condition over the last 13 years was generally responsive to freshwater inflows to the Coorong, with relatively better condition (i.e. 'moderate') in 2011/12–2013/14 and 2016/17 after flood/high flows. This was reflected by increased abundance and recruitment, expanded spatial distribution, and the establishment of new, strong cohort(s). In contrast, the population condition was 'very poor' or 'poor' in drought (2008/09 and 2009/10) and dry years (2017/18–2019/20). The most recent fishery assessment also defined the stock status of greenback flounder in the Coorong as 'depleted' (Earl and Bailleul 2021). In 2020-21, the population condition improved to 'good'. Although this was not a high flow year, the annual barrage discharge (1,260 GL) was the highest among the low flow years' since 2014/15. This helped reduce salinity in the Coorong particlarly in the Murray Estuary and North Lagoon (Table 4.1), which likely improved estuarine habitat and contributed to the population improvement.

During the extended drought years (2002–2010), the biomass of greenback flounder (legal minimum size is 25 cm TL in South Australia) experienced an order of magnitude decline in the Coorong (mean commercial catch ~4 t y^{-1}), compared to the peak levels in 1990–1992 (mean catch 62 t y^{-1}). The distribution of this species substantially contracted northward with the fishing area largely (99%) confined to the Murray Estuary in late drought years (2008–2010). Such reduction in abundance and distribution was probably due to habitat deterioration including extremely hypersaline conditions throughout most of the Coorong, in conjunction with likely reduced productivity and food resources during the extended low flow period (Ye *et al.* 2016; Giatas *et al.* 2018). After the Millennium Drought broke in late 2010, a remarkable increase in annual catch (31 t) occurred in 2011/12 (high flow), with the harvest broadly distributed throughout the North and South Lagoons. This catch increase was driven by an increase in the abundance of recent recruits including a strong cohort that originated in the 2010/11 flood year. The 2010 cohort continued to dominate the age structure in 2012 and was present in the fishery catch in subsequent years until 2015. Regardless, the abundance declined drastically after 2012/13 and remained at a low level (commercial catches ≤4.5 t y^{-1}) over the last eight years, likely due to the predominant low flow conditions, except for 2016/17 when there were high barrage flows. The low catch level was unlikely to exceed the ecological target of abundance (≥24 t y^{-1}), even with the consideration of seal interference on fishing in recent years. Across the 13 study years, the abundance target (≥24 t) was only met in one year (2011/12), but the target of increasing 4-year trend in catch was achieved in 2011/12, 2012/13 and 2016/17, which were moderate to high flow years, as well as in 2020/21 when there was a substantial reduction in salinities in the Coorong. Freshwater flow has been considered an important factor explaining the variability in abundance of greenback flounder in the Coorong (Hall 1984; Earl 2014). Strong recruitment from flow events often translate to increased fishery production after a 1–2 year lag (Earl *et al.* 2014).

Greenback flounder is a fast-growing fish, which can live to more than 10 years (Sutton *et al.* 2010). The maximum age reported in this study was 5 years from the Coorong, although most of the fish caught were ≤3 years. The highly truncated age structures could partially be due to fishing impact via the removal of larger, older individuals (Hall 1984; Ferguson *et al.* 2013; Earl and Ye 2016), and/or the influence of emigration after their second or third years of life from the estuary to marine environment (Earl *et al* 2017). However, their subsequent population dynamics in offshore habitats and the size of the spawning biomass remain poorly understood.

Freshwater flow is important to facilitate the recruitment of greenback flounder in estuaries, likely by influencing salinity regime, providing favourable estuarine habitat, and increasing food resources (Gillanders and Kingsford 2002; Robins and Ye 2010; Ye *et al.* 2020b). Over the last 13 years, recruitment of YOY occurred annually in the Coorong, although the CPUE and distribution varied among years. As this species has a strong preference for brackish and near-marine conditions (Earl *et al.* 2017), and salinity can influence its reproduction with optimum fertilization rates occurring between 35–45 psu and egg tolerance range of 14–45 psu after fertilization (Hart and Purser 1995), the YOY distribution seemed highly responsive to freshwater inflows and subsequent changes in salinities along the Coorong gradient. In late drought years, YOY were almost completely excluded from the North and South Lagoons due to the elevated hypersaline salinities which made the habitat unfavorable for this species. Therefore, the exceptionally high YOY CPUE in 2008/09 and 2009/10 were more likely due to the aggregation of juveniles into reduced habitat within the Murray Estuary leading to increased catchability. In post-drought years, YOY distribution showed extensive expansion into the North and South Lagoons, with the CPUE meeting the ecological target (>1.04 fish.seine net^{-1}) in four of the 11 years including 2020/21. This highlights the importance of freshwater inflow and salinity in maintaining estuarine nursery habitat, supporting the recovery of greenback flounder population in the Coorong.

5.5. Smallmouth hardyhead

Smallmouth hardyhead is a small-bodied 'solely estuarine' species, generally living to one year of age (Molsher *et al.* 1994). Their population condition in the North and South lagoons of the Coorong was highly variable, ranging from 'extremely poor' to 'very good' over the last 13 years. The best population condition ('very good') was observed in 2011/12 and 2016/17 due to increased recruitment, abundance and distribution of this species during high flows and reduced salinities along the Coorong. Accordingly, the 'extremely poor' condition occurred in the drought years (i.e. 2008/09 and 2009/10). In more recent low flow years (2018/19 and 2019/20), the population condition remained 'moderate'. However, it improved to 'good' in 2020/21, likely due to elevated inflows and reduced salinities in the Coorong.

As a euryhaline species, smallmouth hardyhead can tolerate high salinities (up to 106 psu) (Lui 1969). However, the extreme hypersaline conditions in the late drought years (e.g. 2007/08 and 2008/09) restricted its southerly distribution, when salinities increased to 4–5 times that of seawater (i.e. >140 psu) in summer/autumn (Noell *et al*. 2009; Ye *et al*. 2011b). These years represented an extremely hypersaline phase in the long-term salinity fluctuations of the Coorong as a consequence of no freshwater flows following an extended drought in the MDB. In 2009/10, localised salinity reduction in the South Lagoon (due to increased inflows from Salt Creek of 15.2 GL in 2009/10 compared to 2.1 GL in 2008/09) may have facilitated patchy increases in abundance of this species; but the scale of effect was insufficient to meet any ecological target levels. Since 2010/11, following substantial increases in barrage flows, salinities reduced substantially, with the mean ranging between 24–51 psu in the North Lagoon, and generally below 100 psu in the South Lagoon. Adults and new recruits showed a broad distribution almost across all sampling sites in the Coorong.

The increases in abundance of this small-bodied fish were mostly driven by enhanced spawning and recruitment following increased inflows from the River Murray to the Coorong. Seasonal reductions of salinity by freshwater inflow has been suggested as a partial cue to spawning in smallmouth hardyhead (Molsher *et al.* 1994). Freshwater inflows not only help maintain a suitable salinity gradient, but also enhance productivity (e.g. zooplankton food resources, Shiel and Tan 2013; Furst *et al.* 2014), and thus improved habitat quality and extent for this species across the

Coorong. At times (e.g. 2009/10), dispersion of the remnant population and new recruits from Salt Creek could also help maintain the population in the South Lagoon, as suggested by earlier monitoring (Ye *et al*. 2011b). Furthermore, changing numbers of piscivorous predators and/or competitors in the Coorong could also affect the abundance of smallmouth hardyhead given this prey species plays an important role in the trophic ecology of the region (Giatas and Ye 2016; Giatas *et al.* 2018).

Smallmouth hardyhead can reproduce in hypersaline waters (Lenanton 1977). However, when salinities exceeded its tolerance threshold (108 psu), such as the levels observed in the southern Coorong during the drought period (2006/07–2009/10), the abundance and recruitment of this species was negatively impacted (Noell *et al.* 2009; Ye *et al.* 2010b). This was demonstrated by the lowest CPUE of new recruits of this 13-year study occurring during the late drought years (2008/09 and 2009/10). High salinity is known to impact the reproductive performance of other atherinids (e.g. Carpelan 1955; Hedgpeth 1967). Although a previous Coorong study did not identify any clear effect of salinity on reproduction of smallmouth hardyhead at a lower salinity range (32–74 psu), it suggested that salinity may limit food resources and thus affect recruitment (Molsher *et al.* 1994).

Following the flood/high flows from the River Murray in 2010/11 and 2011/12, substantially increased barrage releases (~9,000–12,800 GL y^{-1}) led to broadly reduced salinities throughout the Coorong (<100 psu in the South Lagoon). This, coupled with other flow induced conditions (e.g. enhanced productivity and food resources), restored extensive areas of suitable habitat and facilitated spawning and recruitment of smallmouth hardyhead. A remarkable increase in new recruit abundance was evident in 2010/11 and 2011/12 when CPUE was >15 times that observed in drought years. From 2012/13 to 2014/15, the abundance of new recruits steadily declined, coinciding with continuous reduction in barrage flows to the Coorong. Similarly, the increase of new recruit abundance in 2016/17 was associated with high barrage flows (~6,500 GL y^{-1}) and salinity reduction throughout the Coorong; whereas the abundance decline in 2017/18 followed reduced flow (~850 GL y^{-1}).

With lower barrage flows in 2018/19 and 2019/20, mean salinity increased to 87 and 108 psu, respectively, in the South Lagoon. However, the CPUE of new recruits did not reduce, and in fact, showed increases in both North and South lagoons. A similar pattern occurred in 2015/16 after three consecutive years of low flow. Such unexpected results could be due to reduced abundance of predators/competitors caused by further increased salinities, as observed during fish assemblage monitoring in the Coorong (e.g. Ye *et al.* 2015a). Also to note, increased water turbidity and filamentous algae abundance in recent years may have reduced prey accessibility and thus reduced predation efficiency of piscivorous waterbirds in the Coorong (Dan Rogers, 2020, pers. comm.). Additionally, increased presence of *Ruppia* over the last five years in the southern Coorong (Waycott *et al.* 2020) may potentially benefit the reproduction of smallmouth hardyhead. For example, the eggs of smallmouth hardyhead have been observed attaching to *Ruppia* in the Coorong (Figure 5.1). The importance of macrophytes to atherinids has been documented, as they provide a sessile medium for egg adhesion and retention in areas of favourable salinity, thus facilitating egg survival and subsequently enhancing recruitment (Molsher *et al.* 1994; Ivanstoff and Crowley 1996).

In 2020/21, the abundance of new recruits increased further, with highest CPUE occurring in the South Lagoon. This coincided with the salinity reduction in this region to ≤106 psu, which is the maximum tolerance level of this species. Such higher range of salinities would have forced other fish species out of the area due to increased osmoregulatory stress and provided opportunities for smallmouth hardyhead to expand their niche where there was less predation and competition for food resources. Further improvements in *Ruppia* abundance have also likely supported smallmouth hardyhead recruitment in the South Lagoon.

Figure 5.1. Smallmouth hardyhead and eggs attaching to *Ruppia* sampled at Hells Gate in the South Lagoon of the Coorong in 2021.

6. CONCLUSION

Condition monitoring for smallmouth hardyhead since 2008/09 indicated that the ecological objective (F-3) to maintain abundant self-sustaining populations of this species in the North and South lagoons of the Coorong was achieved in four out of the 13 years, including 2020/21. In 2020/21, the population was characterised by a broad distribution of both new recruits and adults throughout the North and South Lagoons and high abundance of juveniles (1,628 fish.UE^{-1}) and adults (476 fish.UE^{-1}), both well above the ecological target of 800 fish.UE^{-1} and 120 fish.UE^{-1}, respectively, although the extent of recruitment was 75% and just missed the target of >75% of sites. Although 2020/21 is a relatively low flow year, the annual barrage flow was 1,260 GL, which was a substantial increase compared to the previous three years', 2017/18 (854 GL), 2018/19 (337 GL) and 2019/20 (685 GL). The population improvement to 'good' condition in 2020/21 from 'moderate' in previous three years (2017/18 to 2019/20), was likely supported by increased barrage releases, reduced salinities in the Coorong, and increased abundance of *Ruppia* in the South Lagoon.

For black bream and greenback flounder, the ecological objective (F-4) to restore resilient populations of these species in the Coorong was partially met in 2020/21, with the greenback founder population in 'good' condition and the black bream remaining in 'moderate' condition. In the first nine of the 13 monitoring years, the population condition of black bream were 'extremely poor' or 'poor' in the Coorong, although it improved in more recent years (2017/18, 2019/20 and 2020/21) to 'moderate'. The 'moderate' condition in 2020/21 was characterised by:

- An increasing 4-year catch trend (meeting the target about a positive trend) despite a low relative abundance (annual commercial catch of 3.2 t vs the target: ≥8 t)
- Increased distribution of the commercial catches (73% from the southern Coorong, meeting the target: >50%);
- The presence of two strong cohorts with both ≤5 years (meeting the target) despite only 9.7% of the catches >10 years of age (vs the target: >20%);
- No detection of YOY (vs the target CPUE: >0.77 fish.net $night^{-1}$);

For greenback flounder, the population condition improved from 'extremely poor' during the late drought (2008/09 and 2009/10) to 'moderate' during the three post-drought years (2011/12–2013/14). It then declined to 'poor' in 2014/15 and 2015/16, with low river inflows (<1,300 GL y^{-1}). In 2016/17, the population condition improved to 'moderate' following high flows to the Coorong although it declined again with flow reductions in subsequent three years. Nevertheless, in

2020/21, the population condition improved to 'good' with elevated flows and a general reduction in salinity particularly in the Murray Estuary and North Lagoon. In this year, the 'good' population condition was characterised by:

- A broad distribution of commercial catches (>89% from the southern Coorong, meeting the target: >70%).
- An increasing 4-year trend in catches (meeting the target) despite a low relative abundance (annual commercial catch 4.5 t vs the target: >24 t)
- The presence of a very strong cohort (82% 1 year olds, meeting the target: >60%);
- Increased recruitment with a high YOY CPUE (1.3 fish.seine net^{-1} vs the target: >1.04 fish.seine net^{-1}) and a broad distribution (present at 56% sites vs the target: >50% sites)

Black bream and greenback flounder have different life-histories and belong to different 'estuarine use functional guilds'. Their population status and flow responses also differed in the Coorong over the last 13 years. Therefore, we suggest that future evaluation of the ecological objective F-4 be separated for these two species, by setting up the following two objectives, whereas specific targets remain as defined in the LLCMM Icon Site Condition Monitoring Plan (revised, 2017):

- F-4a: Restore a resilient population of black bream in the Coorong.
- F-4b: Restore a resilient population of greenback flounder in the Coorong.

Freshwater flow is important in facilitating successful recruitment of black bream and greenback flounder, through maintaining/restoring estuarine habitats (providing a favourable salinity gradient and environmental conditions) and increasing productivity in the Coorong. As a marine-estuarine opportunist and relatively fast growing species with a moderate life-span (~10 years), greenback flounder seem to be more responsive to freshwater inflows and salinity improvement in the Coorong. It is encouraging to see this species meeting the ecological objective, reaching 'good' population condition the first time in 2020/21 since the monitoring began in 2008/09. In contrast, black bream is a slower growing, solely estuarine long-lived fish (~32 years). Their population recovery requires a longer term, particularly given the current depleted spawning biomass (Earl *et al.* 2016) and a truncated age structure, which have likely compromised the population resilience of this species in the Coorong. The evidence of some improvements in the black bream population in recent years was likely due to the improved estuarine habitats in the Coorong supported by the delivery of water for the environment and improved Murray barrage operations (Ye *et al.* 2020a).

This study suggests that river inflows and allocations of water for the environment are critical to improve estuarine fish habitats (salinities, connectivity and productivity), enhance fish recruitment and abundance, and improve population resilience in the Coorong. Importantly, flow management should consider inter-annual and intra-annual flow regimes, including small to moderate freshwater releases that may meet different environmental or life-history process requirements of different species (e.g. low to moderate flows, as per the releases in 2003/04, 2006/07, 2012/13 and 2017/18 associated with stronger black bream recruitment). The management needs to be supported by detailed knowledge, which could be obtained through further investigations to: (1) understand the influence of freshwater flows on population dynamics and recruitment of medium- and large-bodied estuarine species; (2) evaluate the benefit/impact of various flow scenarios (both natural and managed flows including water for the environment) for these populations; and (3) assess population recovery (abundance and demographics). Furthermore, to support the recovery of the solely estuarine black bream, fishery management should continue to seek to protect the remnant spawning biomass and maximise the survival of new recruits to rebuild population abundance and age structure to improve resilience.

The fish monitoring over the last 13 years (2008/09–2020/21) provided valuable information on the abundance, distribution, age/size structures and recruitment ecology of the black bream, greenback flounder and smallmouth hardyhead populations in the Coorong. Moreover, the study occurred over an extended period with substantial hydrological variability, including extreme drought (2008/09 and 2009/10, no flow), low flows (e.g. 2014–2016, 2017–2021, <1,300 GL y^{-1}) and flood/high flows (2010–2012 and 2016/17, >6,000 GL y^{-1}), which allowed an assessment of biological responses to flow variability and an investigation on population recovery. This report is based on the framework of fish condition assessment in the Coorong using a multiple lines of evidence approach. It facilitated annual quantitative assessment of the ecological targets and objectives for the three species and the classification of population condition for each species. In recent years, there was a reduction in sampling effort (e.g. in 2015/16, 2018/19 and 2019/20, no spring/early summer sampling occurred for adult smallmouth hardyhead) due to funding constraints, which limited our capacity to evaluate some of the ecological targets. Therefore, future monitoring should ensure the maintenance of the sampling regime as recommended in the LLCMM Condition Monitoring Plan (revised, DEWNR 2017). Overall, the results of this study form an important basis to inform the adaptive management of barrage flows and the delivery of environmental water to ensure the ecological sustainability of iconic estuarine fish species in the LLCMM region.

REFERENCES

Barnett, C. W. and Pankhurst, N. W. (1999). Reproductive biology and endocrinology of greenback flounder *Rhombosolea tapirina* (Günther 1862). *Marine and Freshwater Research* **50**, 35-42.

Bice, C. M., Furst, D., Lamontagne, S., Oliver, R. and Zampatti, B. P. (2016). The influence of freshwater discharge on productivity, microbiota community structure and trophic dynamics in the Coorong: evidence of freshwater derived trophic subsidy in the sandy sprat. Goyder Institute for Water Research Technical Report Series No. 15/40, Adelaide.

Bice, C. M., Hammer, M. P., Wedderburn, S. D., Ye, Q. and Zampatti, B. P. (2018). Fishes of the Lower Lakes and Coorong: an Inventory and Summary of Life History, Population Dynamics and Management. In: Mosley L, Ye Q, Shepherd S, Hemming S, Fitzpatrick R (eds) Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe). Royal Society of South Australia, Adelaide. pp 371-399.

Bice, C. M., Zampatti, B. P. and Fredberg, J. (2019). Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2018/19. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000186-9. SARDI Research report Series No. 1043. 67pp.

Bice, C. M., Zampatti, B. P., Ye, Q. and Giatas, G. C. (2020). Lamprey migration in the lower River Murray in association with Commonwealth environmental water delivery in 2019. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2020/000203-01. SARDI Research Report Series No. 1061, 25 pp.

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

Burridge, C. P., Hurt, A. C., Farringdon, L. W., Coutin, P. C. and Austin, C. M. (2004). Stepping stone gene flow in an estuarine-dwelling sparid from south-east Australia. *Journal of Fish Biology*, **64**, 805–819.

Butcher, A. D. (1945). Conservation of Bream Fishery. *Victorian Department of Fisheries and Game, Fisheries Pamphlet* **1**, 16 pp.

Butcher, A. D. and Ling, J. K. (1962). Bream tagging experiments in East Gippsland during April and May 1944. *Victorian Naturalist* **78**(1), 256–264.

Carpelan, L. H. (1955). Tolerance of the San Francisco topsmelt, *Atherinops affinis affinis*, to conditions in salt producing ponds bordering San Francisco Bay. *California Fish and Game* **40**, 279–284.

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

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

Coutin, P., Walker, S. and Morison A. (eds.) (1997). Black bream – 1996. Compiled by the Bay & Inlet Fisheries and Stock Assessment Group. Fisheries Victoria Assessment Report No.14 (Fisheries Victoria: East Melbourne).

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

Crawford, C. M. (1984b). Preliminary results of experiments on the rearing of Tasmanian flounders, *Rhombosolea tapirina* and *Ammotretis rostratus*. *Aquaculture* **42**, 75–81.

Crawford, C. M. (1986). Development of eggs and larvae of the flounders *Rhombosolea tapirina* and *Ammotretis rostratus* (Pisces: Pleuronectidae). *Journal of Fish Biology* **29**, 325–334.

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

Deegan, B. M., Lamontagne, K. T., Aldridge, K. T. and Brooks, J. D. (2010). Trophodynamics of the Coorong: spatial variability in food web structure along a hypersaline coastal lagoon. Water for a Healthy Country Flagship Report. CSIRO. ISSN: 1835-095X.

DEW (2020). http://www.waterconnect.sa.gov.au

DEWNR (2015). Long-term environmental watering plan for the South Australian River Murray water resource plan area. Department of Environment, Water and Natural Resources, Adelaide.

DEWNR (2017). Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site. DEWNR technical report 2016–17. Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

Dunstan, D. J. (1963). Biologists take stock of our bream. The Fisherman **1** (4), 1–4.

DWLBC (2008). Fact sheet 23: Murray Mouth sand pumping project. The Department of Water, Land and Biodiversity Conservation: Adelaide, South Australia.

Earl, J. (2014). Population biology and ecology of the greenback flounder (*Rhombosolea tapirina*) in the Coorong estuary, South Australia. PhD Thesis, Flinders University, Adelaide. 155pp.

Earl, J. and Bailleul, F. (2021). Assessment of the South Australian Lakes and Coorong Fishery in 2019/20. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2020/000208-2. SARDI Research Report Series No. 1092. 81pp.

Earl, J., Fowler, A. J., Ye, Q. and Dittmann, S. (2014). Age validation, growth and population characteristics of greenback flounder (*Rhombosolea tapirina*) in a large temperate estuary. *New Zealand Journal of Marine and Freshwater Research* **48**(2): 229–244.

Earl, J., Fowler, A. J., Ye, Q. and Dittmann, S. (2017). Complex movement patterns of greenback flounder (*Rhombosolea tapirina*) in the Murray River estuary and Coorong, Australia. *Journal of Sea Research* **122**, 1–10.

Earl, J. and Ye, Q. (2016). Greenback Flounder (*Rhombosolea tapirina*) Stock Assessment Report 2014/15. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F20007/000315-2. SARDI Research Report Series No. 889.

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.

Elsdon, T. S. and Gillanders, B. M. (2006). Identifying migration contingents of fish by combining otoliths Sr:Ca with temporal collections of ambient Sr:Ca concentrations. *Journal of Fish Biology* **69**, 643–657.

Ferguson, G. (2012). The South Australian Lakes and Coorong Fishery: Fishery Stock Status Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000669-4. SARDI Report Series No. 675.

Ferguson, G., Ward, T. M., Ye, Q., Geddes, M. C. and Gillanders, B. M. (2013). Impacts of drought, flow regime and fishing on the fish assemblage in southern Australia's largest temperate estuary. *Estuaries and Coasts* **36**(4), 737–753.

Froese, R. and Pauly, D. E. (2013). Fishbase. http://www.fishbase.org (accessed June 2014).

Furst, D. J., Aldridge, K. T., Shiel, R. J., Ganf, G. G., Mills, S. and Brookes, J. D. (2014). Floodplain connectivity facilitates significant export of zooplankton to the main River Murray channel during a flood event*. Inland Waters* **4**, 413–424. doi:10.5268/IW-4.4.696

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

Geddes, M. C. (2005). The ecological health of the North and South lagoons of the Coorong in July 2004. Report prepared for the Department of Water, Land and Biodiversity Conservation. South Australian Research and Development Institute (Aquatic Sciences): Adelaide, South Australia. SARDI Aquatic Sciences Publication No. RD03/0272–2.

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

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

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

Giatas, G. C. and Ye, Q. (2015). Diet and trophic characteristics of mulloway (*Argyrosomus japonicus*), congolli (*Pseudaphritis urvillii*) and Australian salmon (*Arripis truttaceus* and *A. trutta*) in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000479-1. SARDI Research Report Series No. 858.

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

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

Gillanders, B.M., Izzo, C., Doubleday Z. A. and Ye, Q. (2015). Partial migration: growth varies between resident and migratory fish. *Biology letters* **11**(3), 20140850.

Gillanders, B. M. and Kingsford, M. J. (2002). Impact of changes in flow of freshwater on estuarine and open coastal habitats and the associated organisms. *Oceanography and Marine Biology: an Annual Review* **40,** 233–309.

Goldsworthy, S. D. and Boyle, M. (2019). Operational interactions with Threatened, Endangered or Protected Species in South Australian Managed Fisheries: 2017/18. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000544-9. SARDI Research Report Series No. 1032. 39pp.

Gomon, M. F., Bray, D. J. and Kuiter, R. H. (2008). Fishes of Australia's Southern Coast. Reed New Holland: Chatswood, NSW.

Haddy, J. A. and Pankhurst, N. W. (1998). Annual change in reproductive condition and plasma concentrations of sex steroids in black bream, *Acanthopagrus butcheri* (Munro) (Sparidae). *Marine and Freshwater Research*, **49**, 389–397.

Haddy, J. A. and Pankhurst, N. W. (2000). The effects of salinity on reproductive development, plasma steroid levels, fertilisation and egg survival in black bream, *Acanthopagrus butcheri*. *Aquaculture*, **188**, 115-131.

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

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

Harvey, N. (1996). The significance of coastal processes for management of the River Murray Estuary. *Australian Geographical Studies* **34**, 45–57.

Hedgpeth, J. W. (1967). Ecological aspects of the Laguna Madre. A hypersaline estuary. *In* G. H. Lauff (eds.), 'Estuaries' pp 408–419. (American Academy for the Advancement of Science, Publication 83, Washington).

Hilborn, R. and Walters, C. J. (1992). Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. London, Chapman and Hall.

Hindell, J. S., Jenkins, G. P. and Womersley, B. (2008). Habitat utilisation and movement of Black Bream Acanthopagrus butcherii (Sparidae) in an Australian estuary. *Marine Ecology Progress Series* **366**, 219–229.

Hoeksema, S. D., Chuwen, B. M., Hesp, S. A., Hall, N. G. and Potter, I. C. (2006) Impact of environmental changes on the fish faunas of Western Australian south-coast estuaries. Centre for Fish and Fisheries Research, Murdoch University, Perth.

Hossain, M. A., Hemraj, D. A., Ye, Q., Leterme, S. C. and Qin, J. G. (2017). Diet overlap and resource partitioning among three forage fish species in Coorong, the largest inverse estuary in Australia. *Environmental Biology of Fishes*. DOI 10.1007/s10641-017-0592-3.

Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. *Austral Ecology* **28**, 423–443.

Islam, M. S., Hibino, M. and Tanaka, M. (2006). Distribution and diets of larval and juvenile fishes: influence of salinity gradient and turbidity maximum in a temperate estuary in upper Ariake Bay, Japan. *Estuarine, Coastal and Shelf Science* **68**, 62–74.

Ivanstoff, W. and Crowley, L. E. L. M. (1996). Family Atherinidae: Silversides or Hardyheads. *In***:** McDowell, R.M. (eds.) *Freshwater Fishes of South-eastern Australia*. pp. 123–133. Chatswood, NSW: Reed Books.

Jenkins, G. P., Conron, S. and Morison, A. K. (2010). Highly variable recruitment in an estuarine fish is determined by salinity stratification and freshwater flows: implications of a changing climate. *Marine Ecology Progress Series* **417**, 249–261.

Jenkins, G. P., May, H. M. A., Wheatley, M. J. and Holloway, M. G. (1997). Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with emphasis on commercial species. *Estuarine, Coastal and Shelf Science* **44**, 569–588.

Kailola, P. J., Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A. and Greive, C. (1993). *Australian Fisheries Resources* (Bureau of Resource Sciences, Fisheries Research and Development Corporation: Brisbane).

Kimmerer, W. J. (2002). Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? *Marine Ecology Progress Series* **243**, 39–55.

Kurth, D. (1957). An investigation of the greenback flounder, *Rhombosolea tapirina* Günther. PhD thesis, University of Tasmania, Hobart.

Lenanton, R. C. J. (1977). Fishes from the hypersaline waters of the stromatolite zone of Shark Bay, WA. *Copeia* **2**, 387–390.

Lui, L. C. (1969). Salinity tolerance and osmoregulation in *Taenomembrus microstomus* (Gunther, 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. *Australian Journal of Marine and Freshwater Research* **20**, 157–162.

Mackay, A. I., McLeay, L., Tsolos, A. and Boyle, M. (2016). Operational interactions with Threatened, Endangered or Protected Species in South Australian Managed Fisheries. Data summary: 2007/08–2014/15. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000544-6. SARDI Research Report Series No. 905.

Maunsell Australia Pty Ltd. (2009). Lower Lakes, Coorong and Murray Mouth Icon Site condition monitoring plan. South Australian Murray–Darling Basin Natural Resources Management Board, Adelaide.

McDowall, R. M. (1980). Freshwater fishes of South-eastern Australia (A H & A W Reed Pty Ltd, Sydney).

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

MDBA (2014). Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan. MDBA Publication No 10/14.

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

Morison A. K., Coutin, P. C. and Robertson, S. G. (1998). Age determination of black bream, *Acanthopagrus butcheri* (Sparidae) from the Gippsland Lakes of south-eastern Australia indicates slow growth and episodic recruitment. *Marine and Freshwater Research* **49**, 491–498.

Mosley, L, Ye., Q., Shepherd, S., Hemming, S. and Fitzpatrick, R. (2018). Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe). Royal Society of South Australia, Adelaide.

Newton, G. M. (1996). Estuarine icthyoplankton ecology in relation to hydrology and zooplankton dynamics in a salt-wedge estuary. *Marine and Freshwater Research* **47**, 99–111.

Nicholson, G. and Gunthorpe, L. (2008). Western minor inlets fish habitats 2000. Fisheries Victoria Assessment Report Series, Department of Primary Industries: 1–33.

Nicholson, G., Jenkins, G. P., Sherwood, J. and Longmore, A. (2008). Physical environmental conditions, spawning and early-life stages of an estuarine fish: climate change implications for recruitment in intermittently open estuaries. *Marine and Freshwater Research* **59**, 735–749.

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

Norriss, J. V. Tregonning, J. E., Lenanton, R. C. J. and Sarre, G. A. (2002). Biological synopsis of the black bream, *Acanthopagrus butcheri* (Munroe) (Teleostei: Sparidae) in Western Australia with reference to information from other southern states: Fisheries Research report. Department of Fisheries, Western Australia, Perth.

North, E. W. and Houde, E. D. (2003). Linking ETM physics, zooplankton prey, and fish early life histories to striped bass *Morone saxatilis* and white perch *M. americana* recruitment. *Marine Ecology Progress Series* **260,** 219–236.

North, E. W., Hood, R. R., Chao, S-Y. and Sanford, L. P. (2005). The influence pf episodic events on transport of striped bass eggs to the estuarine turbidity maximum nursery are. *Estuaries* **28**, 108–123.

Partridge, G. J. and Jenkins, G. I. (2002). The effect of salinity on growth and survival of juvenile black bream (*Acanthopagrus butcheri*). *Aquaculture*, **210**, 219–230.

Paton, D. C. (2010). At the end of the River: the Coorong and Lower Lakes. ATF Press, Adelaide.

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

Planque, B., Fomentin, J., Cury, P., Drinkwater, S., Jennings, S., Perry, R. I. and Kifani, S. (2010). How does fishing alter marine populations and ecosystems sensitivity to climate. *Journal of Marine Systems* **79** (3-4), 403–417.

Potter, I. C., Hyndes, G. A., Platell, M. E., Sarre, G. A., Valesini, F. J., Young, G. G. and Tiivel, D. J. (1996). Biological data for the management of competing commercial and recreational fisheries for King George whiting and Black bream. Fisheries Research and Development report FRDC Project 93/82, p. 104.

Potter, I. C., Ivantsoff, W., Cameron, R. and Minnard, J. (1986). Life cycles and distribution of atherinids in the marine and estuarine waters of southern Australia. *Hydrobiologia* **139**, 23–40.

Potter, I. C., Loneragan, N. R., Lenanton, R. C. J., Chrystal, P. J. and Grant, C. J. (1983). Abundance, distribution and age structure of fish populations in the Western Australian estuary. *Journal of Zoology* **200**, 21–50.

Potter, I. C., Tweedley, J. R., Elliott, M. and Whitfield, A. K. (2015). The ways in which fish use estuaries: a refinement and expansion of the guild approach. *Fish and Fisheries* **16**, 230–239.

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

Robinson, W. A. (2015). The Living Murray Condition Monitoring Plan Refinement Project: Summary Report. Technical report to the MDBA, March 2015. 95pp.

Rowland, S. J. and Snape, R. (1994). Labile protogynous hermaphroditism in the black bream, *Acanthopagrus butcheri* (Munro) (Sparidae). *Proceedings of the Linnean Society of New South Wales* **114** (4), 225–232.

Sakabe, R., Lyle, J. M. and Crawford, C. M. (2011). The influence of freshwater inflows on spawning success and early growth of an estuarine resident fish species, *Acanthopagrus butcheri*. *Journal of Fish Biology* **78**, 1529–1544.

Sarre, G. A., Platell M. E. and Potter I. C. (2000). Do the diet compositions of *Acanthopagrus butcheri* (Sparidae) in four estuaries and a coastal lake very with body size and season and within and amongst these water bodies? *Journal of Fish Biology* **56**, 103–122.

Sarre, G. A. and Potter, I. C. (2000). Variations in age compositions and growth rates of *Acanthopagrus butcheri* (Sparidae) amongst estuaries: some possible contributing factors. *Fishery Bulletin* **98**, 785–799.

Sherwood, J. E. and Blackhouse, G. N. (1982). Hydrodynamics of salt wedge estuaries – implications for successful spawning in black bream (*Acanthopagrus butcheri*). Warrnambool Institute of Advanced.

Shiel, R. J. and Tan, L-W. (2013). Zooplankton response monitoring: Lower Lakes, Coorong and Murray Mouth September 2012 – March 2013. Final report to Department of Environment, Water and Natural Resources, Adelaide. 41pp.

Sutton, C. P., MacGibbon, D. J. and Stevens, D. W. (2010). Age and growth of greenback flounder (*Rhombosolea tapirina*) from southern New Zealand. New Zealand Fisheries Assessment Report 2010/48.

Van den Enden, T., White, R. W. G. and Elliott, N. G. (2000). Genetic variation in the greenback flounder *Rhombosolea tapirina* Günther (Teleostei, Pleuronectidae) and the implications for aquaculture. *Marine and Freshwater Research* **51**, 21–33.

Vega-Cendejas, Ma. E. and Hernández de Santillana, M. (2004) Fish community structure and dynamics in a coastal hypersaline lagoon: Rio Lagartos, Yucatan, Mexico. *Estuarine, Coastal and Shelf Science* **60**, 285–299.

Walker, S. and Neira, F. J. (2001). Aspects of the reproduction biology and early life history of black bream, *Acanthopagrus butcheri* (Sparidae), in brackish lagoon system in southeastern Australia. *Aqua, Journal of Ichthyology and Aquatic Biology* **4**, 135-142.

Walsh, C. T., Gray, C. A., West, R. J., van der Meulen, D. E., and Williams, L. F. G. (2010). Growth, episodic recruitment and age truncation in populations of a catadromous percichthyid, *Macquaria colonorum*. *Marine and Freshwater Research* **61** (4), 397–407.

Waycott, M., O'Loughlin, E., Foster, N., McGrath, A., Jones, A. and Van Dijk, K. J. (2020). Distribution and dynamics of filamentous green algae and the *Ruppia* aquatic plant community in the Southern Coorong. Goyder Institute for Water Research Technical Report Series No. 20/02.

Wedderburn, S. D., Bailey, C. P., Delean, S. and Paton, D. C. (2016). Population and osmoregulatory responses of a euryhaline fish to extreme salinity fluctuations in coastal lagoons of the Coorong, Australia. *Estuarine, Coastal and Shelf Science* **168,** 50–57**.**

Whitfield, A. K. (1994). Abundance of larval and 0+ juvenile marine fishes in the lower reaches of three southern African estuaries with differing freshwater inputs. *Marine Ecology Progress Series* **105**, 257–267.

Williams, J., Hindell, J. S., Swearer, S. E. and Jenkins, G. P. (2012). Influence of freshwater flows on the distribution of eggs and larvae of black bream *Acanthopagrus butcheri* within a drought-affected estuary. *Journal of Fish Biology*, **80**, 2281–2301.

Winemiller, K. O. and Rose, K. A. (1992). Patterns of life-history diversification in North American fishes: implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* **49**, 2196–2218.

Ye, Q., Bice, C. M., Bucater, L., Ferguson, G. J., Giatas, G. C., Wedderburn S. D. and Zampatti, B. P. (2016). Fish monitoring synthesis: Understanding responses to drought and high flows in the Coorong, Lower Lakes and Murray Mouth. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2016/000348-1. SARDI Research Report Series No. 909.

Ye, Q., Bucater, L., Furst, D., Lorenz, Z., and Giatas, G. and Short, D. (2019b). Monitoring salt wedge dynamics, food availability and black bream (*Acanthopagrus butcheri*) recruitment in the Coorong during 2018-19. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2018/000425-2. SARDI Research Report Series No. 1045. 48pp.

Ye, Q., Bucater, L., Ferguson, G. and Short, D. (2011a). Coorong fish condition monitoring 2008-2010: population and recruitment status of the black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication Number F2011/000331-1. SARDI Research Report Series Number 572.

Ye, Q., Bucater, L., Giatas, G. and Short, D. (2014). The Living Murray Icon Site Condition Monitoring Plan Refinement. Section 13: LLCCMM Small-mouthed hardyhead populations in the Coorong.

Ye, Q., Bucater, L., Lorenz, Z., Giatas, G. and Short, D. (2019a). Monitoring salt wedge conditions and black bream (*Acanthopagrus butcheri*) recruitment in the Coorong during 2017-18. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2018/000425-1. SARDI Research Report Series No. 1012. 42pp.

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

Ye, Q., Bucater, L. and Short, D. (2015a). Fish response to flows in the Murray Estuary and Coorong during 2013/14. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. F2014/000786-1, SARDI Publication No. F2014/000786-1. SARDI Research Report Series No. 884.

Ye, Q., Bucater, L. and Short, D. (2015b). Intervention monitoring for black bream (*Acanthopagrus butcheri*), recruitment in the Murray Estuary. South Australian Research and Development Institute (Aquatic Sciences). SARDI Publication No. F2015/000685-1. Adelaide, SARDI Research Report Series No. 875.

Ye, Q., Bucater, L., Short, D. A. and Giatas, G. C. (2021a). Coorong fish condition monitoring 2008–2020: 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. F2011/000471-8. SARDI Research Report Series No. 1091. 76pp.

Ye, Q., Bucater, L., Short, D. and Livore, J. (2012). Fish response to barrage releases in 2011/12, and recovery following the recent drought in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2012/000357-1. SARDI Research Report Series No. 665.

Ye, Q., Dittmann, S., Giatas, G., Baring, R., Nitschke, J., Bucater, L. and Furst, D. (2019b) 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., Earl, J., Bucater, L., Cheshire, K., McNeil, D., Noell, C. and Short, D. (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 Publication No. F2009/000014-2. SARDI Research Report Series No. 698.

Ye, Q., Giatas, G., Bice, C., Brookes, J., Furst, D., Gibbs, M., Nicol, J., Oliver, R., Shiel, R., Zampatti, B., Bucater, L., Deane, D., Hipsey, M., Huang, P., Lorenz, Z. and Zhai, S. (2021b). Commonwealth Environmental Water Office Monitoring, Evaluation and Research Project: Lower Murray 2019-20 Technical Report. A report prepared for the Commonwealth Environmental Water Office by the South Australian Research and Development Institute, Aquatic Sciences.

Ye, Q., Giatas, G., Brookes, J., Furst, D., Gibbs, M., Oliver, R., Shiel, R., Zampatti, B., Aldridge, K., Bucater, L., Busch, B., Hipsey, M., Lorenz, Z., Maas, R. and Woodhead, J. (2020a). Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project 2014–2019: Lower Murray River Technical Report. A report prepared for the Commonwealth Environmental Water Office. South Australian Research and Development Institute, Aquatic Sciences.

Ye, Q., Giatas, G., Dittmann, S., Baring, R., Bucater, L., Deane, D., Furst, D., Brookes, J., Rogers, D. and Goldsworthy, S. (2020b). 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., Short, D.A., Green C. and Coutin, P.C. (2002). 'Age and growth rate determination of southern sea garfish.' In 'Fisheries Biology and Habitat Ecology of Southern Sea Garfish (*Hyporhamphus melanochir*) in Southern Australian Waters, pp 35-99.' (eds. KG Jones, Q Ye, S Ayvazian and P Coutin). FRDC Final Report Project 97/133. Fisheries Research and Development Corporation, Canberra, Australia.

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

APPENDIX

Appendix A. Sampling effort (number of fyke net.night) for collecting juvenile black bream using single-wing fyke nets at regular and additional sites in the Coorong from 2008/09–2020/21. sw=saltwater, fw=freshwater, HI=Hindmarsh Island, SRP=Sir Richard Peninsula, YHP=Young Husband Peninsula, Phrag. Opp= *Phragmites* opposite Rumbelow shack.

No. of fyke net.night per year													
Location	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**
Regular sampling sites													
Goolwa Barrage sw HI	16	24	24	15	24	32	NS	16	16	12	5	4	4
Goolwa Barrage sw SRP	21	24	16	22	32	32	NS	16	16	12	8	4	4
Mundoo Barrage	4		24	24	32	31	NS	8	16	8	6	4	4
Boundary Creek	23	24		16	32	30	NS	12	16	5	7	4	4
Additional sampling sites													
Goolwa Barrage fw HI	4												
Goolwa Barrage fw SRP	2	4											
Beacon 19											8	4	4
Swan Point				4							2	4	4
Munddo Channel	8												
Mundoo Channel in front of house				4									
Boundary Creek Barrage	4							4					4
Boundary Creek Pole								4					
Boundary Creek Structure								4					
Godfrey's Landing				4							5	4	4
Ewe Island										4	5	4	
Ewe Island Causeway	4	16											
OppositeTauwitchere Barrage	3	4											
Pelican Point	4												
Pelican Pt. YHP	8												
Pelican Pt. YHP Opposite Rumbolow Shack				4									
Cattle Point			4	12	4	4			8	4	8	4	4
South Cattle Point				4	4	4			8				
Mark Point	8		8	12	4	4			12	4	8	4	4
Mark Point beach				4	4	4			4				
Opposite Mark Point YHP				4									
Long Point			8	4	4	4			8	4	8	4	4
Long Point beach				4	4	4			4				
Long Point corner									4				
Long Point reef				4	4	4			4				
Long Point sand dune			4			4			12	4	7	4	4
Long Point YHP side, opp. jetty				4	4								
Robs Point			4										
Noonameena			4										
Overall	**109**	**96**	**96**	**145**	**152**	**157**	**0**	**64**	**128**	**57**	**77**	**48**	**48**

Appendix B. Sampling effort (number of seine net shots) for collecting juvenile greenback flounder using large seine net at the Coorong from 2008/09–2020/21. NS=no sampling. Sugars beach site was replaced by Beacon 19 from 2014/15.

Number of seine net shots per year													
Location	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**
Sugars Beach/Beacon	9	9	9	15	9	9	12	6	9	6	3	3	9
Godfrey's Landing	9	9	15	15	15	15	12	6	9	6	3	3	9
Mark Point	12	15	15	15	15	15	12	6	9	6	3	3	9
Noonameena	12	15	15	15	15	15	12	6	9	6	3	3	9
Mt Anderson	NS	NS	9	15	15	15	12	6	9	6	3	3	9
Hells Gate	12	15	15	15	15	15	12	6	9	6	3	3	9
Villa dei Yumpa	NS	NS	9	15	15	15	12	6	9	6	3	3	9
Jack Point	12	15	15	15	15	15	12	6	9	6	3	3	9
Salt Creek	12	15	15	15	15	15	12	6	9	6	3	3	9
Overall	**78**	**93**	**117**	**135**	**129**	**129**	**108**	**54**	**81**	**54**	**27**	**27**	**81**

Appendix C. Sampling effort (number of seine net shots) for new recruit and adult smallmouth hardyhead using large and small seine nets in the Coorong from 2008/09–2020/21. NS=no sampling. Note: 2014/15 data are from 'Coorong fish intervention monitoring'; no small seine netting was conducted.

Number of seine net	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**
Large seine net													
Mark Point	12	12	12	12	12	12	12	6	9	6	3	3	6
Long Point	NS	12	12	12	12	12	12	6	9	6	3	3	6
Noonameena	12	12	12	12	12	12	12	6	9	6	3	3	6
Mt Anderson	NS	6	12	12	12	12	12	6	9	6	3	3	6
Hells Gate	12	12	12	12	12	12	12	6	9	6	3	3	6
Villa dei Yumpa	NS	6	12	12	12	12	12	6	9	6	3	3	6
Jack Point	12	12	12	12	12	12	12	6	9	6	3	3	6
Salt Creek	12	12	12	12	12	12	12	6	9	6	3	3	6
Overall	**60**	**60**	**84**	**96**	**96**	**96**	**96**	**48**	**72**	**48**	**24**	**24**	**48**
Small seine													
Mark Point	3	9	12	12	12	12	NS	6	9	6	3	3	6
Long Point	NS	NS	12	12	12	12	NS	6	9	6	3	3	6
Noonameena	3	9	12	12	12	12	NS	6	9	6	3	3	6
Mt Anderson	NS	NS	6	12	12	12	NS	6	9	6	3	3	6
Hells Gate	NS	12	12	12	12	12	NS	6	9	6	3	3	6
Villa dei Yumpa	NS	NS	6	12	12	12	NS	6	9	6	3	3	6
Jack Point	NS	12	12	12	12	12	NS	6	9	6	3	3	6
Salt Creek	NS	12	12	12	12	12	NS	6	9	6	3	3	6
Overall	**6**	**54**	**84**	**96**	**96**	**96**		**48**	**72**	**48**	**24**	**24**	**48**

Appendix D. Mean CPUE (fish.UE^{-1}) of adult smallmouth hardyhead (i.e. ≥40 mm TL) sampled by large and small seine nets in November and December across eight sites in the North Lagoon (NL) and South Lagoon (SL). SE: Standard error. Sub-regional and overall means are presented in bold (also see Figure 4.12). Note: 2014/15 values are based on large seine net data only; sampling in 2015/16 and 2018-2020 was conducted in late summer/autumn.

Year	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19		2019/20		2020/21	
Site	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE
Mark Point (N1)	0	0	341	69	91	14	230	101	1	1	9	5	7	2	266	204	141	53	0	0	904	278	1984	680	15	8
Long Point (N2)					152	29	251	78	14	7	22	3	97	36	476	126	93	35	16	6	322	192	3967	1299	620	145
Noonameena (N3)	247	59	197	92	254	90	871	567	9	3	223	38	58	37	268	171	126	38	30	28	422	132	2208	117	238	23
Mt Anderson (N4)					0	0	279	103	68	19	59	15	51	21	462	182	27	12	9	5	342	38	609	68	659	275
Mean (NL)	**124**	**124**	**269**	**72**	**166**	**48**	**408**	**155**	**23**	**16**	**79**	**50**	**53**	**19**	**368**	**58**	**97**	**25**	**14**	**6**	**497**	**137**	**2192**	**689**	**383**	**155**
Hells Gate (S1)	1	0	0	0	71	20	531	226	288	42	38	10	105	14	1082	531	193	31	70	8	445	76	258	56	1388	231
Villa de Yumpa (S2)					0	0	69	12	98	18	66	31	57	18	84	252	663	131	52	5	115	42	119	7	139	48
Jack Point (S3)	0	0	1	1	2	1	115	43	72	22	75	14	192	59	106	570	41	11	46	4	820	85	396	133	334	189
Salt Creek (S4)	1	1	14	7	1	0	253	104	133	26	20	6	61	13	251	262	3	1	72	8	131	28	53	6	415	30
Mean (SL)	**1**	**0**	**5**	**5**	**25**	**23**	**242**	**104**	**148**	**49**	**50**	**13**	**104**	**31**	**381**	**474**	**225**	**152**	**60**	**7**	**378**	**166**	**207**	**76**	**569**	**279**
Overall	**50**	**38**	**110**	**69**	**95**	**39**	**325**	**92**	**85**	**33**	**64**	**24**	**78**	**19**	**375**	**113**	**161**	**75**	**37**	**10**	**438**	**102**	**1199**	**494**	**476**	**152**

Appendix E. Mean CPUE (fish.UE^{-1}) of smallmouth hardyhead new recruits (i.e. <40 mm TL) sampled by large and small seine nets in January and February across eight sites in the North Lagoon (NL) and South Lagoon (SL). SE: Standard error. Sub-regional and overall means are presented in bold (also see Figure 4.13). Note: 2014/15 values are based on large seine net data only; 2015/16 and 2016/17 values are based on sampling conducted in February and March, whilst 2015/16, 2018/19 – 2020/21 values are based on March only sampling.

Year	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19		2019/20		2020/21	
Site	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE
Mark Point (N1)	73	28	357	54	699	267	233	110	99	24	254	94	48	17	582	204	620	173	230	52	683	141	353	57	927	12
Long Point (N2)					3352	1525	499	152	161	25	345	42	23	14	523	126	561	80	319	81	1148	473	521	82	767	144
Noonameena (N3)	149	39	242	27	2447	645	4707	1922	378	64	626	44	26	14	385	171	810	60	1716	636	1069	267	1152	320	403	97
Mt Anderson (N4)					2863	816	2248	495	423	72	562	65	9	4	641	182	1101	277	160	22	454	55	1534	345	1322	60
Mean (NL)	**111**	**38**	**300**	**58**	**2340**	**578**	**1922**	**1030**	**265**	**80**	**447**	**88**	**26**	**8**	**533**	**55**	**773**	**122**	**606**	**371**	**839**	**164**	**890**	**275**	**855**	**190**
Hells Gate (S1)	0	0	0	0	2123	209	1654	493	1740	173	578	108	527	176	1658	531	1806	522	1103	246	1808	284	856	115	1988	285
Villa de Yumpa (S2)					2337	916	1470	172	373	26	688	195	364	130	1264	252	1974	518	363	20	1009	211	2003	108	1171	66
Jack Point (S3)	0	0	0	0	141	29	1699	232	2098	495	646	67	333	45	1618	570	1336	158	460	115	2180	167	3622	583	2206	477
Salt Creek (S4)	0	0	80	38	583	47	2120	269	1269	350	371	39	231	34	1351	262	1090	259	765	175	2129	211	797	92	4239	129
Mean (SL)			**27**	**27**	**1296**	**1097**	**1736**	**137**	**1370**	**373**	**571**	**70**	**364**	**61**	**1473**	**97**	**1551**	**205**	**673**	**167**	**1782**	**270**	**1819**	**662**	**2401**	**652**
Overall	**111**	**38**	**136**	**71**	**1818**	**418**	**1829**	**482**	**817**	**273**	**509**	**57**	**195**	**70**	**1003**	**185**	**1162**	**184**	**640**	**189**	**1310**	**72**	**1355**	**375**	**1628**	**429**