Coorong Fish Condition Monitoring 2008–2023: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouth hardyhead (*Atherinosoma microstoma*) populations

Qifeng Ye, Luciana Bucater and David Short

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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 (MDBA, 2014) was developed, which included fish ecological 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 15 years' monitoring (2008/09–2022/23) 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 (2008/09–2009/10, no flow), low flows (e.g., 2013/14–2015/16, 2017/18–2020/21, <1,300 GL y^{-1}) and flood/high flows (2010/11–2011/2, 2016/17, 2021/22–2022/23, >6,000 GL y^{-1}), which allowed investigations of biological responses to flow variability and population recovery over time. This monitoring involved evaluation of two objectives for fish: (1) Maintaining abundant self-sustaining populations of smallmouth hardyhead in the North Lagoon and South Lagoon of the Coorong (F-3); and (2) Restoring 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 2022/23 with an extensive flood. The 'good' population condition was reflected by a broad distribution of both adults and new recruits throughout the North and South Lagoons; and high abundance of adults and new recruits (139 fish.UE^{-1} and 1,014 fish.UE^{-1}, respectively) with both meeting the ecological targets (≥120 fish.UE^{-1} and >800 fish.UE^{-1}, respectively). Although the extent of recruitment was 75%, just missing the target (>75% of sites), it is noteworthy that sampling efficiency may be reduced due to flood and high water levels in the Coorong in this year. 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 into the Coorong, showing rapid increases in abundance, recruitment and distribution after increased flows. This was corroborated by significant improvement and 'good/very good' population conditions in 2011/12, 2012/13, 2016/17, 2021/22 and 2022/23, following flood/high flows, as well as the 'extremely poor' population condition during the latter part of the Millennium Drought (2008/09 and 2009/10). Also, in recent low flow years (2017/18–2019/20), the population condition generally declined to 'moderate' due to increased salinities in the Coorong. This study highlights the importance of freshwater flows to the population ecology of smallmouth hardyhead in the Coorong, and its population resilience in this region.

For black bream and greenback flounder, the ecological objective (F-4) to restore resilient populations of these species in the Coorong was not met in 2022/23, with the population condition for both species being 'moderate'. For black bream, the population condition showed an improvement in recent years (2017–2023 except 2018/19) to 'moderate' or 'good' compared to the first nine monitoring years when the condition was 'extremely poor', 'very poor' or 'poor'. In 2022/23, the 'moderate' population condition was characterised by:

- Increased abundance (adjusted annual commercial catch of 12.8 t, meeting the target: ≥8 t) and the positive trend of the 4-year catches (meeting the target);
- Increased distribution of the commercial catches (93% from the southern Coorong, meeting the target: >50%);
- The presence of two strong cohorts with one ≤5 years (meeting the target) and 37.7% of the catches >10 years of age (vs the target: >20%);
- No YOY were detected.

For greenback flounder, the 'moderate' population condition in 2022/23 may reflect a decline from 'good' condition in the previous two years, although this should be treated with caution as the low CPUE of YOY could be caused by reduced sampling efficiency due to flooding. Overall, the population of this species responded to freshwater inflows. The population was in 'extremely poor' condition during the late drought (2008/09 and 2009/10), but showed a general improvement particularly after subsequent floods/high flows. In 2022/23, the 'moderate' population condition was characterised by:

- Increased abundance (annual commercial catch of 25.4 t, meeting the target: ≥24 t) and the positive trend of the 4-year catches (meeting the target);
- A broad distribution of commercial catches (95% from the southern Coorong, meeting the target: >70%);
- The presence of a very strong cohort (83% 2-year-olds, meeting the target: >60%);
- Low YOY CPUE (0.2 fish.seine net^{-1} vs the target: >1.04 fish.seine net^{-1}) and the distribution of 44% of the sites (not meeting the target: >50% sites).

Freshwater flow is important for 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 are more responsive to freshwater inflows and salinity improvement in the Coorong. In contrast, black bream is a slower growing, solely estuarine, long-lived fish (~32 years) with specific habitat requirements (salt wedge) for successful recruitment, and their population recovery requires a longer time frame. It is encouraging to see some improvements in the black bream population in recent years with it reaching 'good' condition in 2021/22 for the first time since the monitoring began in 2008/09. Despite the 'moderate' population condition in 2022/23, there was a notable increase in adult biomass in the Coorong supported by recent successful recruitment. The improved estuarine habitats following increased inflows (including water for the environment) to the Coorong and improved Murray barrage operations have likely contributed to black bream population improvements. Seasonal fishing closures may have also helped protect black bream during the spawning season and supported population recovery.

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 and higher freshwater releases that may meet a range of environmental or life-history process requirements of different species (e.g., barrage flow releases in 2017/18 and 2021/22 were associated with stronger black bream recruitment). Further investigations are needed to support management including: (1) understanding the influence of freshwater flows on population dynamics and recruitment of medium and large-bodied estuarine species; (2) evaluating the benefit/impact of various flow scenarios (both natural and managed flows including water for the environment) for these populations; and (3) assessing population recovery (abundance and demographics). Furthermore, to rebuild the population abundance and resilience of the solely estuarine black bream population, fishery management should continue to seek to protect the spawning biomass and to maximise the survival of new recruits. 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, estuarine fish, freshwater flow, salinity, recruitment.

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; Ferguson *et al.* 2018).

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 located 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 the 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 Coorong South Lagoon received small volumes of fresh/brackish water (mean = 15.9 GL y^{-1}, between 2000/01–2022/23) 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 environment ranged from marine to extremely hypersaline (Brookes *et al.* 2009). Many native fish species that reside in the Coorong and depend 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., 2010–2012, 2016/17, 2021–2023), and the delivery of water for the environment to this region, have contributed to increased barrage releases to the Coorong; and have ensured the continuous connection between the freshwater and marine environments (with barrages and fishway openings) (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.* 2016; 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) and incorporated in the revised Condition Monitoring Plan (DEWNR 2017). These ecological targets and objectives are presented in Tables 1.1 and 1.2, with slight adaptations due mainly to recent high flow conditions in 2021/22 and 2022/23.

The current report presents the findings of fish condition monitoring from 2008–2023, with a focus on assessing whether the ecological targets and objectives have been achieved for the populations of three target fish species in the Coorong in 2022/23. The assessment builds on data collected from commercial fishery (fishery-dependent) and fishery-independent research sampling between 2008/09–2022/23.

Table 1.1. Ecological objectives and targets for black bream and greenback flounder (adapted from 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) (mean across nine sites) >0.35 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)*

*Underlined target was updated from the previous mean of 0.77 fish.net night^{-1} across four regular sites (all within Murray Estuary) to the mean across nine sites, which included five additional sites in the North Lagoon to better represent the mean abundance of YOY black bream across the Coorong.

Table 1.2. Revised ecological objective and targets for smallmouth hardyhead (adapted from 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 the 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*

* Underlined target was adjusted from the previous >120 fish.UE^{-1} to ≥120 fish.UE^{-1}.

1.2. Objectives

This project undertook condition monitoring for black bream, greenback flounder and smallmouth hardyhead in the Coorong in 2022/23, 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 for 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 TARGET 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 fishery species (Rowland and Snape 1994; Haddy and Pankhurst 1998; Sarre and Potter 2000), which 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 life-cycle 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 to freshwater flows and associated factors including 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). Furthermore, 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 populations in Victorian estuaries, have 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 black bream can extend to late summer, based on back-calculated spawning dates of YOY (Jenkins *et al.* 2018; 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 *et al.* 2019b). As individuals generally complete their entire life-cycle within a single estuary (Sherwood and Blackhouse 1982; Elsdon and Gillanders 2006, Tracey *et al.* 2020), 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 that 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 oocyte 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; Ferguson *et al.* 2018). 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*. 2023a). 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). 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 marine habitats.

Given their ecological and commercial importance to the LCF, greenback flounder has been a key 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.* 2023a). Within the Coorong, individuals have been recorded 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). Tolerance to such hypersaline conditions is likely to be advantageous to smallmouth hardyhead 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 with this ovary holding batches of asynchronously developing adherent eggs (Ye *et al.* 2023a). This species dies after spawning, completing its life span in only one year (Molsher *et al.* 1994). It grows to a maximum length of 100 mm (TL) (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 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 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 waterbirds (Paton 2010; Giatas *et al.* 2018; Ye *et al.* 2019c; 2020b). 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 2016).

3. METHODS

3.1. General approach

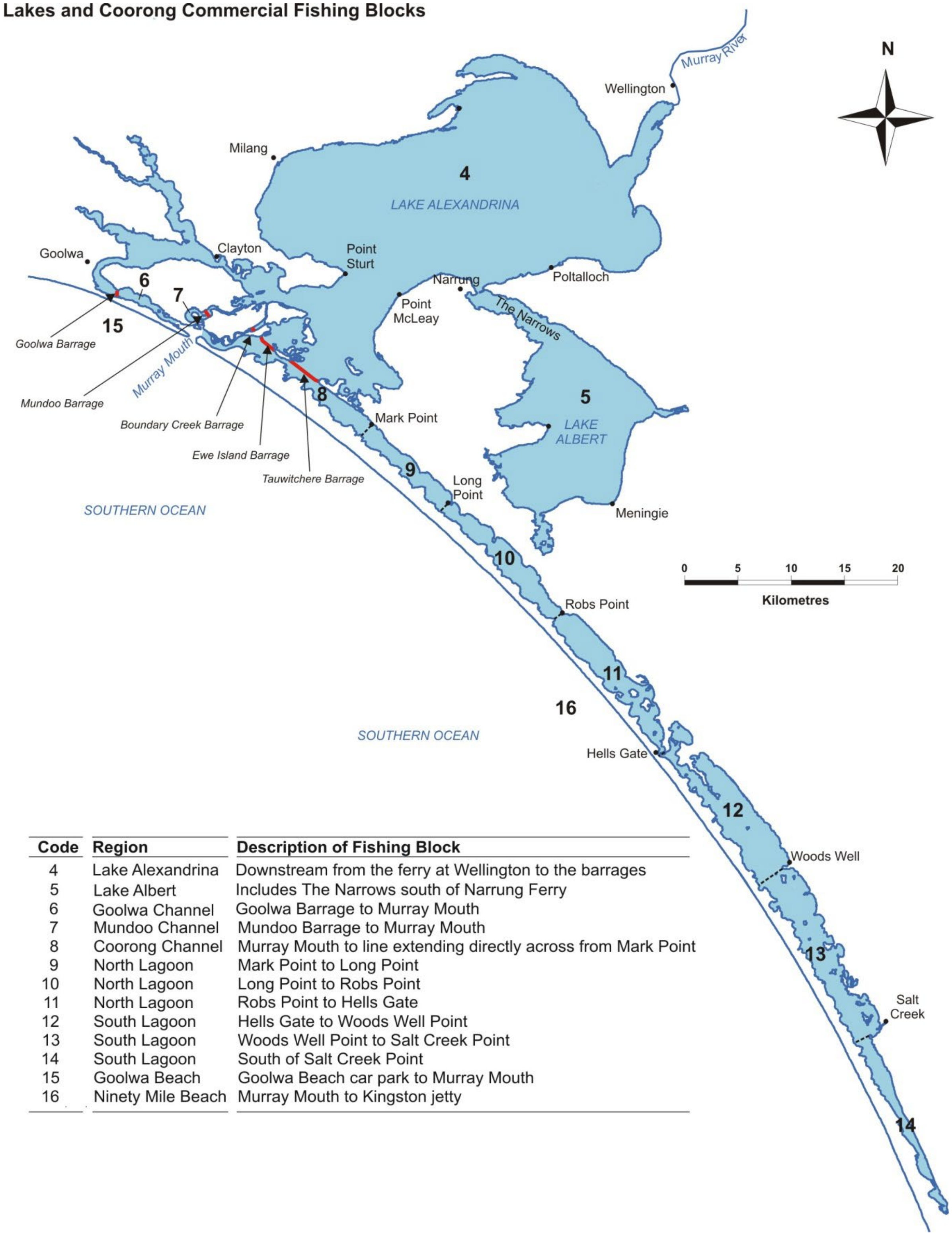
Four indicators were used to assess the population condition of black bream, greenback flounder and smallmouth hardyhead in the Coorong (Ye *et al.* 2014), with each indicator having 1–2 quantitative targets (Tables 1.1 and 1.2). For the two large-bodied species (i.e., black bream and greenback flounder), three indicators, namely relative abundance (catch), adult fish distribution and age structure, were based on data/samples collected from the LCF. The fourth indicator, recruitment, was assessed based on fishery-independent sampling to collect data on relative abundance (catch per unit effort, CPUE) and spatial distribution of 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 2022/23) from the LCF for black bream and greenback flounder were obtained from PIRSA fisheries and Aquaculture 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 2023, based on the estimates from 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.



Lakes and Coorong Commercial Fishing Blocks

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, along with barrage flows were plotted for each financial year for the period between July 1984 and June 2023. Temporal catch trends were analysed to examine the fluctuation in abundance of these species in the Coorong. The annual catch of each species was compared against target values to determine whether the target had been met (Table 1.1). Additionally, linear regression analysis was performed on the annual catches of the most recent 4-year period to describe the trend of increase or decrease in population biomass. 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

Samples of black bream and greenback flounder taken from commercial gill net catches were used to establish the age/size structures of the fishery for the years 2008/09–2022/23. These samples were from multiple locations within the Murray Estuary and North Lagoon of the Coorong (Figures 3.2 and 3.3).

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).

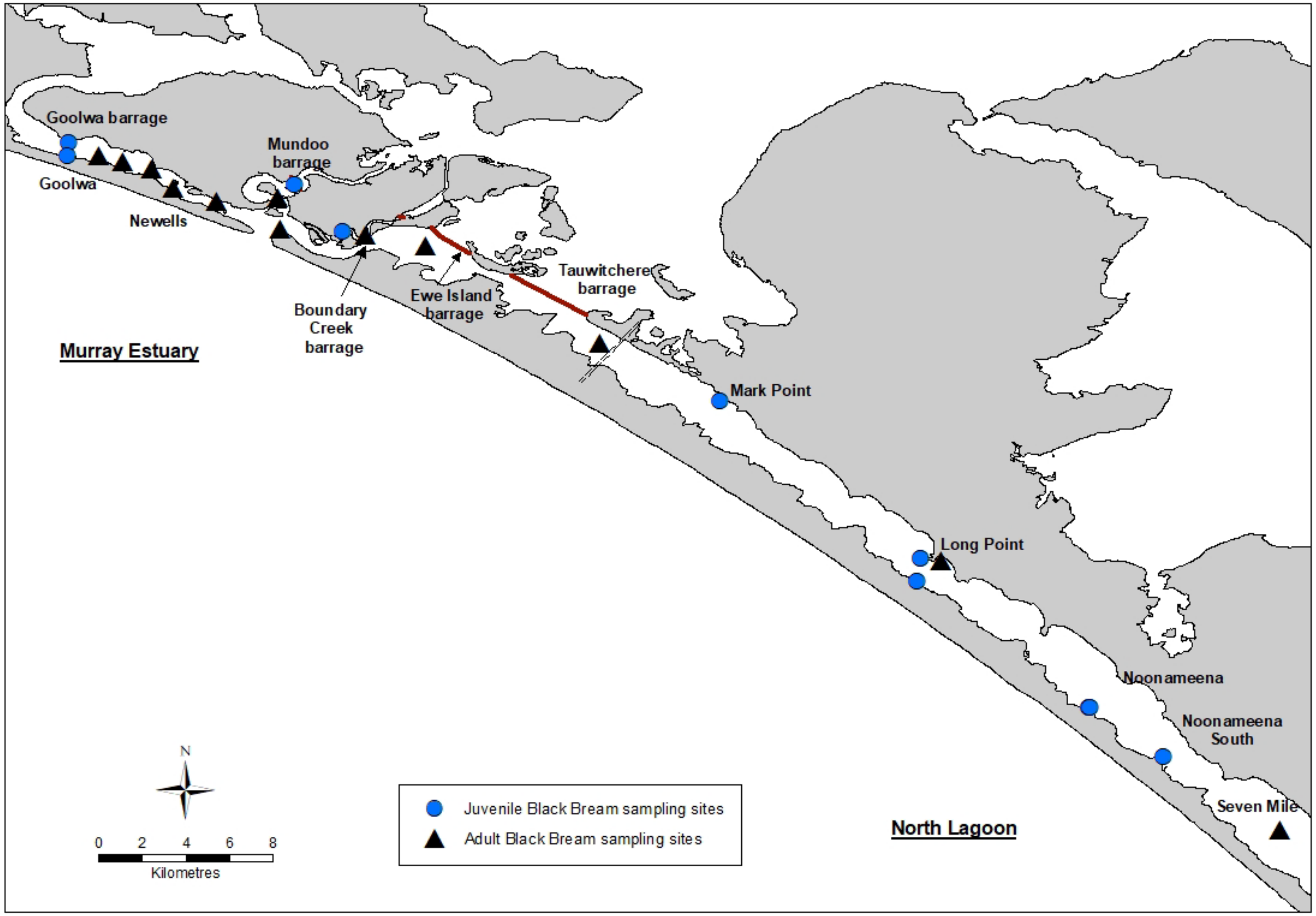


Figure 3.2. Condition monitoring sampling sites for adult and juvenile black bream at the Coorong. Adult black bream samples were from commercial fishery sampling sites.

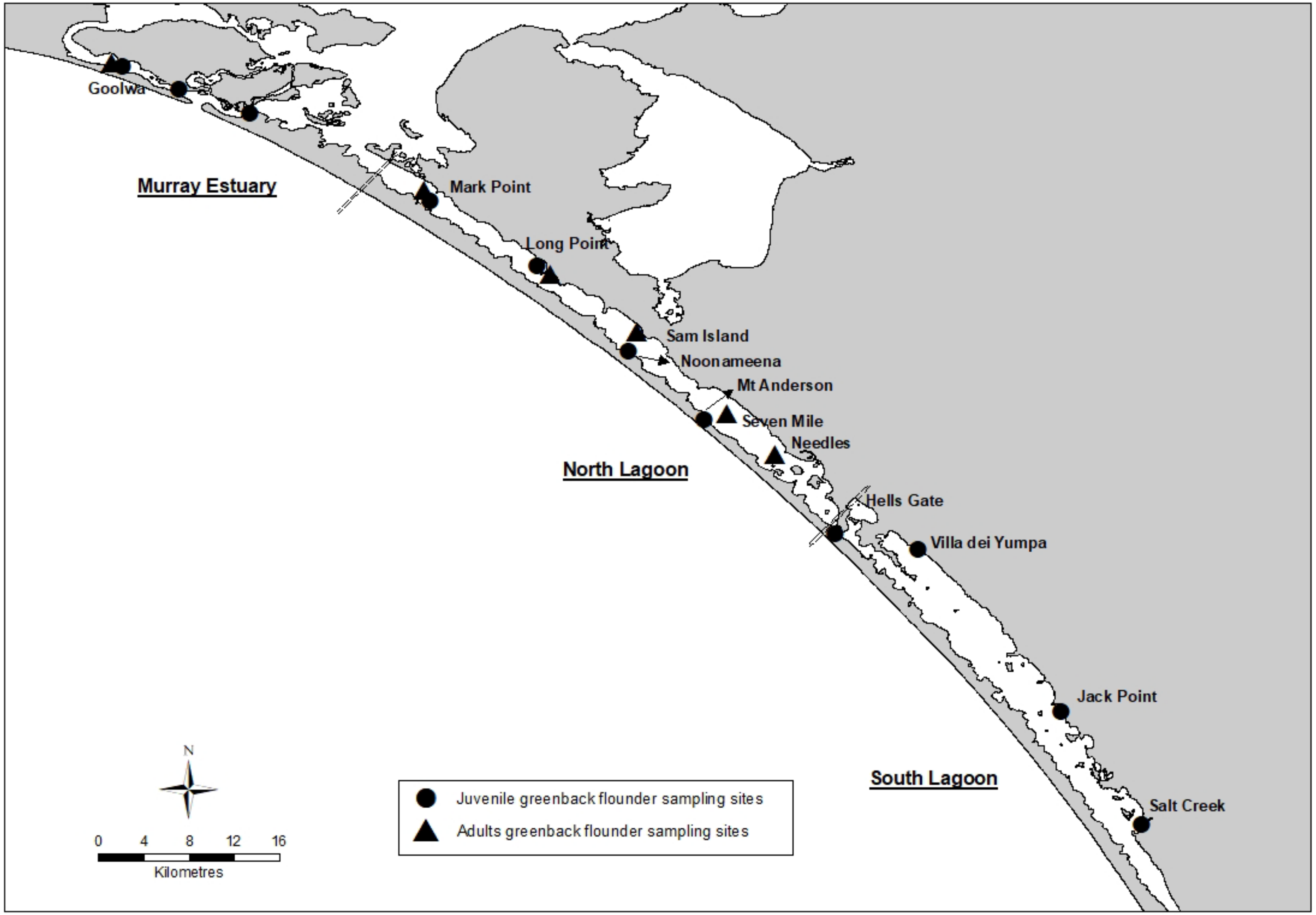


Figure 3.3. Condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong. Adult greenback flounder samples were from commercial fishery sampling sites.

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–May) from 2008/09–2020/21, sampling was conducted to target YOY black bream typically across four to seven sites in the Coorong using single-wing fyke nets (*n* = 1–3 trips per year) (Figure 3.2; Table 3.5). In 2021/22, high flows led to a substantial salinity reduction in the Coorong, with the levels ranging from 0.3–1.6 psu in the Murray Estuary and 1.8 to 51.2 psu in the North Lagoon (24 psu at Noonameena, compared to seawater salinity of 36 psu) (Ye *et al.* 2023a). Therefore, two additional sites in the North Lagoon (Noonameena and Noonameena South) were included. To ensure the results were comparable across years, the ecological target for YOY black bream was adjusted (Table 1.1) and mean CPUEs of YOY were recalculated for all years based on nine sampling sites to compare with the new target. In 2022/23, all sites were sampled except for ‘Long Point sand dune’ due to high water levels and high density of algae. 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 (mostly September–March) from 2008/09–2022/23, 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). The net, which 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 the last 15 years (2008/09–2022/23) (*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 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 numbers 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). The cut-off length for YOY black bream and greenback flounder was set at 160 mm and 200 mm TL, respectively, based on the age-at-length data collected from the Coorong for this project since 2008/09.

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 15 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.

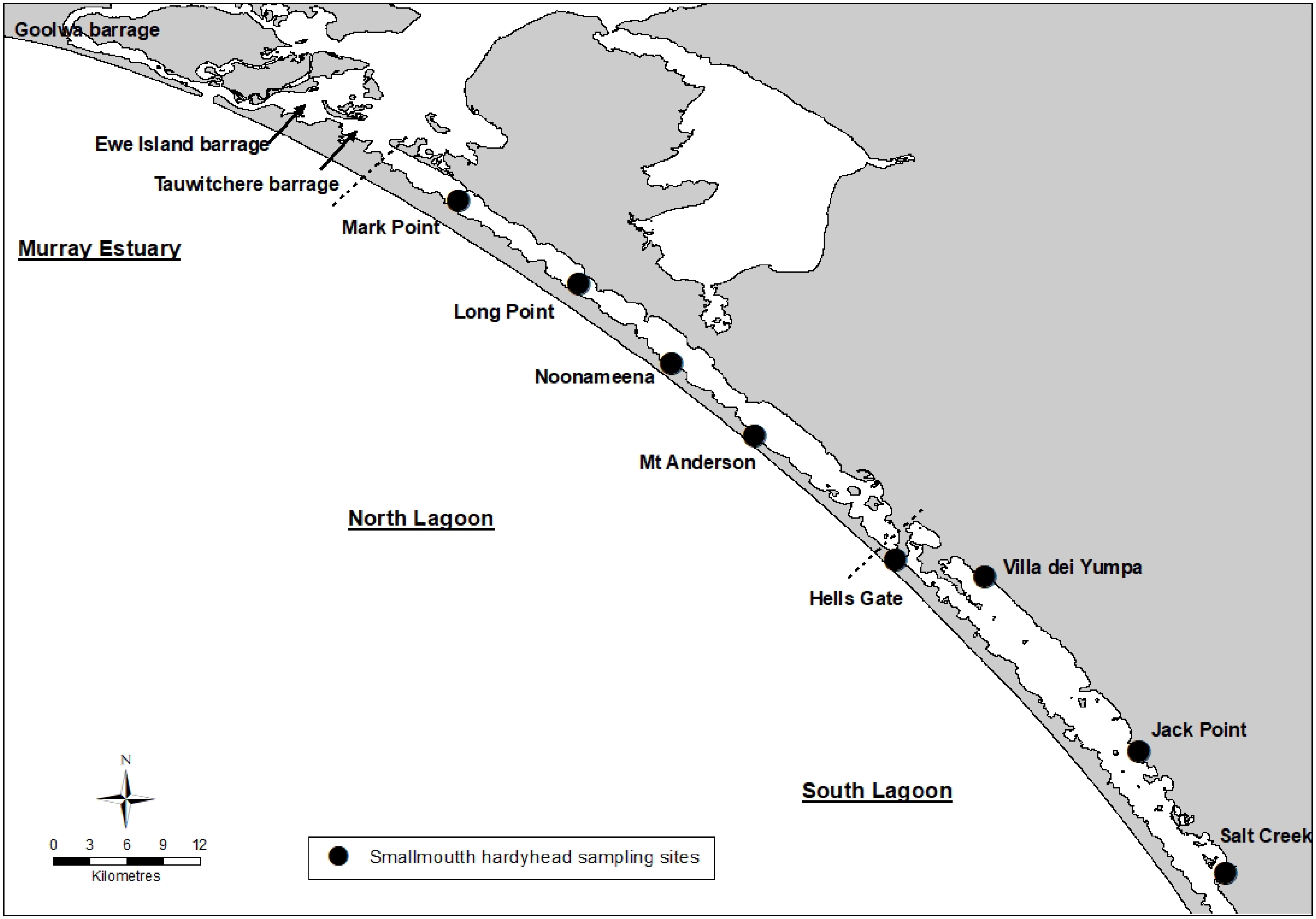


Figure 3.4. Condition monitoring sampling sites for smallmouth hardyhead in the Coorong.

Table 3.1. List of sampling sites, species targeted, and sampling gear used for fishery-independent sampling during the Coorong fish condition monitoring project from 2008/09–2022/23. Both seine nets = large and small seine nets.

Sites	Site code	Species targeted	Sampling gear
Murray Estuary			
Goolwa Barrage Hindmarsh Island	E1	Black bream	Fyke net
Goolwa Barrage Sir Richard Peninsula	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	Black bream Greenback flounder/smallmouth hardyhead	Fyke net Both seine nets
Long Point	N2	Black bream Greenback flounder/smallmouth hardyhead	Fyke net Both seine nets
Long Point sane dune	N2a	Black bream	Fyke net
Noonameena	N3	Black bream Greenback flounder/smallmouth hardyhead	Fyke net Both seine nets
Noonameena South	N3a	Black bream	Fyke net
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: 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 nine sampling sites since 2021/22, and for previous years, CPUEs were standardised to nine sites for comparison to the adjusted target value (Ye *et al.* 2023a). To determine the distribution of YOY, the proportion of sampled sites where black bream were present was used. Note, in some years there was reduced sampling effort (e.g., in 2014/15 and 2015/16) due to funding constraints, limiting assessment of distribution.

Estimates of CPUE (fish.seine net^{-1}) of YOY greenback flounder were analysed to compare recruitment through time, using data from large seine net samples 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 TL collected in spring/early summer were defined as adults, whereas those <40 mm TL 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 1984/85–2022/23, freshwater flow from the River Murray to the Coorong fluctuated substantially. Annual discharge was >4,000 GL in ten out of the 17 years between 1984/85 and 2000/01 (inclusive) (Figure 4.1). During the drought (2001/02–2009/10), 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. For the period between 2017/18 and 2020/21, annual barrage flows ranged between 337 and 1,260 GL, then increased to ~6,200 GL in 2021/22 with sustained high flows. In 2022/23, due to a significant flood in the River Murray, the annual barrage discharge reached the highest (16,657 GL) volume since 1984/85. The seasonality of daily discharge was highly variable with peaks occurring at different times in different years; in 2022/23, the peak of daily flow occurred in December.

Freshwater flows from Salt Creek into the South Lagoon were similarly variable among years during 2000/01–2022/23 (Figure 4.2). Annual discharges were generally low from 2000/01 to 2009/10 (mean 7.3 GL), and increased substantially thereafter (mean 22.7 GL from 2010/11 to 2022/23). In contrast, the discharge was low in 2015/16, 2019/20 and 2020/21 with less than 4.5 GL y^{-1}. In 2021/22 and 2022/23, the South East region received high rainfall in winter–spring, enabling increased flows from Salt Creek to the Coorong, with above average annual discharge of 31.9 and 37.2 GL, respectively. Freshwater flows were highly seasonal in most years, generally peaking from July to October (winter–spring) but in 2022/23, daily flow didn't increase until late autumn/winter (i.e. May–June 2023). Salinity in Salt Creek was also variable and seasonal, ranging between ~3 and 30.4 psu from 2010 onwards.

For this 15-year study, based on the freshwater flows from the River Murray to the Coorong, 2008/09 and 2009/10 were defined as drought years, whereas 2010/11–2022/23 were referred to as post-drought years. Within the post-drought period, 2010/11 and 2022/23 were flood years; 2011/12, 2016/17 and 2021/22 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.

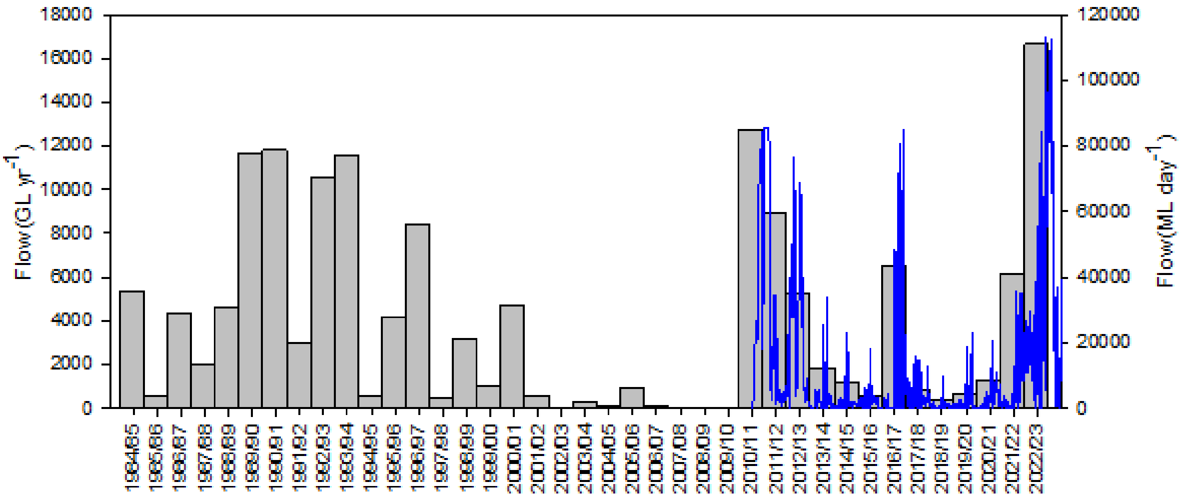


Figure 4.1. Annual (grey bar) and daily (blue line) freshwater flows across the barrages from July 1984 to June 2023 (sources: MDBA and DEW). Note the fish monitoring program commenced in 2008/09.

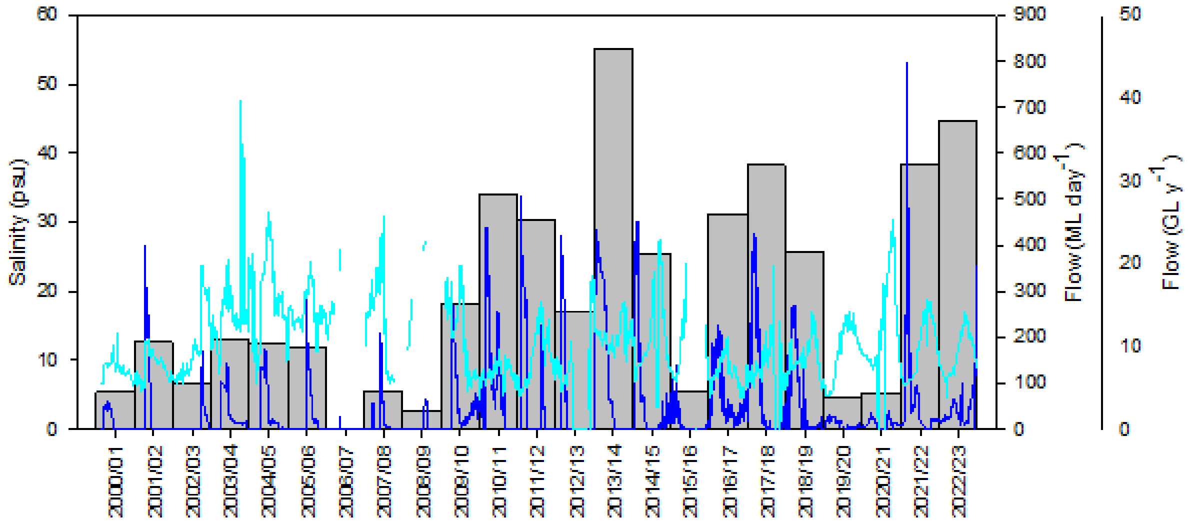


Figure 4.2. Annual (grey bar) and daily (blue line) discharge through the Salt Creek outlet, with salinity levels (cyan line) from July 2000 to June 2023 (DEW 2022, Water Data SA, Station A2390568).

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 15-year monitoring period was 16, 40 and 95 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, in 2016/17–2017/18, and in 2021/22–2022/23. 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, 2016/17, 2021/22 and 2022/23) were 3 psu in the Murray Estuary, 28 psu in the North Lagoon and 82 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 generally remained lowest and 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 flood and high flow years (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 core sampling period (January–March) over the last 15 years of monitoring (2008/09–2022/23). Highlighted cells show annual mean salinity ≤ long-term (15 years).

	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)
2021/22	1	20	97	**37** (± 29.4)
2022/23	1	25	63	**31** (± 18.0)
Mean among years	**16** (± 3.5)	**40** (± 4.2)	**95** (± 5.5)	

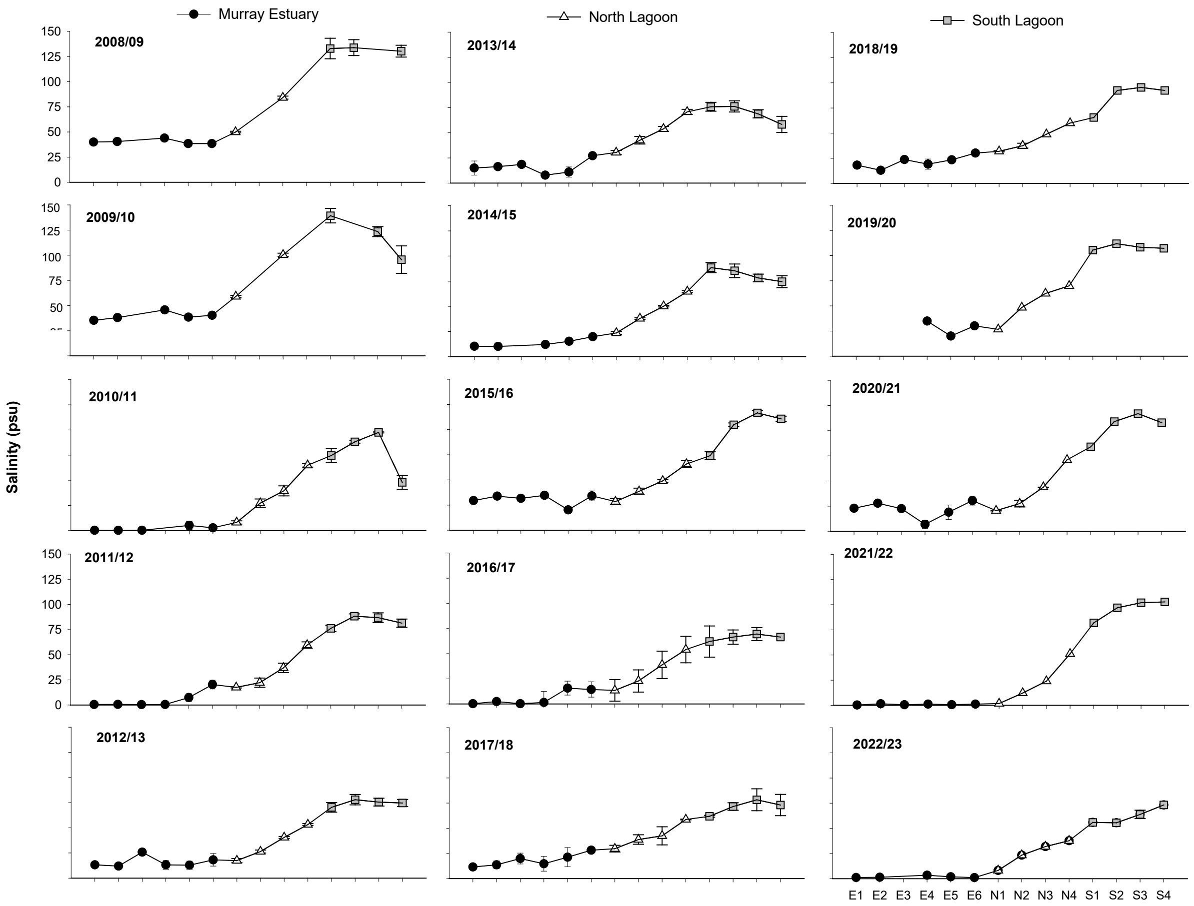


Figure 4.3. Mean values ± S.E. of salinity (psu) over the core sampling period (January–March) at each sampling site from the Murray Estuary (E1, E2, E3, E4), to the North Lagoon (N1, N2, N3, N4) and South Lagoon (S1, S2, S3, S4) of the Coorong between 2008/09 and 2022/23. See Table 3.1 for site code.

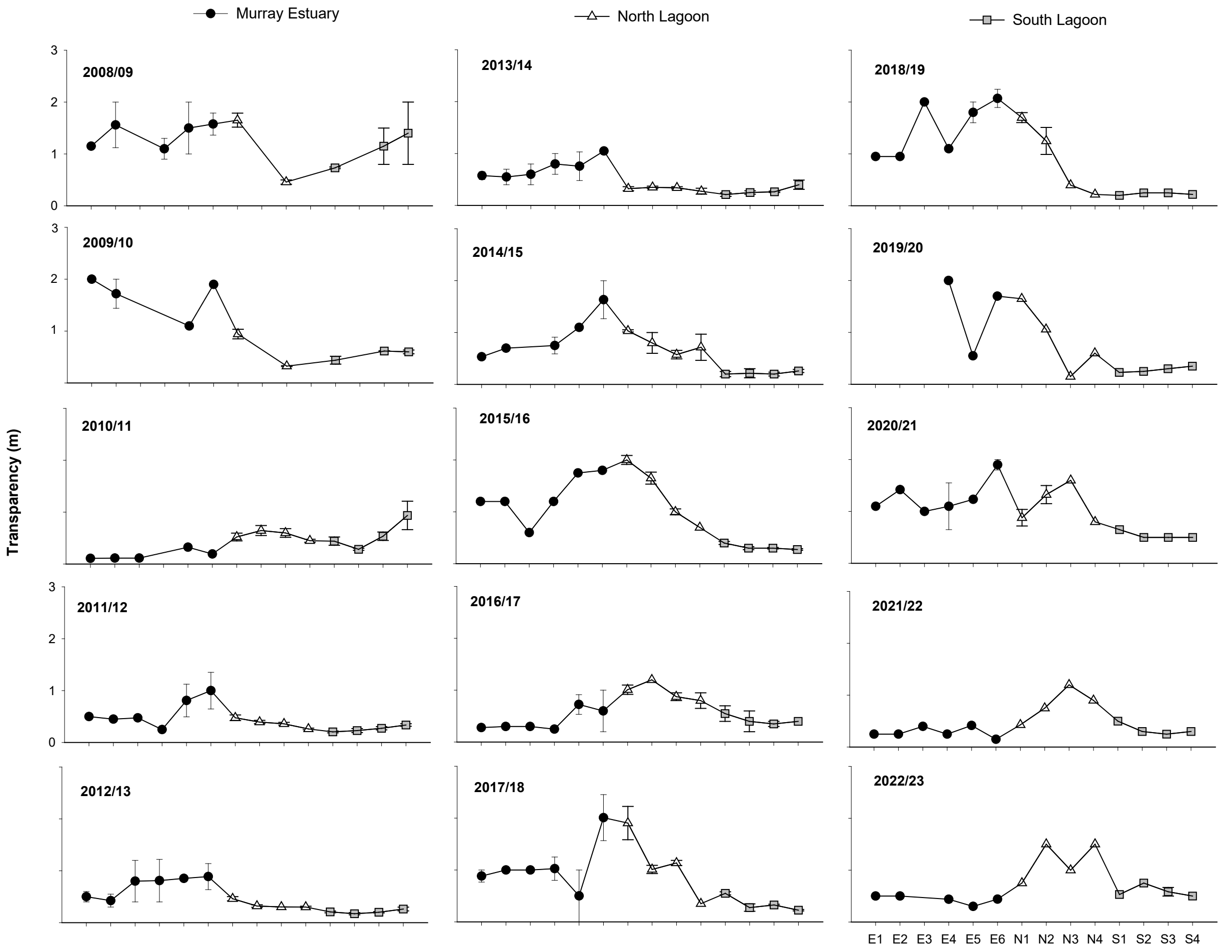


Figure 4.4. Mean values ± S.E. of transparency (m) over the core sampling period (January–March) at each sampling site from the Murray Estuary (E1, E2, E3, E4), to the North Lagoon (N1, N2, N3, N4) and South Lagoon (S1, S2, S3, S4) of the Coorong between 2008/09 and 2022/23. See Table 3.1 for site code.

4.3. Black bream

4.3.1. Relative abundance (fishery catch)

The annual catch of black bream was no more than 3.2 t in most years of the study (2008/09–2020/21) (Figure 4.5), until 2021/22 and 2022/23 when the reported commercial catch was 3.4 t and 3.8 t, respectively. The catches in the last two years occurred only from January to July due to seasonal fishing closures to protect black bream prior to and during the spawning season. Therefore, an adjustment was made to estimate the annual catch to 11.4 t and 12.8 t, respectively (Figure 4.5). Adjustments were also made for the years 2018/19 and 2019/20, when closures occurred from September to November (inclusive). Adjustments were made using the percentage of monthly catch derived from historical data (2013/14-2017/18) to estimate the catch if fishing closures were not enforced. The adjusted catch in 2022/23 was similar to the adjusted catch in 2021/22, but was fourfold greater than the 2020/21 catch. Since 2004/05, the only years when the annual catch of black bream exceeded the target of 8 t were 2021/22 and 2022/03 (adjusted catches). Annual catches during the most recent 4-year period showed a positive trend, suggesting a general increase in the population abundance/biomass from 2019/20 to 2022/23 (Figure 4.6).

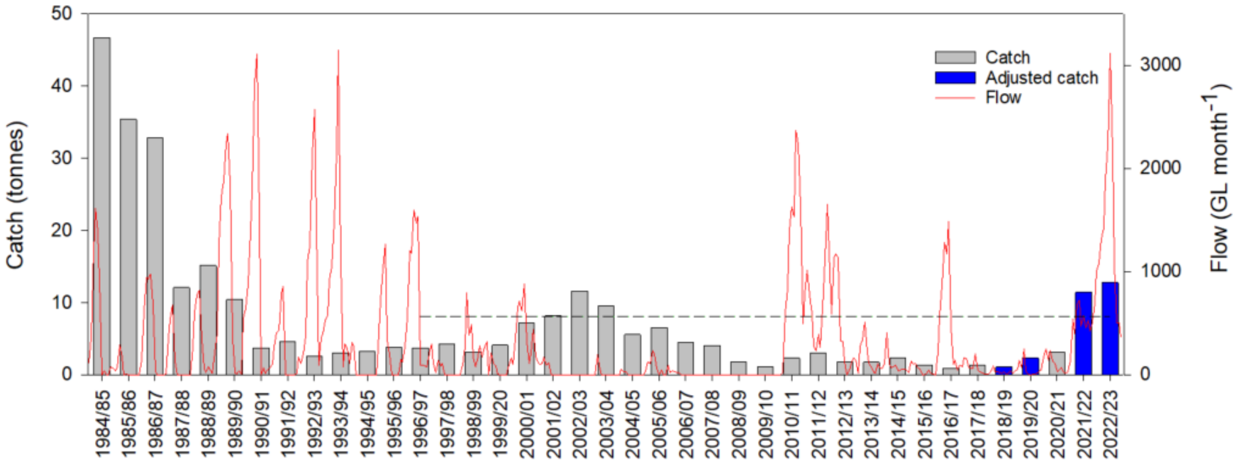


Figure 4.5. Annual commercial catch of black bream from the Coorong between 1984/85 and 2022/23. The redline represents modelled monthly flow discharge to the Coorong (GL month^{-1}) between July 1984 and June 2023 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (8 t) between 2000/01 and 2005/06.

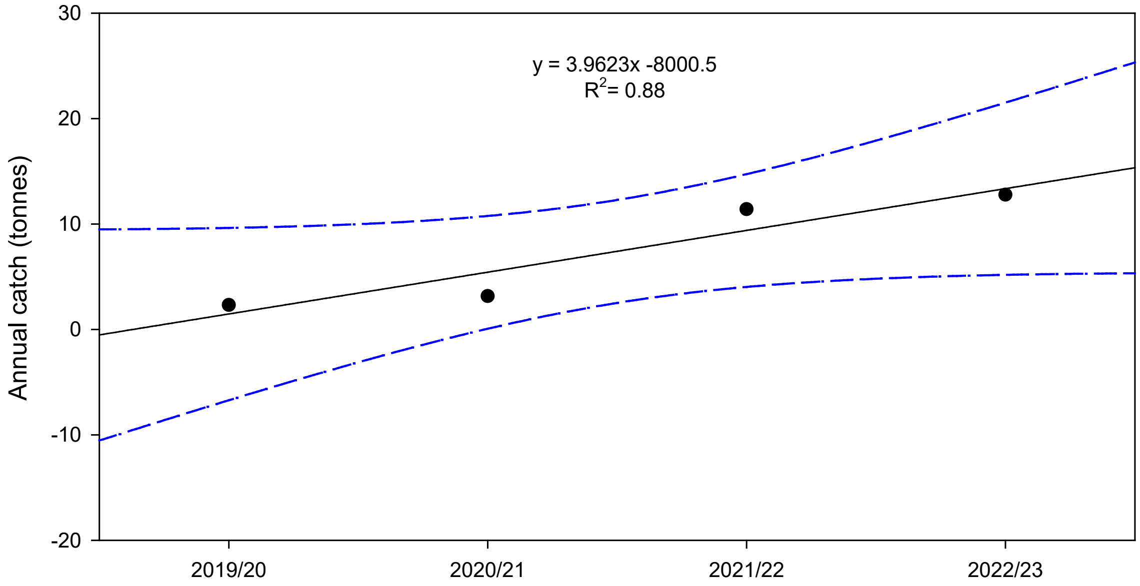


Figure 4.6. Trend in the black bream catches over four years (2019/20–2022/23). Blue dashed lines show 95% confidence intervals.

4.3.2. Distribution

The spatial distribution of commercial fishery catches of black bream varied across the Coorong over the last 38 years (Figure 4.7). Prior to the mid-1990s, most 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 nine years, this proportion was >50% in six out of nine years (i.e., 2016/17, 2017/18, 2019/20–2022/23, e.g., 93% in 2022/23).

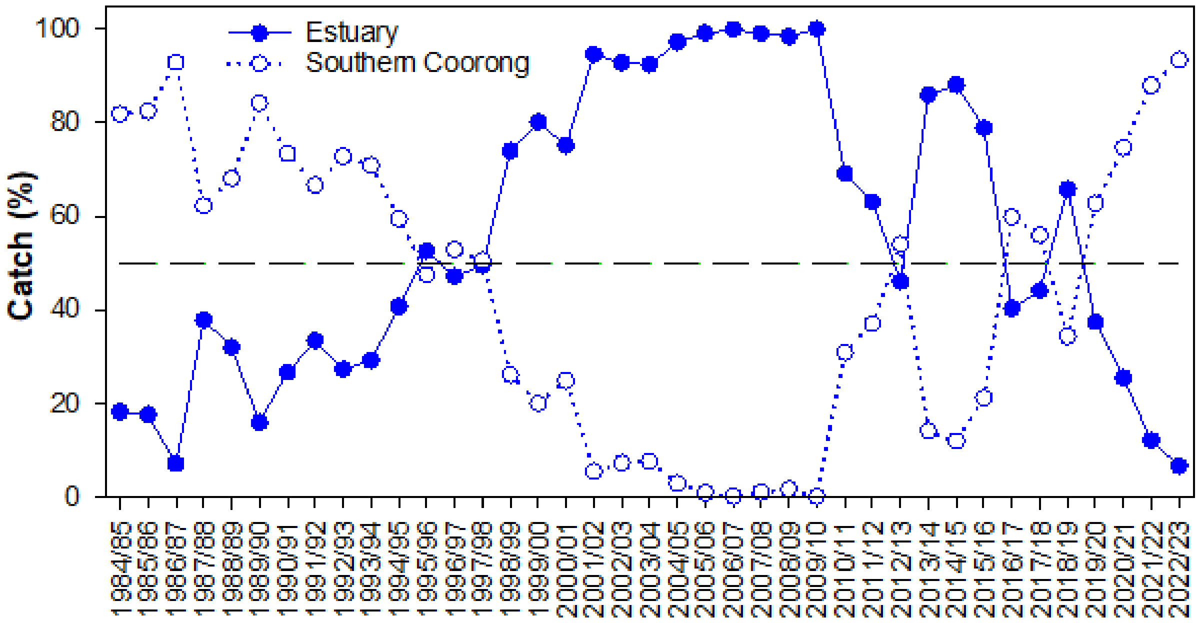


Figure 4.7. Black bream commercial fishery catches from different areas (proportional catches from the north (Estuary) vs the south of Mark Point in the Coorong (Southern Coorong)) between 1984/85 and 2022/23. Dashed black line indicates 50%.

4.3.3. Age structure

From 2008/09 to 2022/23, black bream sampled from commercial fishery catches ranged in age from 2 to 32 years, although most fish were <10 years old (Figure 4.8). In 2008/09 and 2009/10, there was a greater proportion of fish >10 years old (30% and 36%, respectively) compared to 2010/11–2020/21.

The time-series of annual age structures during the last 15 years suggested that several relatively strong cohorts (i.e., ≥15% of the sampled population) of black bream had occurred in the Coorong population, because one–three strong year classes were present in each sampling 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, which originated in 1997/98, persisted as 11- and 12-year-olds in 2008/09 and 2009/10, respectively, but were poorly represented from 2010/11.

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

In 2018/19, the black bream age structure had no dominant age class with 73% of fish evenly distributed between 3 and 6 years old. In 2019/20, the age structure was dominated by the 2016/17 and 2015/16 cohorts (3- and 4-year-olds, respectively), and the 2006/07 cohort was still distinct in the age structure, as 13-year-olds. In 2020/21, the 2016/17 cohort continued to dominate the age structure, representing 34% of the sampled population, whereas the 2015/16 and 2006/07 cohorts became less distinct.

In 2021/22, the strongest cohort originated in 2017/18 (4-year-olds). The 2016/17 cohort, remained distinct, as 5-year-olds, and 2006/07 cohort (as 15-year-olds) was still present as the third strongest cohort. The oldest black bream collected in 2021/22 was 24 years old.

In 2022/23, the 2017/18 cohort continued to dominate the age structure as 5-year-olds, whereas the 2016/17 cohort (6-year-olds) was diminished. The 2009/10 cohort (as 13-year-olds) was the second strongest identified in this year and the oldest black bream collected was 30 years old.

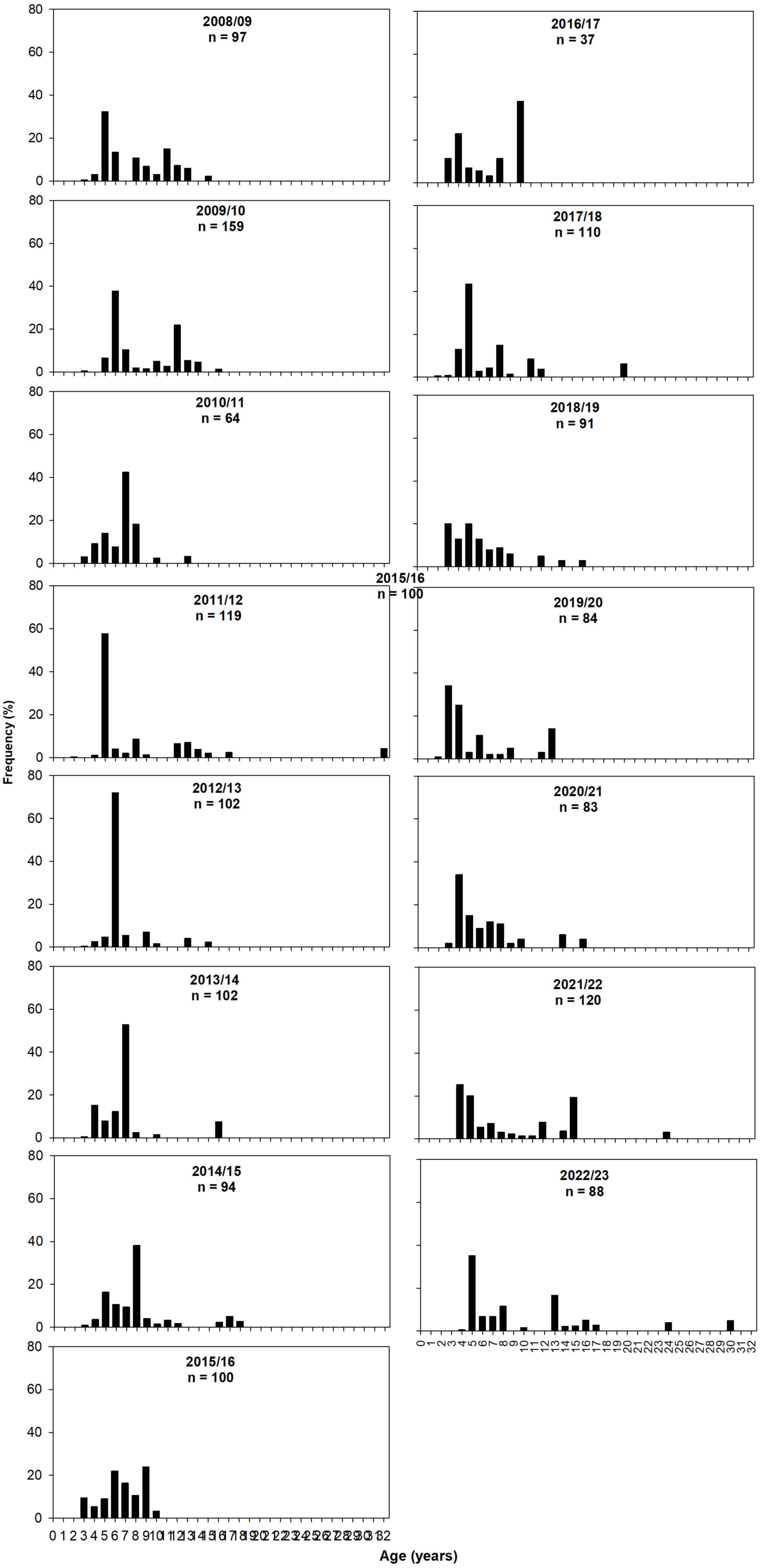


Figure 4.8. Age structure of black bream from the Coorong during 2008/09–2022/23 (commercial fishery samples).

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 15 years (2008/09–2022/23) (Table 4.2). Since 2010/11, based on the adjusted mean CPUE across nine sites, YOY abundance only met the target (>0.35 fish.net.night^{-1}) in 2012/13, 2017/18 and 2021/22. There were no catches of YOY black bream in 2022/23, thus CPUE could not be estimated. During 2008/09 and 2009/10 (drought years), although YOY CPUE exceeded the target in 2008/09, the number of sampling sites were limited (i.e., three or four) and restricted within the Murray Estuary in both years. Therefore, results should be treated with caution (see Table 4.3).

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 4.3). In 10 out of the 15 years sampled, the black bream population condition in the Coorong, was ‘extremely poor’, ‘very poor’ or ‘poor’. In 2017/18, 2019/20 and 2020/21, the condition improved to ‘moderate’, due to the increased distribution of adults, along with increased recruitment or an increasing trend in commercial catch. The population condition further improved to ‘good’ in 2021/22, meet the ecological objective for this species for the first time since the monitoring began in 2008/09. However, the condition declined to ‘moderate’ because no YOY were detected in 2022/23.

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). 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**		**2021/22**		**2022/23**	
	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**	**Mean**	**SE**	**Mean**	**SE**
Goolwa Barrage HI	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	0.00	0.00	0.00	0.00
Goolwa Barrage side SRP	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	0.00	0.00	0.00	0.00
Mundoo Barrage	0.25	0.25	NS	NS	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	0.25	0.25	0.00	0.00
Boundary Creek	0.09	0.09	0.00	0.00	NS	NS	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	0.00	0.00	0.00	0.00
Mark Point					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					0.00	0.00	0.88	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	13.50	7.23	0.00	0.00
Long Point sand dune											0.00	0.00					0.00	0.00	2.00	1.68	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.95	NS	NS
Noonameena																											21.63	13.92	0.00	0.00
Noonameena South																											1.00	0.60		
Average across sites	**2.42**	**1.15**	**0.56**	**0.30**	**0.00**	**0.00**	**0.02**	**0.01**	**0.57**	**0.24**	**0.01**	**0.01**			**0.05**	**0.03**	**0.00**	**0.00**	**2.16**	**0.54**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**4.18**	**2.47**	**0.00**	**0.00**
Adjusted mean (9 sites)	**1.07**	**0.36**	**0.21**	**0.14**	**0.00**	**0.00**	**0.01**	**0.01**	**0.38**	**0.19**	**0.00**	**0.00**			**0.02**	**0.02**	**0.00**	**0.00**	**1.68**	**0.52**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**4.18**	**2.47**	**0.00**	**0.00**
# Sites sampled	4		3		5		6		6		7		0		4		7		7		7		7		7		9		8	
# Sites black bream YOY	4		2		0		2		3		1				1		0		6		0		0		0		5		0	
% of site YOY present	100%		67%		0%		33%		50%		8%				25%		0%		86%		0%		0%		0%		56%		0%	

Table 4.3. Condition assessment for black bream populations in the Coorong from 2008/09 to 2022/23. 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	**2021/22** High flow	**2022/23** Flood	
Relative abundance	Catch (t/year)	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	≥8 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Positive (slope)
	Score	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	1	**1**	**1**	**1**	
Distribution	Proportional catch	No	No	No	No	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	>50% from southern Coorong
	Score	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	
Age structure	% fish >10 years	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	>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	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	Yes	Yes	≥2 strong cohorts
	Score	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	
Recruitment indices	YOY CPUE	Yes	No	No	No	Yes	No	NS	No	No	Yes	No	No	No	Yes	No	>0.35 YOY.net night^{-1}
	YOY distribution	---*	---*	No	No	No	No	NS	No	No	Yes	No	No	No	Yes	No	>50% sites (detected)
	Score	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	
Icon site total score		**1**	**1**	**0**	**2**	**2**	**1**	**1**	**0**	**1**	**3**	**1**	**3**	**3**	**4**	**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**	**Good**	**Moderate**	

*Although YOY were present at >50% sites in 2008/09 and 2009/10, the results should be treated with caution as the sampling sites were restricted within the Murray Estuary. Therefore, these values were 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 and 2022/23 (Figure 4.12). The high catch in 2011/12 (~30 t) indicated an increase in relative abundance following high flows in 2010/11 and 2011/12. Annual catches, however, decreased in the following years and remained <5 t y^{-1} until 2022/23 when the catch increased to 25.4 t. The catch in 2022/23 was the second highest since monitoring started in 2008/09. Additionally, the annual catches of the last 4-year period showed a positive trend, suggesting an increase in the population abundance/biomass from 2019/20 to 2022/23 (Figure 4.13).

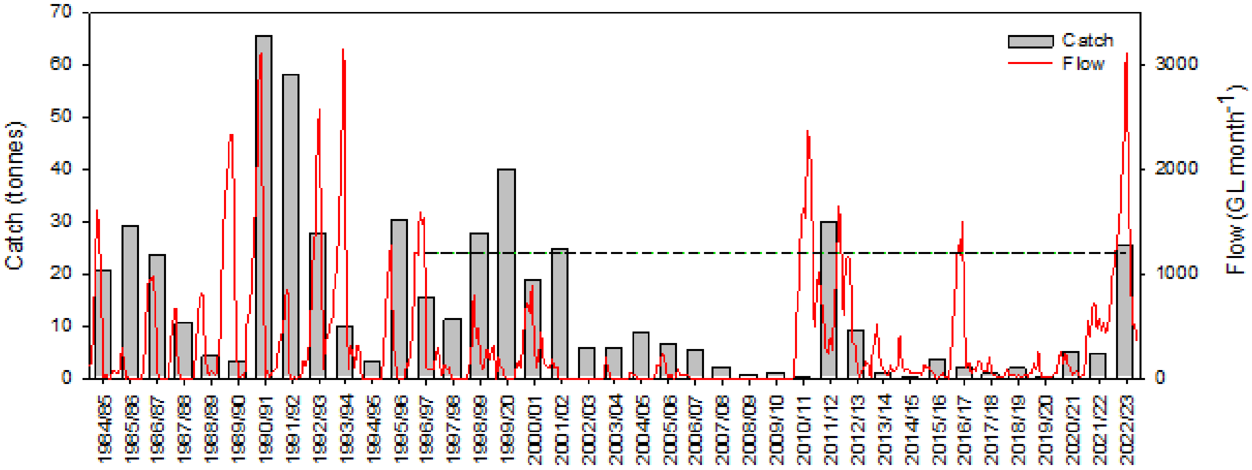


Figure 4.9. Annual commercial catch of greenback flounder from the Coorong between 1984/85 and 2022/23. The red line represents modelled monthly flow discharge to the Coorong (GL month^{-1}) between July 1984 and June 2023 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (24 t) between 1995/96 and 2001/02.

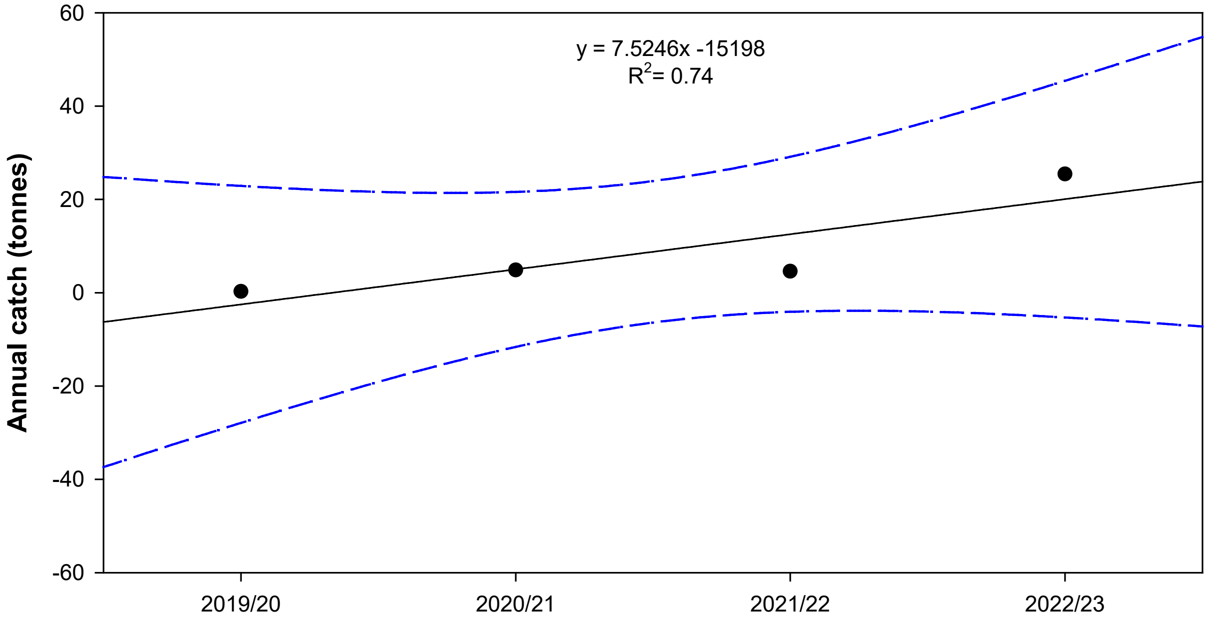


Figure 4.10. Trend in the greenback flounder catches over four years (2019/20–2022/23). Blue dashed lines show 95% confidence intervals.

4.4.2. Distribution

The spatial distribution of commercial fishery catches of greenback flounder varied across the Coorong over the last 39 years (Figure 4.14). 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 during 20010/11–2011/12, flounder 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 (~85–100%) of annual catches were from the southern Coorong, thus meeting the ecological target (>70%). In 2022/23, the proportional catch was 95% from the southern Coorong.

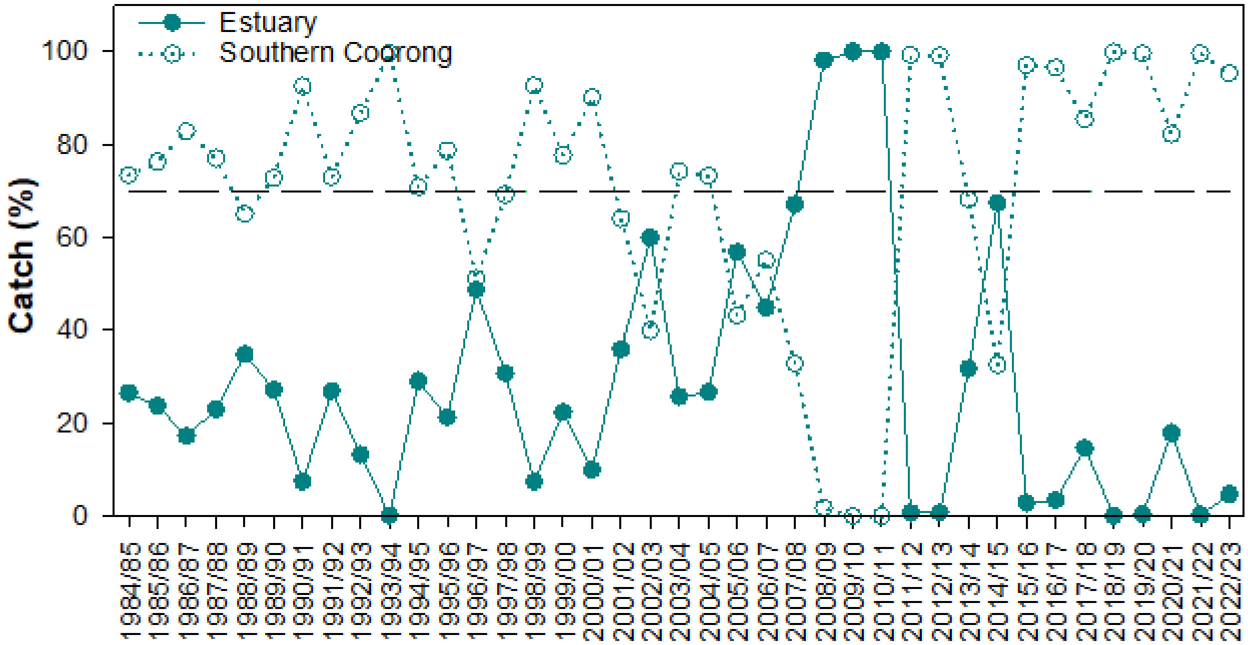


Figure 4.11. Greenback flounder commercial fishery catches from different areas (proportional catches from the north (Estuary) vs the south of Mark Point (southern Coorong)) in the Coorong between 1984/85 and 2022/23. Dashed black line indicates 70%.

4.4.3. Age structure

Greenback flounder, sampled from the commercial fishery during 2009–2023, ranged in age from 0 to 5 years, with most individuals caught in the Coorong ranging 1–3 years old (Figure 4.15). In most years, the age structure was dominated by 1- or 2-year-olds.

In 2011, the age structure comprised a strong cohort (i.e., >60% of samples) of 1-year-olds, that originated in 2010 and recruited to the Coorong following high flows. This cohort persisted as a dominant (66%) year class 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 low in 2016 (*n* = 8). In 2020 and 2021, a strong cohort (>80%) of 1-year-olds was present, whilst in 2022 and 2023 the strongest cohort was of 2-year-olds (>90%). 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.

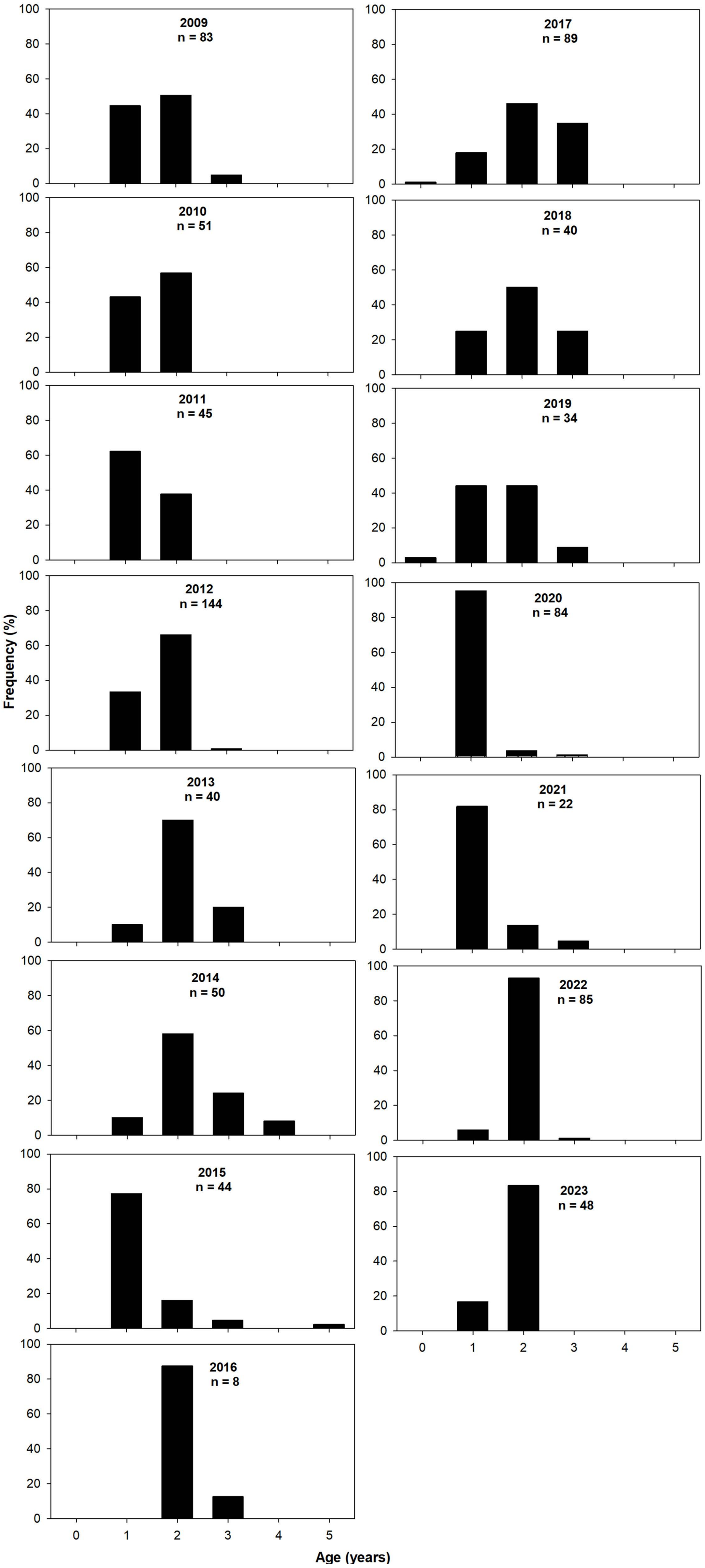


Figure 4.12. Age structure of greenback flounder from the Coorong from 2009 to 2023 (commercial fishery samples).

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 15 years (2008/09–2022/23) (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. In 2015/16, both abundance and distribution had declined compared to previous years. In the following four years, mean CPUE across sampling sites remained no more than 1 fish.seine net^{-1} although the spatial distribution was broader in 2016/17 and 2017/18 than the other two years. In 2020/21 and 2021/22, YOY abundance and distribution increased with the CPUE in 2021/22 (2.2 fish.seine net^{-1}) being the highest since 2010/11. In 2022/23, the CPUE of YOY reduced substantially to 0.2 fish.seine net^{-1} and the YOY were only detected across 44% of the sampling 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 and 2021/22, the population condition improved substantially to ‘good’, however in 2022/23 it declined to ‘moderate’ mainly due to the decrease in the YOY CPUE.

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 2022/23.

CPUE (fish.seine net^{-1})	**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**		**2021/22**		**2022/23**	
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**	**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	0.4	0.0	0.0	0.8	0.6	1.3	1.3	0.0	0.0	0.3	0.3	7.0	5.9	14.9	13.9	0.2	0.1
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	2.1	1.1	0.0	0.0
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	0.3	0.2	0.1	0.1
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	1.4	0.6	0.8	0.3
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	0.7	0.4	0.0	0.0
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	0.2	0.1	0.4	0.4
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	0.1	0.1	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	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	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**	**2.2**	**1.6**	**0.2**	**0.1**
# Sites sampled	**7**		**7**		**9**		**9**		**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**		**7**		**4**	
% of site YOY present	**43%**		**43%**		**56%**		**56%**		**67%**		**67%**		**67%**		**44%**		**67%**		**78%**		**33%**		**33%**		**56%**		**78%**		**44%**	

Table 4.5. Condition assessment for greenback flounder population in the Coorong from 2008/09 to 2022/23. 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	**2021/22** High flow	**2022/23** Flood	**(Reference Point)**
Relative abundance	Annual catch	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes	≥24 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	Yes	Positive (slope)
	Score	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	1	
Distribution	% catch	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	>70% from southern part
	Score	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**1**	**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	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	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**	**1**	**1**	
Recruitment	YOY CPUE	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	Yes	Yes	No	>1.04 fish.seine net^{-1}
	YOY distribution	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No	>50% sites
	Score	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	
Icon site total score		**0**	**0**	**2**	**3**	**3**	**3**	**2**	**2**	**3**	**2**	**1**	**2**	**4**	**4**	**3**	
Greenback flounder condition		**Extremely poor**	**Extremely poor**	**Poor**	**Moderate**	**Moderate**	**Moderate**	**Poor**	**Poor**	**Moderate**	**Poor**	**Very Poor**	**Poor**	**Good**	**Good**	**Moderate**	

4.5. Smallmouth hardyhead

4.5.1. Relative abundance

Relative abundance of adult smallmouth hardyhead in the Coorong varied over the last 15 years (Figure 4.16). The mean CPUE met the ecological target (≥120 fish.UE^{-1}) in eight out of the 15 years, including 2022/23. 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.

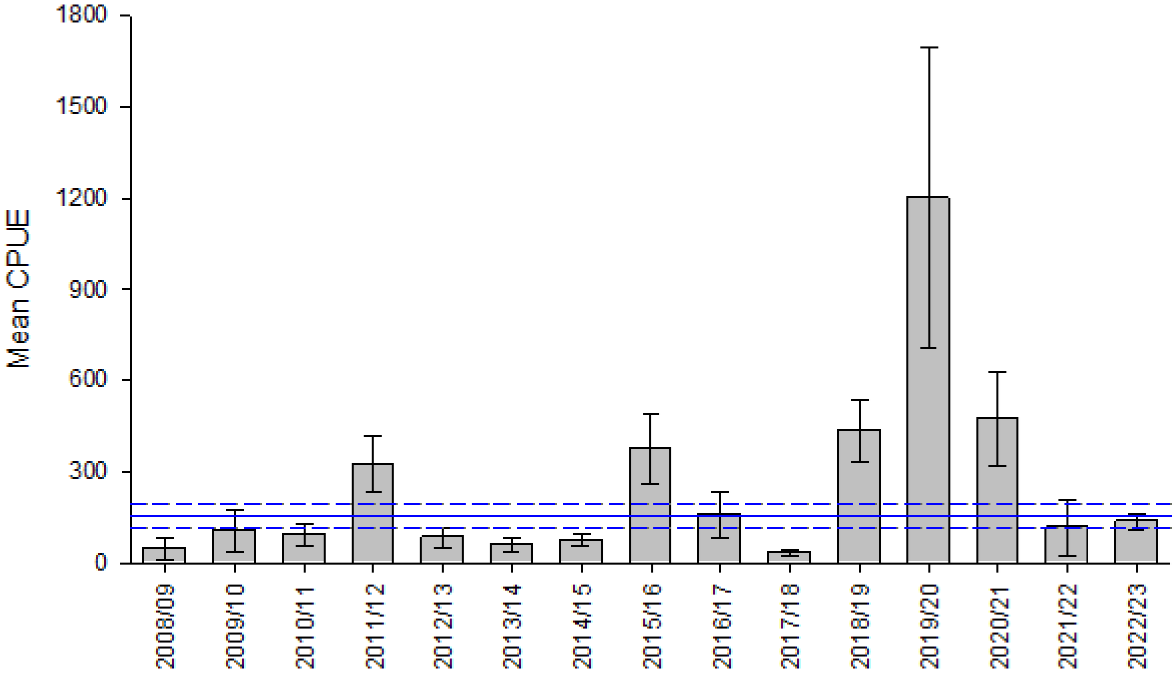


Figure 4.13. Mean seine net catch per unit effort (CPUE) ± SE of smallmouth hardyhead adults (spring/early summer; ≥40 mm TL) in the Coorong from 2008/09 to 2022/23. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are ± 25% (dashed 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 only.

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 4.17). 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 with abundances in the following five years (2018/19–2022/23) all being above the ecological target (800 fish.UE^{-1}). More detailed information on the CPUE of new recruits by sampling site is presented in Appendix E.

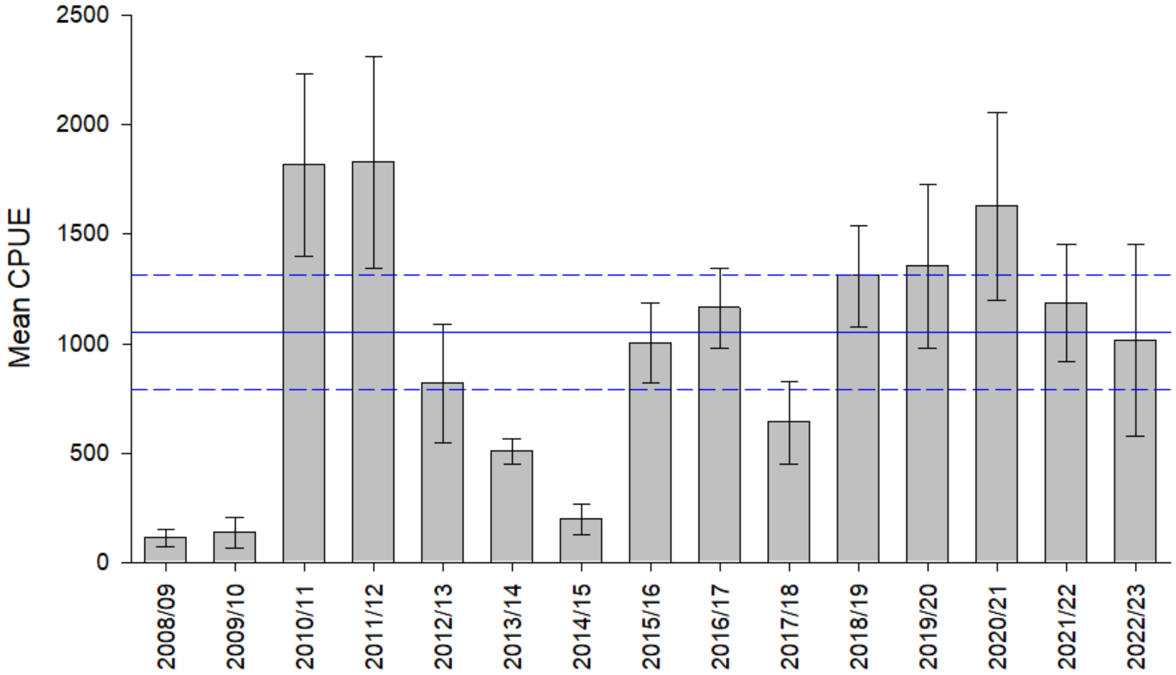


Figure 4.14. Mean seine net catch per unit effort (CPUE) ± SE of smallmouth hardyhead new recruits (late summer/autumn; <40 mm TL) in the Coorong from 2008/09 to 2022/23. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are ± 25% (dashed 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 4.6). 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 from 2010/11–2013/14 and 2016/17–2017/18 (six years), with all years following high flows. From 2018/19 to 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. In 2021/22 and 2022/23, 75% of the sites had significant recruitment, narrowly falling short of meeting the ecological target.

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 2022/23 (Table 4.7). 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%), meeting the ecological target (>87%), except for the adult distribution in 2010/11 and 2021/22. It is worth noting that although random sampling in 2021/22 didn’t detect adult smallmouth hardyhead at three out of eight sampling sites, adults were collected across seven sites out of the eight sites during a separate study of reproduction, and therefore were present at these sites. Based on the presence of adults at 87.5% of the sampling sites, the ecological target of adult distribution was met in 2021/22 (see Table 4.8). In 2022/23, new recruits and adults were present across all sampling sites, with the prevalence of higher abundances in the southern part of the Coorong, particularly at Salt Creek (Table 4.6).

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 2022/23. 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**	**2021/22**	**2022/23**
Site	**CPUE**	**CPUE**	**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	399	18
Long Point (N2)			3352	499	161	345	23	523	561	319	1148	521	767	1964	173
Noonameena (N3)	149	242	2447	4707	378	626	26	385	810	1716	1069	1152	403	693	331
Mt Anderson (N4)			2863	2248	423	562	9	641	1101	160	454	1534	1322	25	161
Hells Gate (S1)		0	2123	1654	1740	578	527	1658	1806	1103	1808	856	1988	2228	1689
Villa de Yumpa (S2)			2337	1470	373	688	364	1264	1974	363	1009	2003	1171	1275	410
Jack Point (S3)		0	141	1699	2098	646	333	1618	1336	460	2180	3622	2206	1493	1786
Salt Creek (S4)		80	583	2120	1269	371	231	1351	1090	765	2129	797	4239	1401	3545
Total abundance (juvenile + adults)															
Mark Point (N1)	73	698	790	463	100	263	55	848	761	230	1587	2337	942	1161	34
Long Point (N2)			3504	750	175	367	120	999	654	335	1470	4488	1387	2017	282
Noonameena (N3)	396	439	2701	5578	387	849	84	653	936	1746	1492	3360	641	780	497
Mt Anderson (N4)			2863	2527	491	621	60	1103	1128	169	797	2143	1981	43	313
Hells Gate (S1)	1	0	2194	2185	2028	616	632	2740	1999	1173	2253	1114	3376	2228	1944
Villa de Yumpa (S2)			2337	1539	471	754	421	1348	2636	415	1123	2121	1310	1275	467
Jack Point (S3)	0	1	143	1814	2170	721	525	1724	1377	506	3000	4017	2540	1493	1937
Salt Creek (S4)	1	94	584	2373	1402	391	292	1602	1093	837	2260	850	4654	1438	3748
Proportional abundance of juvenile (%)															
Mark Point (N1)	100	51	88	50	99	97	88	69	81	100	43	15	98	34	52
Long Point (N2)			96	67	92	94	19	52	86	95	78	12	55	97	61
Noonameena (N3)	38	55	91	84	98	74	31	59	87	98	72	34	63	89	67
Mt Anderson (N4)			100	89	86	90	15	58	98	95	57	72	67	58	51
Hells Gate (S1)	0	0	97	76	86	94	83	61	90	94	80	77	59	100	87
Villa de Yumpa (S2)			100	96	79	91	86	94	75	87	90	94	89	100	88
Jack Point (S3)	-	0	99	94	97	90	63	94	97	91	73	90	87	100	92
Salt Creek (S4)	0	85	100	89	91	95	79	84	100	91	94	94	91	97	95
% of sites with significant recruitment	**20**	**20**	**100***	**88***	**100***	**100***	**63**	**63**	**100***	**100***	**75**	**63**	**75**	**75**	**75**

Table 4.7. Distribution of smallmouth hardyhead adults and new recruits from 2008/09 to 2022/23 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**	**2021/22**	**2022/23**
# Sites sampled	5	5	8	8	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	8	8
# Sites adults smallmouth hardyhead present	3	4	6	8	8	8	8	8	8	7	8	8	8	5	8
% of site YOY present	**40%**	**60%**	**100%**	**100%**	**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%**	**63%***	**100%**

*Note: Although adults were only detected at five sites during the random sampling in December 2021, at least 20 individuals of female adults per site were collected for reproductive biology study at seven out of the eight sites during the same period, and thus the distribution of adults should be 87.5%.

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 the ‘poor’ condition in 2014/15, and ‘very good’ condition in 2016/17. In 2020/21, 2021/22 and 2022/23, the population condition was ‘good'.

Table 4.8. Condition assessment for smallmouth hardyhead populations in the Coorong from 2008/09 to 2022/23. 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	**2021/22** High flow	**2022/23** Flood	
Relative abundance CPUE of adults	No	No	No	Yes	No	No	No	*	Yes	No	*	*	Yes	Yes	Yes	CPUE ≥120 fish.UE^{-1}
Recruitment CPUE of juveniles	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	CPUE >800 fish.UE^{-1}
Extent of recruitment	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	>75% sites with >60% juveniles
Distribution Adults	No	No	No	Yes	Yes	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	Yes	Yes	
Icon site score	**0**	**0**	**3**	**5**	**4**	**3**	**2**	**3**	**5**	**3**	**3**	**3**	**4**	**4**	**4**	
Smallmouth hardyhead condition	**Extremely Poor**	**Extremely Poor**	**Moderate**	**Very Good**	**Good**	**Moderate**	**Poor**	**Moderate**	**Very Good**	**Moderate**	**Moderate**	**Moderate**	**Good**	**Good**	**Good**	

*There was no targeted sampling in spring-early summer for adults in these years.

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 populations 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 15 years of monitoring, barrage flows were highly variable, including two years (2008/09 and 2009/10) of drought, followed by high– moderate flows in 2010/11–2012/13, and subsequent years with predominantly low flows except for two high flow years in 2016/17 and 2021/22 and a flood year (2022/23). 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 2015/16, 2018/19 and 2019/20, barrage flows were 561 GL, 377 GL and 685 GL, respectively, entirely comprised of Commonwealth allocations of water for the environment (Ye *et al.* 2021b). In 2020/21 and 2021/22, barrage flow increased to 1,260 GL and 6,161 GL, respectively, mainly due to increased unregulated flows, with water for the environment comprising 71% and 22% of the annual discharge (Ye *et al.* 2023b). In 2022/23, an extensive flooding occurred in the MDB, which is the second largest recorded over the last 70 years. This resulted in the highest annual barrage discharge (16,657 GL) at least since 1984/85 and the daily discharge peaked at 109,266 ML day^{-1} on 16 January 2023.

Salt Creek flows into the South Lagoon were also highly variable in the last 15 years, ranging between 2–46 GL y^{-1}, with the annual discharge in 2022/23 (37.2 GL) being the second highest among all monitoring years. Peak flows usually occurred during winter–spring. However, the flow peak was delayed in 2022/23 because the Morella regulator was operated to maintain daily discharge at <70 ML day^{-1} during winter–early summer in order to minimise inflow to the Coorong given the already high water levels in the South Lagoon, and to raise storage levels in Morella to 5.1 m AHD in spring 2022. Therefore, higher releases (e.g., >100 ML day^{-1}) from Salt Creek to the Coorong did not occur until May and June 2023. Salt Creek inflows have been shown to affect local salinities in the South Lagoon of the Coorong (e.g., Ye *et al.* 2011b; 2022b).

5.2. Water quality

Salinity has been highly variable in the Coorong, mainly influenced by inflows from the barrages and the 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 (10 out of 13 years) <100 psu in the South Lagoon. Although there were increased salinities during low flow years (e.g., 2015/16, 2019/20, 2020/21), the levels were much lower across the system than during the drought years (2008/09 and 2009/10). Following sustained high flows and flood over the last two years, salinities reduced substantially in 2022/23 with fresh to brackish conditions almost across the entire Murray Estuary and North Lagoon; and the mean salinity in the South Lagoon reduced to the lowest (63 psu) since the monitoring began in 2008/09. 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 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 and 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 (Potter *et al.* 2015; Bice *et al.* 2018). Overall, the abundance, as indicated by commercial fishery catches of legal-sized fish ≥30 cm TL, has declined substantially in the Coorong since the peak (46.5 t) in 1984/85. During 2008/09–2020/21, annual catches remained no more than 3.2 t, but in 2021/22 and 2022/23, they increased to 11.4 t and 12.8 t, respectively, meeting the biomass target of 8 t for this species in the Coorong. The continued increasing 4-year catch trend from 2019/20 further suggested recent biomass increase in the Coorong, and the wider distribution was indicated by >50% of the commercial catch coming from the southern Coorong. Nevertheless, the population of black bream in the Coorong is still recovering considering the relatively low biomass (<30%) even in 2021–2023 compared to the peak level in 1984/85. 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).

The positive trajectory of annual catches and increased distribution may be attributed to habitat improvement across the Coorong following increased inflows in 2016/17, 2021/22 and 2022/23, and additional support of water for the environment particularly in dry years (2017/18 to 2020/21) (Ye *et al.* 2023b). Freshwater flow plays a pivotal role in maintaining suitable salinities and extending favourable estuarine habitat for black bream in the Coorong. This was 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 increased salinities in the Coorong, and the general expansion of fishery catch to the southern Coorong following high flow periods (e.g., 1989/90 to 1992/93, 2016/17, 2021/22, 2022/23). 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). 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), which were post flood/high flow years.

The age structures of black bream sampled from the commercial catches between 2008/09 and 2022/23 indicate 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, 2015/16 and 2017/18), and the 2012/13, 2015/16 and 2017/18 cohorts were also detected as YOY during new recruit sampling in this study (see Section 4.3.4), noting TLM fish monitoring began in 2008/09. In the current modified Coorong estuary, post river regulation, even small-scale barrage releases are important to facilitate recruitment of this species. For example, 2017/18 strong cohort, detected as 4-year-olds in the commercial catch in 2021/22, was linked to YOY recruitment with barrage flows up to 12,000 ML d^{-1}, supported predominantly by 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 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 conditions (i.e., gradient and 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.

Interestingly, the age structures of the commercial catches from 2019/20 to 2021/22 also showed a strong cohort generated in 2016/17, a high flow year, when no black bream YOY were detected in the Coorong. While it might be possible that YOY have been in a refuge from the high flows in an area that was not sampled, it was more likely that the 2016/17 cohort have originated from spawning in other estuaries and then migrated into the Coorong in later years. Although black bream typically complete their life-cycle 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 (Giraldo 2015; Sarakinis *et al.* 2024) particularly after flood/high flows (Hall 1984).

Furthermore, strong recruitment of YOY black bream was detected in 2021/22 with the highest YOY abundance over the last 15 years. Although the annual barrage discharge in this year was similar to that in 2016/17, daily flows were much more variable in 2016/17 with peaks occurring in spring–summer at ~80,000 ML day^{-1} whereas there were sustained moderate daily flows (10,000–30,000 ML day^{-1}) throughout 2021/22. The spawning of black bream occurred between mid- January and late February 2022, corresponding with temperature of 19−26°C and barrage discharge of ~11,000−24,000 ML day^{-1}, aligning with our conceptual understanding that strong recruitment of black bream was associated with low to moderate barrage flows to the Coorong (Ye *et al.* 2023a). It is expected that the 2021/22 cohort should enter the fisheries in approximately four years. In 2022/23, no YOY black bream were detected in the Coorong, like in other flood/high flow years in 2010/11 and 2016/17, potentially due to flood disturbance and lack of favourable salt wedge conditions to support YOY recruitment.

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, flow effects on the 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 among other Victorian estuaries (Jenkins *et al.* 2010). In the Coorong, there has been a concerted effort in recent years to deliver water for the environment to maintain end-of-system connectivity and improve estuarine fish habitat. This included promoting black bream recruitment under suitable hydrological conditions, particularly 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; 2023a). Given the dynamic nature of the Coorong estuary and inter-annual flow variability, further monitoring/research is needed to improve understanding of the hydrological and environmental requirements for recruitment of black bream, to inform flow and Coorong ecosystem management.

Black bream is a slow-growing, long-lived estuarine species (Norriss *et al.* 2002). The maximum age of 32 years reported for the Coorong population was from this study. Nevertheless, few individuals (generally no more than 10%) greater than 15 years old were present in age structures from 2008/09 to 2022/23, and the ecological target of >20% of fish being older than 10 years was only met in five of the 15 years. Given that black bream typically restrict their life-cycle entirely 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 the 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. A recent study also suggested gene flow present between the Coorong and Robe (Sarakinis *et al.* 2024).

Rebuilding and maintaining complexity of age structures 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 several years of high flows (e.g., 2010/11−2012/13, 2016/17, 2021/22, 2022/23) and the delivery of water for the environment, freshwater−estuarine connectivity and estuarine habitat has improved in the Coorong (Ye *et al.* 2020a; 2023b). Given the depleted population biomass in the Coorong (Earl and Bailleul 2021), fishing closures have also been implemented in recent years (e.g., 2018/19, 2019/20, 2021/22, 2022/23) during the reproductive season of this species to protect spawning biomass and minimise fishing interference on spawning events. Indeed, the population condition of black bream had improved to 'moderate' in 2017/18, 2019/20, 2020/21 and 2022/23, and was 'good' in 2021/22. The presence of recent strong cohorts (e.g., 2016/17 and 2017/18) has supported a substantial increase in adult abundance in the Coorong, and the addition of the new 2021/22 strong cohort will further improve resilience and contribute to population recovery. Nevertheless, compared to the level of biomass in the mid-1980s, black bream abundance remains relatively low in the Coorong despite the substantial increase in 2021/22 and 2022/23. Also, 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 continue 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, food resource availability and black bream recruitment dynamics in the Coorong (Ye *et al.* 2019a; 2019b; 2023a). 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 15 years responded to freshwater flows into the Coorong, generally with improved condition after flood/high flows (e.g. in 2011/12–2013/14, 2016/17, 2021/22). 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 'extremely poor' during drought (2008/09 and 2009/10) and 'very poor'/'poor' in dry years (2014/15, 2015/16, 2017/18–2019/20). The 'good' popualtion condition in 2021/22 was associated with high inflows (~6,200 GL yr^{-1}) and an extensive reduction in salinity in the Coorong particularly in the Murray Estuary and North Lagoon (Table 4.1), which likely improved estuarine habitat and food resources (Dittmann *et al.* 2022). In the 2022/23 flood year, there were further reduced salinities throughout the entire Coorong including the South Lagoon, leading to a drastic increase in adult abundance reflected by the increased annual commercial catch, which was ~5.5 times compared to that in 2021/22 (4.6 t) with a broad distribtuion throughout the Coorong. However, the YOY were only detected at 44% of the sites and the CPUE was much lower than that in 2021/22, probably due to 1) flood water disturbance particuarly in the Murray Estuary sub-region resulting in much lower YOY CPUE compared to most monitoring years and 2) reduced sampling effenciency under the flood and high water level conditions. The YOY abundance target was not met, and thus the population condition was 'moderate' in 2022/23.

During the extended drought years (2002/03–2009/10), 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 1990/91–1991/92 (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 (2008/09–2009/10). 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; Ye *et al.* 2020b). After the Millennium Drought broke in late 2010, a notable increase in annual catch (30 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. However, abundance declined steeply after 2012/13 and remained low (commercial catches <5 t y^{-1}) in the following nine years, likely due to the predominant low flow conditions except for 2016/17 and 2021/22. Such 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 (Jason Earl, 2023, pers. Comm.). Following the 2022/23 flood, the annual catch was 25.4 t, meeting the abundance target (≥24 t). Over the 15 monitoring years, the only other year when the biomass target was met was 2011/12. Nevertheless, the target of an increasing 4-year trend in catch was achieved typically in years with increased flows (e.g. 2011/12, 2012/13, 2016/17, 2021/22, 2022/23). 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 translates to increased fishery production after a lag of 1–2 years (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 be partially due to fishing impacts via the removal of larger, older individuals (Hall 1984; Ferguson *et al.* 2013; Earl and Ye 2016), and/or 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, primarily by influencing salinity regime, providing favourable estuarine habitat, and increasing food resources (Gillanders and Kingsford 2002; Robins and Ye 2010; Ye *et al.* 2020b). The major flood in 2022/23 also led to increased water levels in the Coorong, which increased the inundation area of sand/mud flats and expanded available nursery habitat. Over the last 15 years, recruitment of YOY occurred annually in the Coorong, although the CPUE and distribution varied among years. Greenback flounder exhibits a strong affinity for brackish and near-marine environments (Earl *et al.* 2017), and salinity can influence its reproduction; optimum fertilization rates are observed within the range of 35–45 psu, and the eggs can tolerate salinities between 14–45 psu after fertilization (Hart and Purser 1995). Consequently, YOY distribution is highly responsive to freshwater inflows and subsequent changes in salinity gradient along the Coorong. In late Millennium drought years, YOY were almost completely excluded from the North and South Lagoons due to the elevated hypersaline salinities which made the habitat unfavourable for this species. The exceptionally high YOY CPUE in 2008/09 and 2009/10 demonstrated the reduction of nursery ground for this species with juveniles aggregating into suitable habitat within the Murray Estuary. In 13 post-drought years, YOY distribution expanded extensively into the North Lagoon, and sometimes into the South Lagoon following high flows/floods, and the CPUE met the ecological target (>1.04 fish.seine net^{-1}) in five years. These results highlight 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 15 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, 2021/22 and 2022/23, associated with elevated inflows and reduced salinities in the Coorong.

As a euryhaline species, smallmouth hardyhead can tolerate high salinities (up to 108 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 resulting from an absence of freshwater inflows during an extended drought in the MDB. Although inflow from Salt Creek increased from 2.1 GL in 2008/09 to 15.2 GL in 2009/10, resulting in localised salinity reductions and patchy increases in abundance of this species in the southern part of the South Lagoon, the scale of effect was insufficient to change the overall population status from 'extremely poor' in the Coorong. Since 2010/11, following substantial increases in barrage flows, salinities were much reduced, with the mean ranging between 20–51 psu in the North Lagoon, and below 100 psu in the South Lagoon except for some dry years (2015/16, 2018/19 and 2019/20). This, coupled with other flow induced conditions (e.g., enhanced productivity and food resources), has restored extensive areas of suitable habitat, leading to a broad distribution of adult and juvenile smallmouth hardyhead almost across the entire Coorong since 2010/11.

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. This was best demonstrated by a noteworthy increase in new recruit abundance in 2010/11 and 2011/12 when CPUE was >15 times compared to that observed in drought years. Seasonal reductions in salinity caused by freshwater inflow have 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; Dittmann *et al*. 2022), and thus improve habitat quality and extent to support the recruitment of this species across the Coorong. Although a previous Coorong study did not identify any clear effect of salinity on reproduction of smallmouth hardyhead at salinity range 32–74 psu, it suggested that higher salinity may limit food resources and thus affect recruitment (Molsher *et al.* 1994). More recently, our study of gonad histology of adult females collected at salinities ranging 10–80 psu during the spawning season in 2021/22, indicated a negative effect on the reproductive activity of this species at salinities >60 psu (Ye *et al.* 2023a). Therefore, the extensive salinity reduction to <60 psu across most of the Coorong following the 2022/23 flood likely benefitted the recruitment of smallmouth hardyhead. High salinity is also known to impact the reproductive performance of other atherinids (e.g., Carpelan 1955; Hedgpeth 1967).

At times particularly under dry conditions (e.g., 2009/10), dispersion of the remnant population and new recruits from Salt Creek facilitated by inflows could also help maintain the population in the South Lagoon, as suggested by earlier monitoring (Ye *et al*. 2011b). Additionally, increased presence of *Ruppia spp.* and associated macrophytes in recent years in the southern Coorong (Waycott *et al.* 2020) may have benefitted the reproduction of smallmouth hardyhead. This could help explain the generally abundant new recruits since 2016/17. 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). Indeed, smallmouth hardyhead eggs were observed attached to *Ruppia* in the Coorong during fish sampling (e.g., in 2020/21) (Ye *et al.* 2022a). Furthermore, changing numbers of piscivorous predators and/or competitors in the Coorong may also affect the abundance of smallmouth hardyhead, an important prey species in this region (Giatas *et al.* 2018; Ye et al. 2020b). For example, areas with higher salinities (but within tolerance range of smallmouth hardyhead) could force other fish species (including predators and competitors) out due to increased osmoregulatory stress and provide additional niche habitat for smallmouth hardyhead to proliferate.

6. CONCLUSION

For black bream and greenback flounder, the ecological objective (F-4) to restore resilient populations of these species in the Coorong was not met in 2022/23, with the population condition for both species being ‘moderate’. For black bream, the population condition showed an improvement in recent years (2017/18–2022/2023 except 2018/19) to ‘moderate’ or ‘good’ compared to the first nine monitoring years when the condition was ‘extremely poor’, ‘very poor’ or ‘poor’. In 2022/23, the ‘moderate’ population condition was characterised by:

- Increased abundance (adjusted annual commercial catch of 12.8 t, meeting the target: ≥8 t) and a positive trend of the 4-year catches (meeting the target);
- Increased distribution of the commercial catches (93% from the southern Coorong, meeting the target: >50%);
- The presence of two strong cohorts with one ≤5 years (meeting the target) and 37.7% of the catches >10 years of age (vs the target: >20%);
- No YOY were detected.

For greenback flounder, the ‘moderate’ population condition in 2022/23 may reflect a decline from ‘good’ condition in previous two years, although this should be treated with caution as the low CPUE of YOY could be caused by reduced sampling efficiency due to the flood. Overall, the population of this species was responsive to freshwater inflows. It was in ‘extremely poor’ condition during the late drought period (2008/09 and 2009/10), but then showed a general improvement particularly after floods/high flows. In 2022/23, the ‘moderate’ population condition was characterised by:

- Increased abundance (annual commercial catch of 25.4 t, meeting the target: ≥24 t) and a positive trend of the 4-year catches (meeting the target);
- A broad distribution of commercial catches (95% from the southern Coorong, meeting the target: >70%);
- The presence of a very strong cohort (83% 2-year-olds, meeting the target: >60%);
- Low YOY CPUE (0.2 fish.seine net^{-1} vs the target: >1.04 fish.seine net^{-1}) and the distribution of 44% of the sites (not meeting 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 15 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) with minor adaptation (See Tables 1.1 and 1.2):

- 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 for 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 are more responsive to freshwater inflows and salinity improvement in the Coorong. In contrast, black bream is a slower growing, solely estuarine, long-lived fish (~32 years) with specific habitat requirement (salt wedge) for successful recruitment, and their population recovery will require a longer time frame. It is encouraging to see some improvements in black bream population condition in recent years with the population reaching 'good' condition in 2021/22 for the first time since the monitoring began in 2008/09. Despite the 'moderate' population condition in 2022/23, there was a notable increase in adult biomass in the Coorong supported by a strong cohort from 2017/18, and a recent, new strong cohort (2021/22) may support further increase in spawning biomass. The improvement in the black bream population was likely attributed to the improved estuarine habitat supported by inflows (including water for the environment) to the Coorong and improved Murray barrage operations, particularly informed by targeted studies that sought to link barrage flow volumes with salt wedge conditions and recruitment. Seasonal fishing closures may have also helped protect black bream during the spawning season and contributed to population recovery.

For smallmouth hardyhead, 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 six out of the 15 years, including in 2022/23. This species is highly responsive to freshwater inflows to the Coorong, showing substantial population improvements post-drought following floods/high flows. The 'good' population condition in 2022/23 was associated with the extensive flood (annual discharge ~16,657 GL) and reduced salinities throughout the Coorong. 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 (1,014 fish.UE^{-1}) and adults (139 fish.UE^{-1}), which were above the ecological target of 800 fish.UE^{-1} and 120 fish.UE^{-1}, respectively. However, the extent of recruitment was 75%, just missing the target of >75% of sites, although the sampling efficiency may be reduced due to flood water and high water levels 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 and higher 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, and higher flows in 2021/22 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 rebuild the abundance and resilience of the solely estuarine black bream population, fishery management should continue to seek to protect the spawning biomass and to maximise the survival of new recruits.

The Coorong fish monitoring program over the last 15 years (2008/09–2022/23) has provided valuable information on the abundance, distribution, age/size structures and recruitment ecology of 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., 2014/15–2020/2021 except 2016/17, <1,300 GL y^{-1}), flood/high flows (2010/11, 2011/12, 2016/17 and 2021/22, >6,000 GL y^{-1}) and an extensive flood (2022/23 with 16,657 GL y^{-1}) which allowed assessment of biological responses to flow variability and investigations 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. It is important that future monitoring should maintain the sampling regime as recommended in the LLCMM Condition Monitoring Plan (revised, DEWNR 2017) to ensure robust assessment. 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 contribute to the ecological sustainability of iconic estuarine fish species in the LLCMM region.

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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 2008/09–2022/23. HI=Hindmarsh Island and SRP=Sir Richard Peninsula.

No. of fyke net.night per year														
Location	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**
Goolwa Barrage saltwater side HI	16	24	24	15	24	32	16	16	4	5	4	4	4	4
Goolwa Barrage saltwater side SRP	21	24	16	22	32	32	16	16	4	8	4	4	4	4
Mundoo Barrage	4	NS	24	24	32	31	8	16	4	6	4	4	4	4
Boundary Creek	23	24	NS	16	32	30	12	16	1	7	4	4	4	4
Mark Point			4	24	8	8		20	8	16	8	8	8	4
Long Point			4	4	4	4		8	4	8	4	4	4	4
Long Point sand dune						4		12	4	7	4	4	4	
Noonameena													8	4
Noonameena South													8	4
Overall	**84**	**92**	**84**	**117**	**144**	**149**	**72**	**112**	**37**	**65**	**40**	**40**	**48**	**32**

Appendix B. Sampling effort (number of seine net shots) for collecting juvenile greenback flounder using large seine net at the Coorong from 2008/09–2022/23. 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**	**2021/22**	**2022/23**
Sugars Beach/Beacon 19	9	9	9	15	9	9	12	6	9	6	3	3	9	9	9
Godfrey's Landing	9	9	15	15	15	15	12	6	9	6	3	3	9	9	9
Mark Point	12	15	15	15	15	15	12	6	9	6	3	3	9	9	9
Noonameena	12	15	15	15	15	15	12	6	9	6	3	3	9	9	9
Mt Anderson	NS	NS	9	15	15	15	12	6	9	6	3	3	9	9	9
Hells Gate	12	15	15	15	15	15	12	6	9	6	3	3	9	9	9
Villa dei Yumpa	NS	NS	9	15	15	15	12	6	9	6	3	3	9	9	9
Jack Point	12	15	15	15	15	15	12	6	9	6	3	3	9	9	9
Salt Creek	12	15	15	15	15	15	12	6	9	6	3	3	9	9	9
Overall	**78**	**93**	**117**	**135**	**129**	**129**	**108**	**54**	**81**	**54**	**27**	**27**	**81**	**81**	**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 2008/09–2022/23. 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**	**2021/22**	**2022/23**
Large seine net															
Mark Point	12	12	12	12	12	12	12	6	9	6	3	3	6	6	6
Long Point	NS	12	12	12	12	12	12	6	9	6	3	3	6	6	6
Noonameena	12	12	12	12	12	12	12	6	9	6	3	3	6	6	6
Mt Anderson	NS	6	12	12	12	12	12	6	9	6	3	3	6	6	6
Hells Gate	12	12	12	12	12	12	12	6	9	6	3	3	6	6	6
Villa dei Yumpa	NS	6	12	12	12	12	12	6	9	6	3	3	6	6	6
Jack Point	12	12	12	12	12	12	12	6	9	6	3	3	6	6	6
Salt Creek	12	12	12	12	12	12	12	6	9	6	3	3	6	6	6
Overall	**60**	**60**	**84**	**96**	**96**	**96**	**96**	**48**	**72**	**48**	**24**	**24**	**48**	**48**	**48**
Small seine															
Mark Point	3	9	12	12	12	12	NS	6	9	6	3	3	6	6	6
Long Point	NS	NS	12	12	12	12	NS	6	9	6	3	3	6	6	6
Noonameena	3	9	12	12	12	12	NS	6	9	6	3	3	6	6	6
Mt Anderson	NS	NS	6	12	12	12	NS	6	9	6	3	3	6	6	6
Hells Gate	NS	12	12	12	12	12	NS	6	9	6	3	3	6	6	6
Villa dei Yumpa	NS	NS	6	12	12	12	NS	6	9	6	3	3	6	6	6
Jack Point	NS	12	12	12	12	12	NS	6	9	6	3	3	6	6	6
Salt Creek	NS	12	12	12	12	12	NS	6	9	6	3	3	6	6	6
Overall	**6**	**54**	**84**	**96**	**96**	**96**		**48**	**72**	**48**	**24**	**24**	**48**	**48**	**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 4.16). Note: 2014/15 values are based on large seine net data only; sampling in 2015/16, 2018/19 and 2019/20 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**		**2021/22**		**2022/23**	
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	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	761	97	16	10
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	53	18	109	17
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	87	15	166	38
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	18	1	152	27
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**	**230**	**178**	**111**	**34**
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	0	0	255	35
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	0	0	57	7
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	0	0	151	9
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	37	7	203	39
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**	**9**	**9**	**167**	**42**
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**	**120**	**92**	**139**	**27**

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 4.17). 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 2018/19–2022/23 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**		**2021/22**		**2022/23**	
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**	**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	399	120	18	3
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	1964	521	173	3
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	693	195	331	35
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	25	6	161	52
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**	**770**	**421**	**171**	**64**
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	2228	707	1689	466
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	1275	236	410	17
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	1493	186	1786	295
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	1401	269	3545	1354
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**	**1599**	**192**	**1857**	**644**
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**	**1185**	**269**	**1014**	**437**